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Research article

Sulphur fertilization enhanced yield, its uptake, use efficiency and economic returns of *Aloe vera* L.

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ABSTRACT

Sulphur plays a vital role in the formation and biosynthesis of protein, chlorophyll, and few amino acids. To investigate the effect of sulphur fertilizer on leaf biomass yield, critical sulphur concentration, sulphur requirement and uptake by *Aloe vera* L., a pot experiment was carried out following completely randomized design with six levels of sulphur viz., 0, 15, 30, 45, 60 and 80 kg ha^{-1} with three replications. The results of the study revealed that the growth attributes, leaf and gel yield, and sulphur uptake significantly improved with sulphur application and the best results were obtained from the application of 45 kg sulphur ha^{-1}. On average, addition of sulphur enhanced the leaf biomass yield by 47.5% and sulphur use efficiency by 38% compared to control. The effect of sulphur on the growth parameters and their significant and positive correlations with yield signifies the importance of sulphur on the yield and quality of *A. vera*. The calculated minimum amount of sulphur for 80% leaf biomass production was 21.1 kg sulphur ha^{-1} with a critical leaf sulphur concentration of 0.23% in *A. vera*. Moreover, sulphur addition to soil substantially enhanced the economic returns of *A. vera*. Therefore, addition of 45 kg sulphur ha^{-1} could be a better option for obtaining higher yield and economic return of *A. vera*.

1. Introduction

Aloe vera L., commonly known as *Ghrit Kumari* belongs to the family Liliaceae, is one of the oldest medicinal plant worldwide. Aloes are xerophytes in nature cultivated for medicinal, ornamental, vegetable, and cosmetic purposes in Africa, North America, Europe, and Southeast Asia (Tawaraya et al., 2007). Recently, this plant has become a big industry worldwide due to its application in food processing, medicinal and cosmetic industries. *Aloe* gel are commonly used in functional foods and for the preparation of healthy drinks free from laxative effects. Other food products including ice cream, milk, confectionery, etc. are also prepared using *A. vera* gel as flavoring component and food preservative (Christaki and Florou-Paneri 2010). Generally, leaf gel contains polysaccharides, soluble sugars proteins, enzymes, vitamins, amino acids and anthraquinones (Chun-hui et al., 2007). Anthraquinones are extensively used as anti-inflammatory and anti- (cancer, bacterial and viral) medicines due to their cathartic properties (Park et al., 2009; Pellizzoni et al., 2012; Lawrence et al., 2009). *A. vera* is composed of six antiseptic agents: salicylic acid, lupeol, urea-nitrogen, phenols, cinnamonic acid and sulphur (S) which all have inhibitory effects on fungi, bacteria, and viruses (Surjushe et al., 2008). Enzymatic and nonenzymatic antioxidative indices levels in rat livers can also be significantly perturbated by using *A. vera* extract (Gupta et al. 2019, 2020a). Thus, a simple and efficient production technique by the application of optimum fertilizers dose especially S needs to be developed for ensuring product quality and health safety (Eshun and He 2004). Recently, Gupta et al. (2020b) also reported that *A. vera* can be used as preservative of foods and functional food supplement because of high amount of carbohydrates, antioxidant molecules and vitamins as its constituents.

Application of inorganic S is very essential for better growth and biosynthesis of protein and chlorophyll in plants (Brosnan and Brosnan 2006). This important nutrient is available to plants only as sulfate (Haneklaus et al., 2006), hence most S fertilizers consist of sulfate salts. In the last few decades, S requirements for plants have gained special attention due to its increased deficiency in soil and reduction in crop yield and quality (Haneklaus et al., 2006). The deficiency of S resulted in retarded growth, reduced leaf size, and caused leaf chlorosis (Ergle and Eaton, 2005). For optimum plant growth, the requirement of S varies

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between 0.1 and 0.5% of the dry biomass weight (Marschner 2012). The morphology of chloroplast is generally affected by S deficiency due to the presence of functional chloroplasts which are normally rich in S (Hall et al., 2002; Repica et al., 2001). In addition, photosynthesis has been retarded in a profound way because of S deficiency which can be corrected slowly through the addition of external S (Abadie and Tcherkez 2019). Positive and beneficial responses to S fertilization had been reported in date palm (Idris et al., 2012). Previously, Kumar and Yadav (2007) reported that inadequate level of S prolongs the life cycle of *A. vera* plant, delays maturity and decreases its economical yield.

To the best of our knowledge, no detailed study was done on the S requirement and critical S level for the growth and leaf biomass yield of *A. vera* production in the context of Bangladesh. Optimum S requirement need to be calculated for achieving maximum leaf biomass yield of *A. vera*. Based on these considerations, this study was aimed to study the influence of different levels of S on the growth, leaf yield, critical S concentration, S requirement and its uptake by *A. vera*.

