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Research Article

Comparative evaluation of sulphur sources on growth, yield and quality of garlic (*Allium sativum* L.)

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Abstract
Sulphur is a prime nutrient in *Allium* crops. Garlic fertilization with ammonium-based sulphur fertilizers in low pH soils is being practiced by farmers that culminate the soil acidity, which has an adverse effect on plant growth. Hence a field experiment was conducted at Horticultural Research Station, Woodhouse farm, Ooty, the Nilgris in 2021 to evaluate the appropriate sulphur sources and their levels for garlic at acidic hilly soil using four sulphur sources viz., potassium sulphate, magnesium sulphate, zinc sulphate and ammonium phosphate sulphate and three levels viz., 0, 40, 60 kg ha^{-1}. Garlic variety Ooty 2 was used as test crop. The results revealed that application of magnesium sulphate @ 60 kg ha^{-1} produced the highest plant height, leaf numbers, clove numbers bulb^{-1}, neck thickness, polar diameter, equatorial diameter, the weight of 10 cloves, fresh weight, dry weight and bulb yield (16.78 t ha^{-1}) of garlic. Quality parameters *viz*., total soluble solids, ascorbic acid and total phenols of garlic bulbs were improved by the application of potassium sulphate @ 60 kg ha^{-1}. Sulphur source of Magnesium sulphate had a minimal effect of rendering acidity to soil measured in terms of pH (4.74) and exchangeable acidity (0.22 meq 100 g^{-1}). Hence, the promising source for acidic hilly soil and garlic crop was found to be magnesium sulphate @ 60 kg ha^{-1} followed by potassium sulphate @ 60 kg ha^{-1}. This particular investigation focuses not only on yield improvement but also on maintaining soil quality of the area.

Keywords: Acidity, Garlic, Source, Sulphur, Yield

INTRODUCTION

Garlic (*Allium sativum* L.) is a bulbous spice crop cultivated widely for more than 5000 years (Zhang *et al.*, 2020). It is classified under *Alliaceae* family and had its origin in Central Asia. The vernacular names of Garlic are Vellaipoondu, Tellagadda, Velluli and Belluli. It is a frost hardy crop with shallow roots, propagated vegetatively. Garlic is the key ingredient in Indian kitchen, which also has high export potential. India holds second in garlic production after China. In India, major garlic growing states are Rajasthan, Uttar Pradesh, Gujarat and Punjab. The area under garlic cultivation in India is about 352000 ha with a production of 2925000 Mt during 2019-2020 (https://www.indiastat.com/agriculture-data.aspx). In addition to culinary use, it contributes umpteen medicinal properties against medical disorders. It had received esteem in traditional and modern medicine as antimicrobial, antiprotozoal, antithrombotic, antidiabetic, antihypertensive, and anticarcinogenic (Singh *et al.,* 2020). Garlic extract, along with ginger, is recognized as a pesticide and insecticide in organic farming. All these pharmacological values are ascribed to organosulphur compounds. Garlic contains more than thirty-three sulphur compounds such as allin, ajoene, allicin, diallyl trisulfide, allyl propyl disulfide, s-allyl cysteine and others (Prati *et al.,* 2014 and Fojlaley *et al.,* 2020).

Sulphur is the essential secondary nutrient that plays a vital role in synthesising sulphur- containing aminoacids such as cysteine, cystine and methionine. It is a constituent of vitamin A and activates certain enzyme systems (Subramanian *et al.,* 2020). Plants absorb sulphur in the form of sulphate (SO_4^{2-}) ions from the soil and sulphur dioxide (SO_2) from air (Linzon *et al.,*1979). Mainly, plants depend upon soil for sulphur nutrition. Nutrient management in soil plays a vibrant role in increasing the productivity and quality of crops to feed the increasing human population. Most of the inorganic fertilizers provide a ready supply of nutrients for crop growth and its over-use can deteriorate soil health by acidification. Applying acid forming fertilizers to soils of low pH could further augment the acidity (Tong and Xu, 2012 and Tabak *et al.,* 2020). Keeping these facts in view, the present study attempted to evaluate the sulphur sources and optimize the sulphur levels for improving the growth and yield of garlic with minimal disruption of soil quality.

