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Studies on synergistic interaction of different sources and levels of sulphur on growth of black soybean

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Abstract
A field experiment was conducted at agriculture field of Himalayan university, Jollang during kharif season of 2023 and 2024 to study the synergistic interaction of different sources and levels of sulphur on productivity of black soybean [*Glycine max* (L.) Merr.]. The experiment was laid out in factorial randomized block design with nine treatments and three replications. Results revealed that use of treatment T_1 S_1L_3 (Gypsum 45 kg S ha^{-1}) recorded significantly higher plant height (15.43 cm, 35.43 cm, 65.56 cm) at 30 DAS, 60 DAS, 90 DAS, leave length (5.46 cm,7.49 cm, 9.47cm) at 30 DAS, 60 DAS, 90 DAS, number of leaves of plant (26, 36, 45) at 30 DAS, 60 DAS, 90 DAS, However, lowest plant height (13.96 cm, 33.96 cm, 64.03 cm) at 30 DAS, 60 DAS, 90 DAS, lowest leave length (4.13, 6.16, 8.13) at 30 DAS, 60 DAS, 90 DAS, lowest number of leaves (17, 23, 29) at 30 DAS, 60 DAS, 90 DAS was obtained in treatment T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}). Inoculation of Gypsum 45 kg S ha^{-1} improved the quality of soybean in presence of chemical fertilizers. The use of treatment T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) and treatment T_1 S_1L_3 (Gypsum 45 kg S ha^{-1}) gave at par results but statistically superior to T_4 S_2L_2 (Iron Pyrite 15 kg S ha^{-1}). Fresh weight at 30 DAS, 60 DAS, 90 DAS (6.51 g, 21.57 g, 32.11 g) and dry weight at 30 DAS, 60 DAS, 90 DAS (5.46 g, 20.20 g, 31.06 g) were recorded highest with T_1 S_1L_3 (Gypsum 45 kg S ha^{-1}).

Keywords: Sources of sulphur, treatments, black soybean, growth, productivity

Introduction
Black soybean (*Glycine max* L.) cultivation holds significant importance in the agricultural sector, valued for its nutritional benefits and versatile nature. Within the realm of crop productivity, the role of sulphur as an essential nutrient cannot be underestimated. Sulphur plays a pivotal role in various physiological processes of plants, including protein synthesis, enzyme activation, and chlorophyll production, all of which are integral to the growth and development of black soybean crops. The availability of sulphur in the soil is crucial for ensuring optimal plant health and productivity Sharma *et al*. (2019) [8].

The productivity of black soybean can be influenced by the type and quantity of sulphur sources present in the soil. Different sources of sulphur, such as elemental sulphur, sulphate salts (e.g., Epsom salt), and organic sources like compost or manure, offer varying forms of sulphur that impact plant growth differently. Elemental sulphur, for instance, acts as a slow-release form that necessitates microbial activity for conversion into plant-available sulphate, potentially requiring a longer time to manifest visible results in crop performance. In contrast, sulphate salts provide an immediate source of sulphate that is quickly available to plants, leading to a rapid growth response. Organic sources of sulphur contribute sulphur in complex forms, facilitating gradual release over time and potentially improving soil structure and microbial activity (Devi *et al*., 2012) [1]. Furthermore, the levels of sulphur in the soil play a critical role in black soybean productivity. Insufficient sulphur levels can result in reduced protein synthesis, chlorophyll production, and overall growth of the plant, ultimately leading to lower yields. Conversely, optimal sulphur levels support healthy plant growth, enhance nutrient uptake, and contribute to the potential for increased yield. However, excessive levels of sulphur can be detrimental, causing toxicity symptoms such as leaf yellowing, decreased photosynthesis, and stunted growth in black soybean plants Sarkar *et al*., (2002) [6].

Materials and Methods

The field experiment was conducted during summer (Kharif) season of 2023-24, at the Agriculture Field of Himalayan University, Jollang, Itanagar, Arunachal Pradeh. The Crop Research Farm is located in Jullang on the university campus, situated ar 27.14°N latitude and 93.62°E longitude, and an altitude of 320 meters above sea level. The site belongs to the Eastern Himalayan region, and the agro-climatic zone falls under the sub-tropical zone of Arunachal Pradesh. It was undertaken with the objectives to assess the performance of Black Soybean crop and to assess the performance in Kharif seasons.