2. Materials and methods

2.1. Experimental site

The pot trial study was carried out in the farmer's field, *Kashiganj*, Tarakanda, Mymensingh under field conditions during September 2018 to May 2019. Geographically the experimental site was located at 24°75′ N latitude and 90°50′ E longitude at an elevation of 18 m above the sea level. The site belongs to the Non-calcareous Dark Grey Floodplain soil under the Agro-Ecological Zone of Old Brahmaputra Floodplain (AEZ-9) and classified as Inceptisols according to USDA soil classification (FAO and UNDP, 1988). The climate of the experimental area is under the sub-tropical climatic zone, which is characterized by moderate to high temperature, heavy rainfall, high humidity and relatively long day during *kharif* (April to September) and scanty rainfall, low humidity, low temperature and short-day period during *rabi* season (October to March).

2.2. Seedling transplanting and growth analysis

Silty loam soil was collected from *Kashiganj*, Tarakanda, Mymensingh. The soil was collected from 0-15 cm depth of selected area for the experiment. The plant residues and other extraneous materials were removed from the soil through sieving. The physico-chemical properties of soil were analyzed following the standard methods of analysis (Page and Laidlaw, 1982) and presented in Table 1.

Each plastic pot (30 cm in height with 24.5 cm diameter at the top and 20 cm diameter at the bottom) was filled with 10 kg of processed soil leaving 2 cm empty from the top and labeled with proper tagging. *A. vera* seedlings of eighteen-month-old were collected from *Oshudhi* village, Natore Sadar, Natore and transplanted in this experiment. Six levels of S viz., 0 (S_0), 15 (S_{15}), 30 (S_{30}), 45 (S_{45}), 60 (S_{60}) and 80 (S_{80}) kg ha^{-1} was mixed with the soil as treatment from gypsum. In addition, other essential plants nutrients like nitrogen (N), phosphorous (P), potassium (K), zinc (Zn) and boron (B) were also incorporated to soil as basal dose @ 150, 80, 120, 3 and 1 kg ha^{-1} (Biswas, 2010) from urea, triple super phosphate, muriate of potash, zinc sulphate and boric acid, respectively. One-third amount of urea and full doses of other fertilizers were applied one day before transplanting. The rest two installments of urea were applied at 60 and 120 days after transplanting (DAT). Experiment was set up following completely randomized design with three replications. *A. vera* leaf was harvested at 118, 148 and 178 DAT of experiment and the cumulative weight was considered. Leaves were collected carefully and cleaned with tap water followed by distilled water to remove soil and other foreign materials. Paper towel was used to remove adhering water.

Table 1. Physical and chemical properties of the experimental soil.

Physical properties	Value	Chemical properties	Value
Sand (%)	22.53	pH (Water)	5.90
Silt (%)	66.87	Total C (%)	0.59
Clay (%)	10.60	Total N (%)	0.06
Soil Textural class	Silty loam	Available P (μg g^{-1})	3.00
USDA soil class	Inceptisols	Exchangeable K (cmol$_c$kg^{-1})	1.30
Bulk density (g cm^{-3})	1.46	Available S (μg g^{-1})	4.00
Particle density (g cm^{-3})	2.59	Available Zn (μg g^{-1})	1.81
Field capacity (%)	27.24	Available B (μg g^{-1})	0.06
		Exchangeable Ca (cmol$_c$kg^{-1})	4.6
		Exchangeable Mg (cmol$_c$kg^{-1})	3.90

2.3. Determination of mineral nutrients in A. vera plant

For the nutrient's extraction, the fresh leaf was chopped, washed, and cut from the middle to separate the gel by spoon scraping. Then the gel and chopped leaves were sun dried for 2 days followed by oven drying at 70 °C for 48 h and finely ground with a grinder. The powdered samples were preserved in polythene bag and kept in refrigerator till analysis. Requisite quantity of powdered *A. vera* gel and leaf was weighed accurately and taken for extraction. For the determination of mineral nutrients, exactly 0.5 g of leaf and gel powder were taken into a 250 mL conical flask and 10 mL of di-acid mixture (HNO_3:$HClO_4$ = 2:1) was added to it. Then, they were placed on sand bath until the solid particles disappeared and milky dense white fumes were evolved from the flask. Then they were cooled at room temperature, washed with distilled water and filtered into 100 mL volumetric flasks through Whatman No. 42 filter paper making the volume up to the mark with distilled water following the wet oxidation method as described by Jackson (1973). The S uptake was calculated using the formula of Sharma et al. (2012).

$$\text{Uptake}\left(\text{mg pot}^{-1}\right) = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Dry weight}\left(\text{mg pot}^{-1}\right) \quad (1)$$

The sulphur use efficiency (SUE) was estimated using the formula of Syers et al. (2008).

$$\text{SUE (\%)} = \frac{\text{S uptake in leaf } (g \text{ pot}^{-1})}{\text{S applied } (g \text{ pot}^{-1})} \times 100 \quad (2)$$