MATERIALS AND METHODS

Study area

A field experiment was conducted at the Horticultural Research Station research farm, Woodhouse farm, Ooty, The Nilgiris, from January to May of 2021. The site is located at 11.42446^0 N latitude, 76.72256^0 E longitude, and 2463m above mean sea level. The experimental soil was analyzed in the laboratory to assess the initial properties and determined that the soil was clay loam in texture with a soil reaction of pH 4.98 and EC 0.59 dS m^{-1}. Soil available nutrients were low in $KMnO_4$-Nitrogen (229 kg ha^{-1}), high in Bray-Phosphorus (44.8 kg ha^{-1}), low in Neutral Normal NH_4OAc-potassium (220 kg ha^{-1}) and high in available sulphur (19.7 mg kg^{-1}).

Treatments and experimental design

Test crop garlic (var Ooty 2) cloves were planted at 15 x 7.5 cm spacing. The treatments consisted of readily soluble type four sulphur sources (Potassium sulphate, Magnesium sulphate, Zinc sulphate and Ammonium phosphate sulphate) and three levels of sulphur (0, 40, 60 kg S ha^{-1}). The details of treatment combinations were viz., T_1- 100 % NPK + 0 kg S ha^{-1} K_2SO_4, T_2 - 100 % NPK + 40 kg S ha^{-1} K_2SO_4, T_3 - 100 % NPK + 60 kg S ha^{-1} K_2SO_4, T_4 - 100 % NPK + 0 kg S ha^{-1} $MgSO_4$, T_5 - 100 % NPK + 40 kg S ha^{-1} $MgSO_4$, T_6 - 100 % NPK + 60 kg S ha^{-1} $MgSO_4$, T_7 - 100 % NPK + 0 kg S ha^{-1} $ZnSO_4$, T_8 - 100 % NPK + 40 kg S ha^{-1} $ZnSO_4$, T_9 - 100 % NPK + 60 kg S ha^{-1} $ZnSO_4$, T_{10} - 100 % NPK + 0 kg S ha^{-1} APS, T_{11} - 100 % NPK + 40 kg S ha^{-1} APS, T_{12} - 100 % NPK + 60 kg S ha^{-1} APS. The design of the experiment was a factorial randomized block design. Main plots constituted sulphur sources and subplots depicted sulphur levels. The 100 % NPK (75:40:40) was supplied as sulphur free fertilizers in the form of Calcium nitrate, Rock phosphate and Muriate of potash, respectively. Nitrogen, phosphorus, potassium and sulphur were applied basally and the top dressing of nitrogen was carried out at the bulb formation stage of crop growth. Cultural practices were implemented uniformly to all plots as per Tamil Nadu Agricultural University, Crop Production Guide Horticulture, 2020.

Data collection and analysis

Five garlic plants were labelled randomly from each plot for biometric observation. At the harvest stage, plant samples were collected for chemical analysis. Biometric observations were recorded on plant height (cm), number of leaves per plant, number of cloves per bulb, neck thickness (cm), the weight of 10 cloves (g), polar diameter (cm), equatorial diameter (cm), fresh weight of bulb (g), dry weight of bulb (g) and bulb yield (t ha^{-1}). Total soluble solids of garlic bulbs were determined using ERMA portable handheld refractometer. The ascorbic acid was estimated as the dye titration method. The total phenols in the garlic bulbs were determined using Folin-ciocalteau reagent and gallic acid as a standard. The pH of soil was estimated by potentiometric principle (Jackson, 1973). The method employed by Sokolov (1939) and McLean (1965) was used for soil exchangeable acidity determination. The available sulphur was calculated by the turbidimetric method (Chesnin and Yien, 1950). The data obtained were put through statistical analysis of variance as proposed by Gomez and Gomez (1984) using SPSS statistical software version 26. The comparison of treatment effects was performed with Fisher's Least Significant Differences test at 0.05 level of significance. Treatments having differences were considered to be significant at $p < 0.05$.

RESULTS AND DISCUSSION

Effect of sulphur sources on growth parameters

The sulphur sources and levels had a significant effect on plant height. The highest plant height, 67.13 cm was recorded in the treatment that received magnesium sulphate @ 60 kg ha^{-1} (Fig 1). Sulphur along with magnesium, being constituent of chlorophyll, gather photons in photosystem I and II encouraged vegetative