Table 1: Physio-chemical properties of soil in the experimental field

Sl. No	Particulars	Value
1.	Sand (%)	54.2%
2.	Silt (%)	29.5%
3.	Clay (%)	16.3%
4.	Soil Texture	Sandy Loam
5.	Soil pH	4.25
6.	Organic carbon	1.59%
7.	Electrical conductivity	0.452 dS/m
8.	Available Nitrogen	613.5 Kg/ha
9.	Available Phosphorus	4.86 Kg/ha
10.	Available Potassium	218.4 Kg/ha

The experiment constituted of 9 treatment combinations was laid out in Factorial Randomized block design. The details of treatments are given below:

A. Sources

S1 = Gypsum / Calcium Sulphate
S2 = Iron Pyrite / Ferrous Sulfide
S3 = Epsomite+ Sphalerite / Magnesium Sulfate Heptahydrate + Zinc Sulfide

B. Levels

L_1 = 15 kg Sulphur ha^{-1}
L_2 = 30 kg Sulphur ha^{-1}
L3 = 45 kg Sulphur ha^{-1}

Treatment Combination: (3×3=9)

Table 2: Treatment Combinations

Treatment	Treatment Combination
T_1 (S_1L_1)	Gypsum at 15 kg S ha^{-1}
T_2 (S_1L_2)	Gypsum at 30 kg S ha−1
T_3 (S_1L_3)	Gypsum at 45 kg S ha^{-1}
T_4 (S_2L_1)	Iron Pyrite at 15 kg S ha^{-1}
T_5 (S_2L_2)	Iron Pyrite at 30 kg S ha^{-1}
T_6 (S_2L_3)	Iron Pyrite at 45 kg S ha^{-1}
T_7 (S_3L_1)	Epsomite + Sphalerite at 15 kg S ha^{-1}
T_8 (S_3L_2)	Epsomite + Sphalerite at 30 kg S ha^{-1}
T_9 (S_3L_3)	Epsomite + Sphalerite at 45 kg S ha^{-1}

The various methods for calculation of growth parameters are given below

Plant height (cm)

Plant height was taken in cm from the growth level to the tip of the plant from randomly selected 5 (five) plants in each individual plot and these plants were tagged for subsequent observation. A total of 3 (three) observation 30 DAS, 60 DAS and 90 DAS were recorded from the same plants in each plot and the average height of plant in each treatment was worked out for each observation.

Number of leaves per plant

The total number of leaves per plant was recorded 30 DAS, 60 DAS and 90 DAS and average number of each leaf per plant was calculated.

Fresh Weight (g)

The fresh weight of plants refers to the weight of the plant or plant parts immediately after harvest, including the water content present in the product.

Dry Weight (g)

The dry weight of a plant is the weight of the plant after all its water content has been removed. This is typically done by drying the plant material at temperatures higher than ambient temperature until all moisture is evaporated.

Crop growth rate (CGR)

The method was suggested by Watson (1956) [10]. The CGR explains the dry matter accumulated per unit land area per unit time (g m^{-2} day^{-1})

$$CGR = \frac{(W_2 - W_1)}{\rho\ (t_2 - t_1)}$$

Where, W_1 and W_2 are whole plant dry weight at time $t_1 - t_2$ respectively, ρ is the groundarea on which W_1 and W_2 are recorded. CGR of a species are usually closely related to interception of solar radiation.

Relative growth rate (RGR)

The term was coined by Williams (1946) [11]. Relative Growth Rate (RGR) expresses the total plant dry weight increase in a time interval in relation to the initial weight or dry matter increment per unit biomass per unit time or grams of dry weight increase per gram of dry weight and expressed as unit dry weight / unit dry weight / unit time (g $g^{-1}$$day^{-1}$)

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are whole plant dry weight at t_1 and t_2 respectively and t_1 and t_2 are time interval in days.

Results and Discussions

1. Plant Height (cm) 30, 60, 90 DAS

At 30 DAS the maximum increase in plant height was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 15.43 cm and T_9 S_3L_3(Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.,* 14.50 cm was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg Sha^{-1}). Lowest plant height was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i,e.,*13.96 cm. At 60 DAS the maximum increase in plant height was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 35.43 cm cand T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.,* 34.53 cm was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest plant height was observed in treatment T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}) *i,e.,*33.96 cm. At 90 DAS the maximum increase in plant height was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 65.56 cm and T_9

S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 64.50 cm was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest plant height was observed in treatment T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}) *i.e.*, 64.03 cm. .

The higher plant height recorded in T_3 S_1L_3 (Gypsum 45 kg S ha-^{1}) plot may be attributed to the beneficial effects of gypsum on soil structure and water retention. Gypsum application can enhance soil conditions, promoting improved nutrient uptake and overall growth stimulation for the plants. This, in turn, may have led to the observed increase in plant height in the specified treatment group and recording lower plant height in T_4 S_2L_1 (Iron pyrite 15 kg S ha^{-1}) could be a result of the negative impact of iron pyrite on soil quality, such as acidity or toxicity, leading to hindered nutrient uptake and growth inhibition for the plants (Dixit *et al*., 2009) [3].