Relative yield was calculated using the formula of Fageria et al. (2010).

$$\text{Relative yield (\%)} = \frac{\text{Yield of control or treated pot}}{\text{Maximum yield of treated pot}} \times 100 \quad (3)$$

Sulphur requirement to obtain 80% of maximum leaf biomass yield was determined by plotting applied S on the X axis versus the relative leaf biomass yield on the Y axis. For the determination of critical leaf S concentration in *A. vera* leaf the "Critical nutrition concentration" concept advanced by Ulrich (1952) for plant were followed. Critical values as used by Ulrich and Hills (1973) are determined from the relationship of nutrient concentration and relative yield at the time of sampling. The critical S concentration in *A. vera* leaf were estimated from the relative amount of leaf biomass to achieve 80% leaf biomass yield (Kouno and Ogata, 1988). The relative leaf biomass yield was plotted on the Y axis against the respective S concentration of leaf on the X axis. The S concentration corresponding to the arbitrary point at 80% leaf biomass production was estimated by the concept used by Ulrich and Hills (1973).

2.4. Economic analysis

The production cost was analyzed to find out the most economic and profitable S application rate for *A. vera* cultivation in silty loam soil. All input costs including the cost for lease of land and interests on running capital were considered in computing the cost of production. The usual interest rate of 8% for one year was used in this calculation. The current market price of *A. vera* leaf and sucker was considered for estimating the cost and return. The benefit cost ratio (BCR) was calculated using the formula of Tarafder et al. (2020).

$$\text{BCR} = \text{Gross return per hectare (Tk.)/Total cost of production ha}^{-1}\text{ (Tk.)} \quad (4)$$

2.5. Statistical analyses

Collected data on the leaf yield, yield attributes and nutrient concentrations were tabulated and analyzed using statistical software Minitab 2017 Version 17.0 (Minitab Inc, USA). The means for all the treatments were calculated and analysis of variance (ANOVA) for all the characters under consideration was performed and Tukey's range test to determine the significant difference among the treatments. Overall statistical analysis of the present study was done following Gomez and Gomez (1984).

3. Results and discussion

3.1. Plant height

Plant height increased significantly with the application different S rates and the advancement of growth period (Figure 1 & Table 2). Plant height increased progressively up to S_{30} at 60 DAT. Compared to control, addition of various levels of S increased plant height by 2.83–8.60 cm. The tallest (39.47 cm) and shortest plant was obtained from the 45 kg S ha^{-1} and control treatment, respectively. Our results can be supported with the findings of Eisa et al. (2016) who reported that application of 4 g S pot^{-1} significantly increased the plant height of *A. vera* compared to the application of 2 g S pot^{-1}. Similarly, few other studies also found that S fertilization significantly increased the plant height of different crops than the plants receiving no S (Chaubey et al., 2000; Maniruzzaman et al., 2016).

3.2. Number of leaves

Soil incorporation of inorganic S fertilizer significantly increased the number of *A. vera* leaves (Figure 2 & Table 2) which increased with the increasing levels of S up to 45 kg ha^{-1} and then declined with the further addition. The leaf number increased rapidly between 28 and 178 DAT for all the S levels except control. The maximum number of leaves was recorded from the plant fertilized with 45 kg S ha^{-1} which was significantly higher than all other levels of S and the minimum number of leaves was recorded from control. Similarly, Eisa et al. (2016) found the highest leaf number of *A. vera* from the application of 4 g S pot^{-1}. Performance of *A. vera* crop to a great extent is governed by the number of leaves plant^{-1}. It is imperative that if the number of leaves plant^{-1} is higher, the leaf yield will be higher. Maniruzzaman et al. (2016) also observed that the number of leaves plant^{-1} was higher with the increased S rates up to 30 kg ha^{-1}. This finding is also similar with the previous reports for the increased leaf number of different crops with S fertilization (Islam et al., 2013; Lalitha and Gopala 2004).

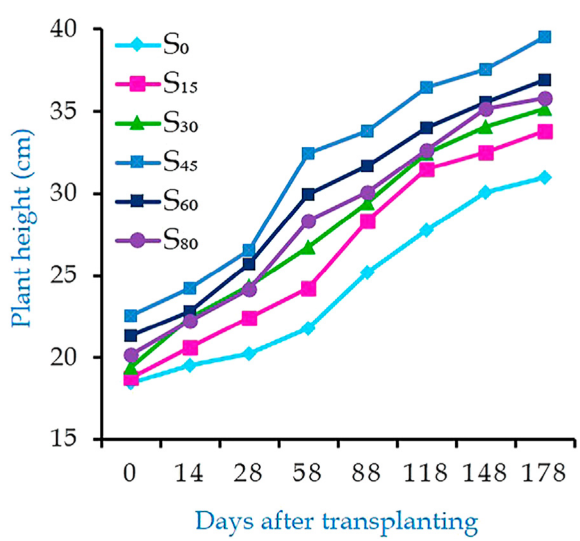

Figure 1. Effects of different levels of sulphur on the plant height of *Aloe vera* L. at different days after transplanting (DAT). Bars indicate standard error.