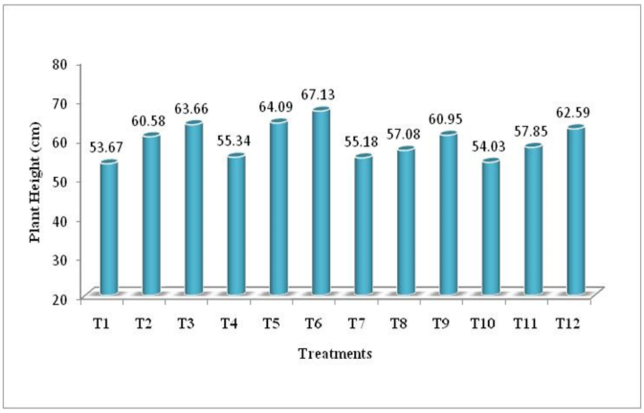

Fig 1. *Effect of sulphur sources on plant height (cm) of garlic*

growth of plants (Chaudhry, 2021) and positive interaction of sulphur with nitrogen increase meristem activity of plants for growth (Verma *et al*., 2013). No significant interaction of sources and levels was observed. The present findings are in agreement with the results reported by Shete *et al*. (2018) in garlic @ 45 kg S ha^{-1}. Sulphur sources had no significant effect on the number of leaves. The maximum number of leaves was 6.88, observed with magnesium sulphate @ 60 kg ha^{-1} and was significantly influenced by sulphur levels (Fig 2). More number leaves provide a large surface area to receive sunlight helping in the food production of plants. Similar findings were also reported by Zaman *et al*. (2011) in garlic by supplying sulphur @ 45 kg ha^{-1} and Priyanshu *et al.* (2019) recorded in garlic supplied with 40 kg S ha^{-1} along with FYM, vermicompost and 75 % RDF.

Effect of sulphur sources on yield and yield components

Both sulphur sources and levels depicted significant differences in cloves per bulb and neck thickness. Application of magnesium sulphate @ 60 kg ha^{-1} recorded the highest number of cloves per bulb and neck thickness with percent increase of 35% and 44 %, respectively, over control (Table 1). This is due to the function of sulphur and companion ion magnesium ranked importance in forming proteins, building blocks of the cell (Babaleshwar *et al*., 2017). In addition to the above points, favourable environmental conditions lead to fully differentiated cloves forming with the papery division between them.

The polar and equatorial diameter of the bulb varied significantly with sources, levels and its interaction. The polar and equatorial diameter significantly increased by 34 % and 21 %, respectively, in the treatment that received magnesium sulphate @ 60 kg ha^{-1} (Table 1). It

Table 1. Effect of sulphur sources and levels on yield attributes of garlic (var Ooty 2)

Treatments	Cloves / bulb			Neck thickness (cm)			Polar bulb diameter (cm)			Equatorial bulb diameter (cm)		
T_1- 100 % NPK + 0 kg S ha	12.35			1.39			3.02			3.31		
T_2 - 100 % NPK + 40 kg S	15.66			1.63			4.15			4.44		
T_3 - 100 % NPK + 60 kg S	16.71			1.85			4.20			4.49		
T_4 - 100 % NPK + 0 kg S	13.11			1.28			3.32			3.61		
T_5 - 100 % NPK + 40 kg S	16.84			1.66			4.23			4.52		
T_6 - 100 % NPK + 60 kg S	17.67			1.92			4.46			4.75		
T_7 - 100 % NPK + 0 kg S	13.08			1.34			2.93			3.22		
T_8 - 100 % NPK + 40 kg S	14.82			1.55			3.75			4.04		
T_9 - 100 % NPK + 60 kg S	15.40			1.76			4.08			4.37		
T_{10} - 100 % NPK + 0 kg S	12.85			1.31			3.52			3.81		
T_{11} - 100 % NPK + 40 kg S	13.63			1.52			3.58			3.87		
T_{12} - 100 % NPK + 60 kg S	14.95			1.68			3.96			4.25		
Mean	14.75			1.57			3.77			4.06		
	S	L	SxL	S	L	SxL	S	L	SxL	S	L	SxL
Sed	0.41	0.35	0.71	0.04	0.04	0.08	0.1	0.09	0.18	0.11	0.1	0.19
CD (0.05)	0.85	0.73	NS	0.09	0.08	NS	0.22	0.19	0.38	0.23	0.2	0.4

is attributed to translocation of photosynthates efficiently from source to sinks paved for size increment of the bulb. Hore *et al*. (2014) also reported that sulphur @ 60 kg S ha^{-1} had a significant effect on the bulb diameter of garlic.