Table 2: Effect of different sources and levels of sulphur on plant height of black soybean

Treatments	Plant height (cm)		
	30 DAS	60 DAS	90 DAS
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	14.27	34.26	64.23
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	14.40	34.4	64.40
T_3 S_1L_3- Gypsum 45 kg S ha^{-1}	15.43	35.43	65.56
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	13.96	33.96	64.03
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	14.25	34.20	64.20
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	14.30	34.30	64.26
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	14.33	34.31	64.32
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	14.36	34.36	64.36
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	14.50	34.53	64.50
F test	NS	NS	S
SEm±	0.23	0.20	0.23
CD (P=0.05)	0.50	0.44	0.49

2. Leaves Length (cm) 30, 60, 90 DAS

At 30 DAS the maximum increase in leave length was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i.e.* 5.46 cm and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 4.78 cm was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest leave length was observed in treatment T_4 (S_2L_1- Iron Pyrite 15 kg S ha^{-1}) *i.e.*,4.13 cm. At 60 DAS the maximum increase in leave length was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i.e.* 7.49 cm and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 6.80 cm was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest leave length was observed in treatment T_4 S_2L_1-(Iron Pyrite 15 kg S ha^{-1}) *i.e.*,6.16 kg s. At 90 DAS the maximum increase in leave length was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i.e.* 9.47 kg s ha and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 8.77 kg s ha was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest leave length was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i.e.*,8.13 kg s ha.

The probable reason for the higher length of black soybean leaves in treatment T_3 (S_1L_3 Gypsum 45 kg S ha^{-1}) compared to the lowest length in treatment T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}) could be due to the varying effects of gypsum and iron pyrite on the soybean plants. Gypsum, being calcium sulfate, may have positively influenced leaf growth due to its impact on soil structure and nutrient availability. On the other hand, iron pyrite, being a source of sulfur and iron, may not have provided the necessary nutrients or conditions for optimal leaf growth, leading to shorter leaves. Factors such as soil pH, nutrient uptake, and plant response to these amendments could also play a role in the observed differences (Sangale *et al*., 2004) [7].

Table 2: Effect of different sources and levels sulphur on leaves length of black soybean

Treatments	Leaves length (cm)		
	30 DAS	60 DAS	90 DAS
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	4.36	6.38	8.36
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	4.77	6.79	8.73
T_3 S_1L_3- Gypsum 45 kg S ha^{-1}	5.46	7.49	9.47
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	4.13	6.16	8.13
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	4.26	6.28	8.26
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	4.41	6.43	8.41
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	4.42	6.47	8.45
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	4.60	6.62	8.59
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	4.78	6.80	8.77
F test	NS	NS	S
SEm±	0.20	0.20	0.19
CD (P=0.05)	0.430	0.43	0.40

3. Numbers of Leaves per plant

At 30 DAS the maximum increase in no. of leaves was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i.e.* 26 and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 24 was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg Sha^{-1}). Lowest no. of leaves was observed in treatment T_4 S_2L_1-(Iron Pyrite 15 kg S ha^{-1}) *i.e.*, 17. At 60 DAS the maximum increase in no.of leaves was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i.e.* 36 and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 33 was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest no.of leaves was observed in treatment T_4 S_2L_1-(Iron Pyrite 15 kg S ha^{-1}) *i.e.*,23. At 90 DAS the maximum increase in no.of leaves was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i.e.* 45 and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i.e.*, 42 was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest no.of leaves was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i.e.*,29.

The probable reason for the higher no.of leaves in T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) could be due to the positive effects of gypsum on plant growth, such as improved soil structure, increased nutrient availability, and enhanced root development. Gypsum may have promoted healthier and longer leaves in this treatment compared to others.

On the other hand, the lowest recording for leaf length in T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}) could be attributed to the negative impact of iron pyrite on plant growth. Iron pyrite may have adverse effects on soil quality, nutrient uptake, and overall plant health, leading to shorter and less healthy leaves in this treatment (Dhageet *et al*., 2014) [2].

Table 3: Effect of different sources and levels of sulphur on number of leaves of black soybean

Treatments	No of leaves per plant		
	30 DAS	60 DAS	90 DAS
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	19	28	37
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	23	32	41
T_3 S_1L_3- Gypsum 45kg Sha^{-1}	26	36	45
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	17	23	29
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	18	27	35
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	20	29	38
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	21	30	39
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	22	31	40
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	24	33	42
F test	NS	S	S
SEm±	1.14	1.02	0.94
CD (P=0.05)	2.42	2.17	1.99

4. Fresh Weight (g)

At 30 DAS the maximum increase in fresh weight was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 6.51 g and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 6.27 g was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest fresh weight was observed in treatment T_4 S_2L_1 (iron pyrite 15 kg s ha $^{-1}$) *i,e.*, 5.31 g.