3.3. Leaf area

Addition of various levels of S showed a significant influence on the leaf area plant^{-1} of *A. vera* at harvest (Table 3). A rapid and gradual increase in leaf area was noticed with the increasing levels of S addition till 45 kg ha^{-1} and further addition of 60 and 80 kg ha^{-1} showed a declining leaf area. The maximum leaf area plant^{-1} (5325 cm^2) and the minimum leaf area (2265 cm^2) was obtained from the plants fertilized with 45 and 0 kg S ha^{-1}, respectively. As an important plant growth index, leaf area determines plant capacity to trap solar energy which ultimately influence the growth, development, and yield of plant. This in agreement with the findings of Eisa et al. (2016) who found the maximum leaf area of *A. vera* with the application of 4 g S pot^{-1} compared to 2 g S pot^{-1}. This result can be further supported by the findings of previous studies where application of 30–45 kg S ha^{-1} showed significantly higher leaf area of different crops than the control treatment (Khanom et al., 2008; Hasan et al., 2013).

3.4. Number of suckers

The number of sucker pot^{-1} responded significantly due to the application of different levels of S presented in Table 3. In general, the number of suckers increased with the increasing levels of S application up to 45 kg ha^{-1} and then declined with further addition. The highest number of sucker pot^{-1} (8.33) at harvest was observed from the plant receiving 45 kg S ha^{-1} which was relatively higher than other levels of S. The lowest number of suckers was found from the control treatment. A similar result was reported by Eisa et al. (2016) where significantly increased number of suckers of *A. vera* was obtained from the application 4 g S pot^{-1} than the lower application rate.

3.5. Leaf biomass yield

A significant increase in leaf biomass yield was monitored with the application of S up to 45 kg ha^{-1} and then reduced at 60 and 80 kg S ha^{-1} application (Figure 3). At harvest, the highest leaf biomass yield pot^{-1} (1760 g) was recorded from the plants fertilized with 45 kg S ha^{-1} which was significantly different from the biomass yields obtained from other treatments. As expected, the lowest leaf biomass yield was measured from the plants receiving no S fertilizer. Compared to control, on average S fertilization increased the leaf biomass yield by 29–66% at harvest. The accumulation of dry matter is a vital crop growth index which is commonly used to determine the economic returns influenced by the effects of different treatments. Sulfur is often considered as a limiting factor for leaf biomass yield in crop ecosystems (Pareek et al., 2012). The improvements in leaf biomass yield obtained in this study might be resulted from the efficient uptake and metabolism of S availability. Sulfur has a synergistic relationship with many essential plant nutrients especially N. The uptake and absorption of N become limited in S deficient soils (Nasreen and Huq, 2005). This growth and yield enhancements obtained from S application in our study is in line with the findings of Ross (2005) who observed positive influence of S application on the growth of *A. vera* plants. Similarly, Eisa et al. (2016) reported that the best increase in fresh and dry weights of *A. vera* was resulted from 4.0 g S

Table 2. Analysis of variance (mean square) for the effects of different levels of sulphur on the plant height and number of leaves of *Aloe vera* L.

Growth parameters	Degrees of freedom		Days after transplanting (DAT)							
			0	14	28	58	88	118	148	178
Plant height	Treat.	5	7.49**	7.93**	15.71**	44.94**	25.85**	25.10**	20.27**	25.21**
	Error	12	1.06	1.06	1.35	3.95	3.77	2.71	2.41	2.59
Number of leaves	Treat.	5	0.59^{ns}	1.42^{ns}	1.70*	4.09**	7.12**	4.37*	7.02**	9.52**
	Error	12	0.22	0.50	0.33	0.56	0.78	0.89	1.28	0.83

* = Significant at 5% level of probability; ** = Significant at 1% level of probability; ns = non-significant, Treat. = Treatment.

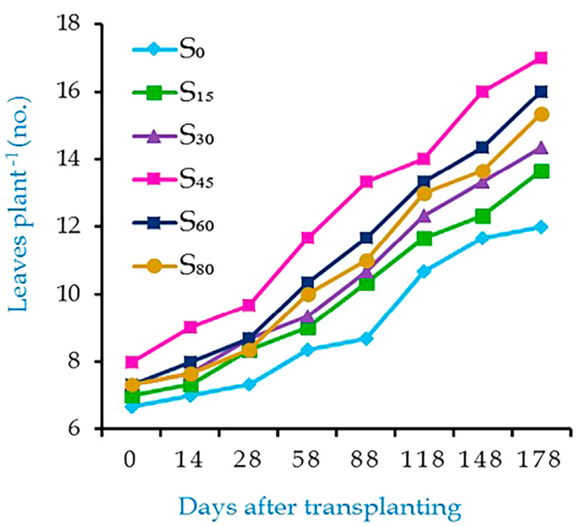

Figure 2. Effects of different levels of sulphur on the number of leaves of *Aloe vera* L. at different days after transplanting (DAT). Bars indicate standard error.

pot^{-1}. Eshun and He (2004) also reported that application of S significantly increased the yield of *A. vera*.