Bulb characteristics viz., fresh weight, dry weight of the bulb and 10 cloves weight were found to be significant at sulphur sources and levels. The treatment that received magnesium sulphate @ 60 kg ha^{-1} recorded the maximum weight of bulb (Table 2). Increased photosynthesis, activation of phosphorylating enzymes and high affinity of RUBP carboxylase towards carbondioxide resulted in phloem loading and stored in bulbs of garlic (Al-Barzinji and Naif, 2014).

The bulb yield was significantly increased at a 5 % level of significance in the treatment that received magnesium sulphate @ 60 kg ha^{-1} with a 36 % increase in yield followed a 16 % increase by applying potassium sulphate @ 60 kg ha^{-1} (Table 2). Magnesium and sulphur have synergistic effect on phosphorus uptake in plants that influence cell division. The increased root to shoot ratio altogether has high photosynthetic rate and accumulation of carbohydrates in bulbs, increasing its size and eventually resulting in maximum yield. Similar findings were in accordance with the results obtained from Choudhary *et al.*(2018) reported that sulphur application @ 60 kg ha^{-1} in garlic enhanced the yield and Patidar *et al.*(2017) who concluded sulphur nutrition @ 50 kg ha^{-1} resulted in 27.5 % increase in bulb yield of garlic over control.

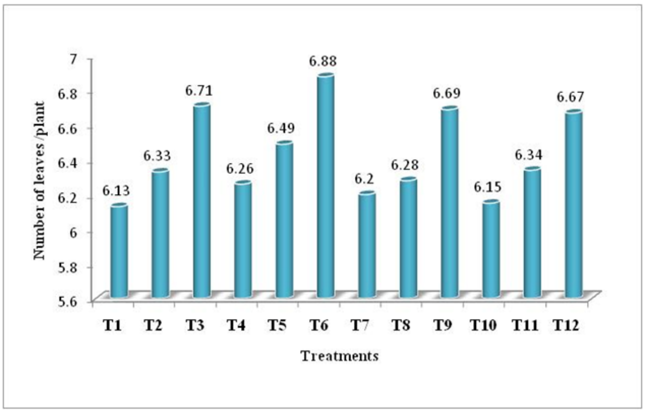

Fig 2. *Effect of sulphur sources on number of leaves per plant of garlic*

The dry matter accumulation of bulb varied significantly at a 5 % level of significance due to sulphur sources and levels. The application of magnesium sulphate registered a 25 % increase of drymatter @ 60 kg ha^{-1} (Fig 3) due to accelerated synthesis of chloroplast by higher uptake of sulphur and magnesium, resulting in more drymatter production. A similar finding was also reported by Diriba-Shiferaw *et al.* (2014) in garlic with sulphur application @ 30 kg ha^{-1}.

Table 2. Effect of sulphur sources and levels on bulb weight and yield of garlic (var Ooty 2)

Treatments	**Weight of 10 cloves (g)**			**Fresh weight of bulb (g)**			**Dry weight of bulb (g)**			**Bulb yield (t ha^{-1})**		
T_1- 100 % NPK + 0 kg S	10.73			11.69			4.03			13.28		
T_2 - 100 % NPK + 40 kg S	12.15			15.92			6.57			14.72		
T_3 - 100 % NPK + 60 kg S	13.28			18.34			6.72			15.43		
T_4 - 100 % NPK + 0 kg S	10.54			12.27			4.34			12.34		
T_5 - 100 % NPK + 40 kg S	13.43			17.46			6.38			15.37		
T_6 - 100 % NPK + 60 kg S	14.74			21.9			7.07			16.78		
T_7 - 100 % NPK + 0 kg S	10.11			12.18			4.18			12.25		
T_8 - 100 % NPK + 40 kg S	11.45			14.85			5.55			13.47		
T_9 - 100 % NPK + 60 kg S	12.87			16.57			6.41			14.88		
T_{10} - 100 % NPK + 0 kg S	10.69			11.2			4.23			12.69		
T_{11} - 100 % NPK + 40 kg S	11.05			14.01			5.56			13.02		
T_{12} - 100 % NPK + 60 kg S	12.62			14.98			6.2			13.98		
Mean	11.97			15.11			5.60			14.02		
	S	L	SxL	S	S	L	SxL	S	S	L	SxL	S
Sed	0.33	0.29	0.57	0.42	0.37	0.73	0.16	0.14	0.27	0.39	0.34	0.67
CD (0.05)	0.69	0.60	NS	0.88	0.76	1.52	0.33	0.28	0.57	0.81	0.70	NS

Effect of sulphur sources on quality

Application of sulphur recorded significant variations on quality parameters of garlic. Total soluble solids were registered to be the highest in the treatment that received potassium sulphate @ 60 kg ha^{-1} with 26 % increase over unfertilized sulphur plot (Table 3). The valuable explanation is the supply of sulphur and potassium enhances the bulb's quality by activating starch synthetase enzyme in carbohydrate metabolism and translocation of sucrose transport from leaves to bulb. These results were in accordance with the findings observed by Chattoo *et al.* (2018) in garlic fertilized with sulphur @ 45 kg ha^{-1}.