3.6. Fresh and dry gel weight

The fresh and dry gel weight of *A. vera* pot^{-1} at harvest was significantly influenced by different levels of S fertilizer (Table 3). Generally, the fresh and dry gel weight increased with the increasing levels of S application up to 45 kg ha^{-1} and then declined with further addition. The highest fresh (1132 g pot^{-1}) and dry (18.51 g pot^{-1}) gel weight at harvest was measured from the plants fertilized with 45 kg S ha^{-1} which was significantly higher than other levels of S except S_{60}. The lowest fresh and dry gel weight was obtained from the control treatment. The results of our study agree with the findings of Eisa et al. (2016) who reported that S application significantly influenced the leaf gel yield of *A. vera*. significantly and maximum leaf and gel yield was obtained from the treatment of 4 g S. Similarly, Ross (2005) also found a positive effects of S fertilization on *A. vera* gel yield.

3.7. Gel S concentration

Soil incorporation of S significantly influenced the concentration and its uptake by *A. vera* gel (Table 4). The gel S concentration increased proportionately with the increasing levels of S fertilization. The highest S concentration (0.41%) was obtained from 80 kg S ha^{-1} and the lowest S concentration and uptake were obtained from the plants receiving no S fertilizer.

3.8. Leaf S concentration and uptake

The S concentration and uptake by *A. vera* leaf was significantly influenced by different levels of S (Table 4). Sulphur concentration and uptake by leaf was increased with the increasing levels of S addition. The highest S concentration (0.49%) and uptake (271 mg pot^{-1}) was

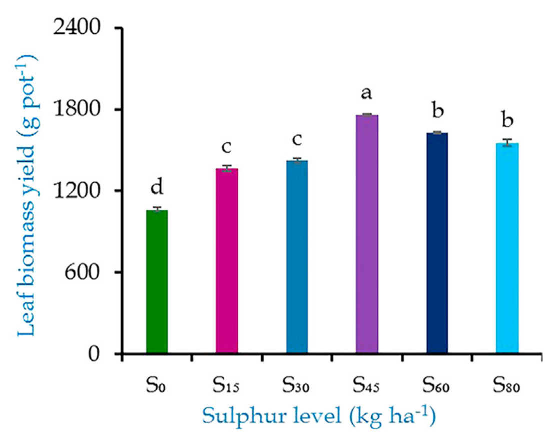

Figure 3. Effects of different levels of sulphur on the leaf biomass yield of *Aloe vera* L. at harvest. Bars indicate standard error.

Table 3. Effects of different levels of sulphur on total leaf area, number of suckers, fresh gel weight, dry gel weight and leaf biomass yield increase over control of *Aloe vera* L.

S level (kg ha^{-1})	Total leaf area plant^{-1} (cm^2)	No. of suckers (pot^{-1})	Fresh gel weight (g pot^{-1})	Dry gel weight (g pot^{-1})	Leaf biomass yield increase over control (%)
S_0	2265d	2.00d	689d	10.23e	-
S_{15}	3102c	3.67c	894c	13.34d	29
S_{30}	3901b	4.67c	930c	14.86c	34
S_{45}	5325a	8.33a	1132a	18.51a	66
S_{60}	4399b	7.67ab	1086a	17.40ab	53
S_{80}	3707bc	6.67b	1005b	16.41b	46
SE	138.01	0.28	11.64	0.21	-
CV (%)	6.60	8.54	2.38	2.84	-

CV = Coefficient of variance, SE± = Standard error of means. Values with the same alphabet in column are not significantly different at 5% level of probability.

Table 4. Effects of different levels of sulphur on gel and leaf sulphur concentration, leaf sulphur uptake and sulphur use efficiency (SUE) of *Aloe vera* L.

S level (kg ha^{-1})	Gel S conc. (%)	Leaf S conc. (%)	Leaf S Uptake (mg pot^{-1})	SUE (%)
S_0	0.11e	0.13e	51.99d	-
S_{15}	0.19d	0.23d	121.79cd	57.61
S_{30}	0.26c	0.31c	153.55bc	39.11
S_{45}	0.34b	0.41b	248.05ab	36.31
S_{60}	0.37ab	0.44ab	262.80a	31.08
S_{80}	0.41a	0.49a	271.00a	24.03
SE	0.01	0.01	18.68	-
CV (%)	0.11	10.27	19.12	-

CV = Coefficient of variance, SE± = Standard error of means. Values with the same alphabet in column are not significantly different at 5% level of probability.

obtained when S was applied at the rate 80 kg ha^{-1} which was significantly different from other treatments. The lowest leaf S concentration was obtained from the plants receiving no S fertilizer. Previously, Mashrafi et al. (2010) concluded that increased S uptake by rice resulted from increased application of S fertilizer. Results of this study are in agreement with the findings of Channagoudar and Janawade (2010) and Lalitha and Gopala (2004) who found highest S uptake by onion with the application of 40 kg S ha^{-1}.