Results clearly showed no significant effect of sulphur sources on ascorbic acid of garlic (Table 3). Ascorbic acid content was the highest in the treatment that received potassium sulphate @ 60 kg ha^{-1} and it was 12 % increase over no sulphur application.

Total phenols in the garlic bulb varied significantly at 5 % level of significance at the sulphur sources and levels (Table 3). The highest phenolic content was registered in the treatment that received potassium sulphate @ 60 kg ha^{-1} followed by magnesium sulphate @ 60 kg ha^{-1}. Synergistic interaction of potassium and sulphur boost potassium to express its role in quality improvement by activating over sixty enzyme systems was reported by Ozkan *et al*. (2018) in the onion crop nutritioned with potassium sulphate and polyhalite.

Effect of sulphur sources on postharvest soil

Though data on pH was found to be non-significant at 5 % level of significance, we could observe a gradual decrement of pH in levels of sulphur source. The decrease in pH recorded minimum of 3 % with magnesium sulphate over no sulphur (Table 4). This indicates that there was an increase in hydrogen ion concentration that may be due to biochemical oxidation of sulphur producing sulphuric acid (Youssif *et al.,* 2015) or reduction of nitrogen to ammonium ions.

The exchangeable acidity of soil varied significantly in terms of sulphur sources, levels and its interaction (Table 4). There was a rise in exchangeable acidity at sulphur levels. Sulphur source of magnesium sulphate contributed 29 % increase in exchangeable acidity over control treatment which was recorded to be minimum than other sulphur sources rendering less acidity by furnishing meagre amount of acid cations to occupy on exchange sites of soil.

The build-up of available sulphur in post-harvest soil

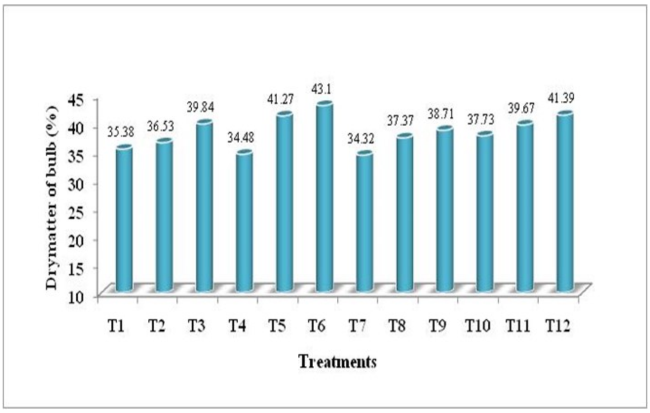

Fig 3. *Effect of sulphur sources and levels on dry matter of garlic bulb (%)*

Table 3. Effect of sulphur sources and levels on quality of garlic (var Ooty 2)

Treatments	**TSS (^{0}Brix)**			**Ascorbic acid (mg 100g^{-1})**			**Total phenols (mg g^{-1})**		
T_1- 100 % NPK + 0 kg S ha^{-1} K_2SO_4	34.18			18.25			0.36		
T_2 - 100 % NPK + 40 kg S ha^{-1} K_2SO_4	40.72			19.87			0.44		
T_3 - 100 % NPK + 60 kg S ha^{-1} K_2SO_4	43.16			20.81			0.49		
T_4 - 100 % NPK + 0 kg S ha^{-1} $MgSO_4$	33.87			17.48			0.32		
T_5 - 100 % NPK + 40 kg S ha^{-1} $MgSO_4$	38.61			19.66			0.42		
T_6 - 100 % NPK + 60 kg S ha^{-1} $MgSO_4$	41.89			20.74			0.48		
T_7 - 100 % NPK + 0 kg S ha^{-1} $ZnSO_4$	33.22			18.39			0.33		
T_8 - 100 % NPK + 40 kg S ha^{-1} $ZnSO_4$	36.14			19.27			0.4		
T_9 - 100 % NPK + 60 kg S ha^{-1} $ZnSO_4$	39.27			20.03			0.45		
T_{10} - 100 % NPK + 0 kg S ha^{-1} APS	33.41			17.52			0.34		
T_{11} - 100 % NPK + 40 kg S ha^{-1} APS	35.53			19.43			0.39		
T_{12} - 100 % NPK + 60 kg S ha^{-1} APS	38.05			19.92			0.44		
Mean	37.34			19.28			0.4		
	S	L	SxL	S	L	SxL	S	L	SxL
Sed	1.04	0.90	1.79	0.53	0.46	0.93	0.01	0.01	0.02
CD (0.05)	2.15	1.86	NS	NS	0.96	NS	0.02	0.02	NS