The plant height, leaf number, leaf area, leaf yield and gel yield were better with the application of 45 kg S ha^{-1} than the other S application rate. This might be due to the results of better synchronization of available S supply according to plant demand which is crucial for better growth and development of plants. Moreover, the adequate supply of available S from 45 kg S ha^{-1} might also synergistically influenced the uptake of other nutrients, especially N and P, and ensured balance nutrients supply whereas this might not be the case for lower and excess application of S. The low application of S might not be able to supply adequate S required for optimum growth and development of plants whereas excess supply of S might cause nutrient toxicity and imbalance in the uptake of other nutrient due to excess S uptake by plants. This can be supported by the S uptake data where significantly higher S uptake was monitored in high S application rate.

3.9. Sulphur use efficiency (SUE)

The SUE of *A. vera* was substantially influenced by application of different levels of S (Table 4). In general, the SUE decreased with the increase of S levels. The highest value of SUE (57.61%) was recorded in S_{15} and the lowest in S_{80}. Improvement of SUE is dependent on S dose, fertilizer source and the application time (Aula et al., 2019). For agricultural crops, Eriksen (2009) observed the SUE of 25%. With the application rate of 15–45 kg S ha^{-1}, Singh Shivay et al. (2014) calculated average SUE to be 34.2% in rice, whereas 29.8% SUE for S rates of 45 kg ha^{-1}. After application, S becomes available to make it more effective when applied at right dose and right time (Chien et al., 2011). The higher SUE in our study for *A. vera* crop was observed which might be due to crop and site specificity of SUE (Aula et al., 2019). Higher SUE was observed with the lower level of S application which might be the results of intense competition of root and efficient S uptake. On the other hand, the lower SUE was noticed in higher S fertilized soil this might be because of smaller proportion of applied S was taken up by plants and the rest part of available S might be lost via leaching or other pathways.

3.10. Correlation and regression among yield and yield attributes of Aloe vera L

Significant and positive relationships were found between leaf biomass yield vs plant height, leaf biomass yield vs leaf area, and fresh gel weight vs leaf biomass yield where correlation coefficients (r) were 0.88**, 0.93** and 0.99**, respectively (Figure 4). The relationships were more evident from the regression equations (y = 66.356x - 881.32, y = 0.2107x + 668.63 and y = 0.6518x + 0.5469, respectively) showing

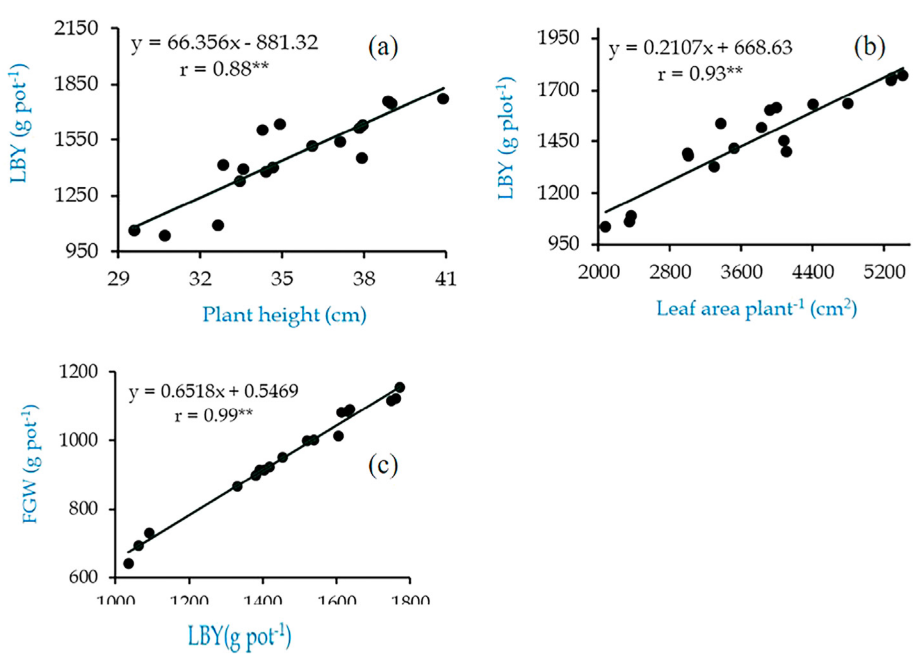

Figure 4. Correlations and regression equations between leaf biomass yield (LBY) and plant height (a), leaf biomass yield (LBY) and leaf area (b), fresh gel weight (FGW) and leaf biomass yield (LBY) (c) of *Aloe vera* L. as influenced by different levels of sulphur. Values are the replicates of all S treatments. **Correlated significantly at P < 0.01.

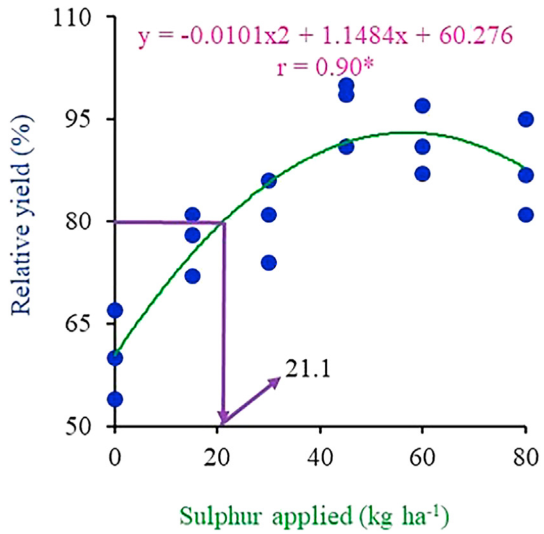

Figure 5. Correlation and regression equation between applied sulphur and relative leaf biomass yield of *Aloe vera* L. Values are the replicates of all S treatments. *Correlated significantly at P < 0.05.

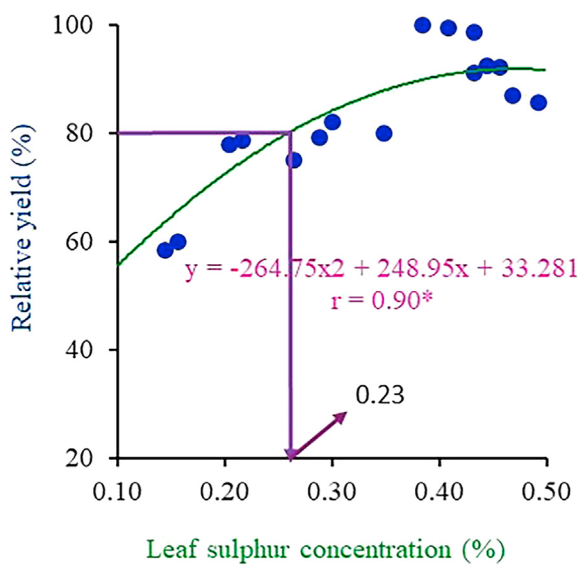

Figure 6. Correlation and regression equation between leaf S concentration and relative leaf biomass yield of *Aloe vera* L. Values are the replicates of all S treatments. *Correlated significantly at P < 0.05.

gradual increase in leaf biomass yield leaf and fresh gel weight with increasing plant height, leaf area and leaf biomass yield. Similarly, Chowdhury et al. (2020) also found significant and positive correlation of plant height, number of leaves and fresh leaf weight with fresh gel weight of *A. vera* due to S fertilization.

3.11. Sulphur requirement for Aloe vera L

The minimum amount of S requirement for 80% leaf biomass production of *A. vera* was estimated to be 21.1 kg ha^{-1} (Figure 5). Previously, Thangasamy et al. (2013) reported significantly increased bulb yield and pungency levels of onion with the application of 20 kg S ha^{-1}. Application of fertilizer, field or pot conditions and the choise of crops are the vital factors influencing the S requirements (Maniruzzaman et al., 2016). Hasan et al. (2013) also found maximum yield and growth of brinjal by applying 45 kg S ha^{-1}.

Table 5. Input cost for the cultivation and prices used to compute economics of *Aloe vera*.

	Particulars of operation	Cost (Tk./ha)	Cost (USD/ha)
A	*Non-material cost*		
1	Land preparation		
	a) Ploughing	10000	118
	b) Levelling, layout of the field (60-man days)	72000	849
2	Seedling transplanting (50-man days)	40000	472
3	Weeding (40-man days)	32000	377
4	Irrigation (10-man days)	12000	142
5	Pesticide application (6-man days)	4800	57
6	Harvesting (40-man days)	48000	566
7	Bearing leaves and sucker (5-man days)	6000	71
B	*Material cost*		
1	Seedling cost	189000	2229
2	Fence making	15000	177
3	Pesticide	15000	177
4	Irrigation cost	10000	118
5	Fertilizer (Common dose)	7460	88
6	Miscellaneous	2000	24
Total		463260	5463

Input prices: Labour wage = Tk.400 day^{-1}, *Aloe vera* seedling = Tk.30/seedling. The Tk was converted to USD according to the Bangladesh bank exchange rate accessed on 29th November 2020 (https://www.bb.org.bd/econdata/exchangerate.php).