Table 4. Effect of sulphur sources and levels on properties of post harvest soil samples

Treatments	pH			Exchangeable acidity (meq100 g^{-1})			Available Sulphur (mg kg^{-1})		
T_1- 100 % NPK + 0 kg S ha^{-1} K_2SO_4	4.92			0.16			13.33		
T_2 - 100 % NPK + 40 kg S ha^{-1} K_2SO_4	4.83			0.20			22.35		
T_3 - 100 % NPK + 60 kg S ha^{-1} K_2SO_4	4.68			0.26			24.01		
T_4 - 100 % NPK + 0 kg S ha^{-1} $MgSO_4$	4.89			0.17			12.67		
T_5 - 100 % NPK + 40 kg S ha^{-1} $MgSO_4$	4.86			0.19			21.33		
T_6 - 100 % NPK + 60 kg S ha^{-1} $MgSO_4$	4.74			0.22			23.31		
T_7 - 100 % NPK + 0 kg S ha^{-1} $ZnSO_4$	4.90			0.17			13.34		
T_8 - 100 % NPK + 40 kg S ha^{-1} $ZnSO_4$	4.78			0.21			22.02		
T_9 - 100 % NPK + 60 kg S ha^{-1} $ZnSO_4$	4.67			0.29			24.67		
T_{10} - 100 % NPK + 0 kg S ha^{-1} APS	4.92			0.17			12.54		
T_{11} - 100 % NPK + 40 kg S ha^{-1} APS	4.71			0.29			21.83		
T_{12} - 100 % NPK + 60 kg S ha^{-1} APS	4.44			0.41			24.04		
Mean	4.78			0.23			19.62		
	S	L	SxL	S	L	SxL	S	L	SxL
Sed	0.13	0.11	0.23	0.01	0.01	0.01	0.57	0.50	0.99
CD (0.05)	NS	NS	NS	0.02	0.01	0.03	NS	1.03	NS

samples was recorded to be non-significant in sulphur treated plots in terms of sulphur sources, whereas it was significant at sulphur levels (Table 4). Among the four sulphur sources, the zinc sulphate source recorded the maximum available sulphur status of 25.27 % increase over the initial value. It indicates less uptake of sulphur in plants resulting in minimal performance compared to other sources. No increase in available sulphur status was registered in treatment that received other nutrients except sulphur. Similar findings were given by Thangasamy *et al*. (2013) in short-day onion supplied with (100:50:50) NPK kg ha^{-1} + 50 kg ha^{-1} sulphur and Solanki *et al.* (2020) in garlic fertilized with 5 t ha^{-1} + 40 kg S ha^{-1}.

The farming community still running behind the yield and quality improvement of crop while the area of attention has already been shifted in sustaining the soil health on par with crop production. Besides nutrients, sulphur is also a soil acidifier. All the sulphur sources compared here was easily soluble and readily available in the active pool of rhizospheric region that maintains dynamic equilibrium with exchangeable pool. Apart from evaluating the suitable sulphur fertilizer to the soils of low pH for enhancing garlic productivity, the present study gained momentum in assessing the fertilizer induced acidity both in active and exchangeable sites of soil.

Conclusion

It was inferred that among various sources of sulphur viz., potassium sulphate, magnesium sulphate, zinc sulphate, ammonium phosphate sulphate, the garlic plants fertilized with magnesium sulphate as sulphur source @ 60 kg ha^{-1} had a significant influence on the growth and yield of garlic by offering less acidity to the soil. Bulb quality was improved by potassium sulphate @ 60 kg ha^{-1}. Application of magnesium sulphate @ 60 kg ha^{-1} could be recommended for enhancing garlic growth and yield by sustaining soil quality.

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Conflict of interest

The authors declare that they have no conflict of interest.

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