3.12. Critical leaf S concentration of Aloe vera L

The calculated critical leaf S concentration was 0.23% which corresponds to the arbitrary point at 80% to achieve the maximum leaf biomass production *A. vera* (Figure 6). Critical values are quite useful in interpreting a plant analysis result. Maniruzzaman et al. (2016) found almost similar result for stevia. Similarly, Bryson and Mills (2015) reported critical S level in cotton, legumes, tomatoes, and tobacco varied from 0.20 to 0.25%. Few other studies also reported critical S concentration of 0.55 and 0.27% for wheat and millet, respectively (Sedlar et al., 2019; Chowdhury 2000).

3.13. Economic analysis

Application of different levels of S showed a significant effect on the economic returns of *A. vera* and the highest gross income (Tk. 1858499) was obtained from the treatment of S_{45} and the second highest gross income (Tk. 1732499) was obtained from S_{60}. As expected, the lowest gross income was calculated from the control. A similar trend was observed in net returns also (Tables 5 and 6). The benefit cost ratio (BCR) of *A. vera* significantly varied among the different treatments of S (Table 3). The highest benefit cost ratio (3.63) was obtained from 45 kg S ha^{-1} application and the lowest BCR was obtained from control. The optimum growth, higher leaf biomass yield and S uptake might be the reason for maximum economic return at 45 kg S ha^{-1} than the other S application rates. Previously, Chowdhury et al. (2020) and Tarafder et al. (2020) reported the highest BCR with the application of inorganic S fertilizer.

Table 6. Comparative per hectare profitability of *Aloe vera* L. as influenced by different levels of sulphur.

S level (kg ha^{-1})	Input cost (Tk.)	Treatment cost (Tk.)	Overhead cost (Tk.)	Total cost (Tk.)	Yield ha^{-1}		Gross income (Tk.)	Net return (Tk.)	Net return (USD)	BCR
					Leaf (No.)	Sucker (No.)				
S_0	463260	0	46493	509753	75600	12600	944999	435246d	5133d	1.85d
S_{15}	463260	500	46538	510298	86100	23100	1207499	697201c	8222c	2.37c
S_{30}	463260	1000	46583	510843	90300	29400	1343999	833156c	9825c	2.63c
S_{45}	463260	1500	46628	511388	107100	52500	1858499	1347111a	15886a	3.63a
S_{60}	463260	2000	46673	511933	100800	48300	1732499	1220566ab	14393ab	3.38ab
S_{80}	463260	2666	46733	512660	96600	42000	1595999	1083339b	12775b	3.11b
SE	-	-	-	-	-	-	-	52555.84	-	0.10
CV (%)	-	-	-	-	-	-	-	12.96	-	7.09

Prices: Urea = Tk.16 kg^{-1}, TSP = Tk.22 kg^{-1}, MoP = Tk.20 kg^{-1}, Gypsum = Tk.6 kg^{-1}, Zinc sulphate = Tk.120 kg^{-1}, Boric acid = Tk.300 kg^{-1}, Leaf price = Tk.10 leaf^{-1}, Seedling price = Tk.15 seedling^{-1}. CV = Coefficient of variance, SE± = Standard error of means. The values with different alphabets in a column are significantly different at 5% level of probability.
The Tk was converted to USD according to the Bangladesh bank exchange rate accessed on 29th November 2020 (https://www.bb.org.bd/econdata/exchangerate.php).

4. Conclusions

Application of different levels of S showed significant influence on the growth, leaf yield and S use efficiency of *A. vera* L. The highest plant height, leaf number, leaf area, number of suckers, leaf and gel fresh and dry weight and profit based on benefit cost ratio, were obtained from the plant fertilized with 45 kg S ha^{-1}. On average, S application increased the leaf biomass yield of *A. vera* by 47% over control. The highest S concentration of gel and leaf, and S uptake by leaf were observed in plants fertilized with 80 kg S ha^{-1}. In contrast, the SUE was higher in lower level of S. However, on average application of S enhanced the SUE by 38% compared to control. Plant height, leaf area and fresh gel weight showed a significant and positive correlation with leaf biomass yield. The minimum amount of S required for 80% leaf biomass production was estimated to be 21.1 kg ha^{-1} with a critical leaf S concentration of 0.23%. The BCR of this important medicinal crop also significantly influenced by different levels of S and the highest BCR (3.63) was noticed with the application of 45 kg S ha^{-1}. The result suggests that farmers can apply 45 kg S ha^{-1} to obtain economically higher yield of *A. vera*. Of course, more research work is required to validate this results in various soil and climatic conditions.

Declarations

Author contribution statement

Md. Akhter Hossain Chowdhury: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Taslima Sultana: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Md. Arifur Rahman: Analyzed and interpreted the data; Wrote the paper.

Biplob Kumar Saha: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tanzin Chowdhury, Subrata Tarafder: Analyzed and interpreted the data.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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