At 60 DAS the maximum increase in fresh weight was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 21.57 g and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 17.99 g was found to be statistically at par with S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest fresh weight was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i,e.*,12.13 g.

At 90 DAS the maximum increase in fresh weight was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 32.11 g and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 227.43 g was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest fresh weight was observed in treatment T_4 S_2L_1-(Iron Pyrite 15 kg S ha^{-1}) *i,e.*,15.27 g. .

The higher fresh weight in T_3 (S_1L_3 Gypsum 45 kg S ha^{-1})could be due to the positive impact of gypsum on plant growth, resulting in increased water and nutrient absorption, improved photosynthesis, and enhanced overall plant vigor. Gypsum may have facilitated better growth conditions, leading to higher fresh weight measurements in this treatment.

Conversely, the lowest fresh weight recording in T_4 (S_2L_1 Iron Pyrite 15 kg S ha^{-1}) may be attributed to the detrimental effects of iron pyrite on plant development. Iron pyrite can lead to soil acidification, reduced nutrient availability, and toxicity to plants, resulting in stunted growth and lower fresh weight measurements in this treatment (Zou *et al*., 2018) [12].

Table 3: Effect of different sources and levels of sulphur on fresh weight of black soybean

Treatments	Fresh weight		
	30 DAS	60 DAS	90 DAS
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	5.56	13.74	17.23
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	6.02	17.43	25.80
T_3 S_1L_3- Gypsum 45 kg S ha^{-1}	6.51	21.57	32.11
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	5.31	12.13	15.27
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	5.39	13.13	16.86
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	5.59	14.39	20.91
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	5.66	14.98	23.45
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	5.81	16.87	25.67
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	6.27	17.99	27.43
F test	NS	S	S
SEm±	0.15	0.66	0.94
CD (P=0.05)	0.32	1.40	1.99

5. Dry Weight (g)

At 30 DAS the maximum increase in dry weight was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 5.46 g and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 4.78 was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest dry weight was observed in treatment T_4 (S_2L_1- iron pyrite 15 kg S ha $^{-1}$) *i,e.*, 4.13 g.

At 60 DAS the maximum increase in dry weight was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 20.20 g and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 16.89 g was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest dry weight was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i,e.*,10.06 g.

At 90 DAS the maximum increase in dry weight was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 31.06 g and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 25.47 g was found to be statistically at par with S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest dry weight was observed in treatment T_4 (S_2L_1- Iron Pyrite 15 kg S ha^{-1}) *i,e.*,13.35 g.

The higher dry weight in T_3 S_1L_3 (Gypsum 45 kg S ha-^{1}) could be a result of the beneficial effects of gypsum on plant growth, such as improved soil structure, enhanced nutrient availability, and better water retention. Gypsum may have created optimal growing conditions, leading to increased biomass accumulation and higher dry weight measurements in this treatment.

Conversely, the lowest dry weight recording in T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}) may be due to the adverse impact of iron pyrite on plant productivity. Iron pyrite can induce soil toxicity, hinder nutrient uptake, and impede plant growth, resulting in reduced biomass accumulation and lower dry weight measurements in this treatment (Varun *et al*., 2011) [9].

Table 4: Effect of different sources ans levels of sulphur on dry weight of black soybean

Treatments	Dry weight		
	30 DAS	60 DAS	90 DAS
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	4.36	11.77	16.03
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	4.77	16.55	24.78
T_3 S_1L_3- Gypsum 45 kg S ha^{-1}	5.46	20.20	31.06
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	4.13	10.06	13.35
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	4.26	11.09	14.97
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	4.41	13.78	19.40
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	4.42	14.64	21.39
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	4.60	15.58	23.06
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	4.78	16.89	25.47
F test	NS	S	S
SEm±	0.20	0.73	1.13
CD (P=0.05)	0.43	1.55	2.39

6. Crop Growth Rate (g m^{-2} day^{-1})

The observations on crop growth rate (g m^{-2} day^{-1}) of black soybean recorded at different intervals (30-60, and 60-90) was statistically analysed and is being presented in table no.6 and graphically depicted in figure no.1.

A sigmoidal but marginal decrease in CGR was observed during the successive growth intervals. At 30-60 DAS the maximum increase in CGR was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e* 0.49 g m^{-2} day^{-1} and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.*, 0.40 g m^{-2} day^{-1} was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest CGR was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1})*i,e.*,0.20 g m^{-2} day^{-1}.

At 60-90 DAS the maximum increase in CGR was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 0.36 g m^{-2} day^{-1} and T_9 S_3L_3 (Epsomite+ Sphalerite 45kgSha^{-1}) *i,e.*, 0.29 g m^{-2} day^{-1} was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest CGR was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i,e.*,0.11 g m^{-2} day^{-1} .

The probale reason for higher crop growth rate in T_3 S_1L_3 Gypsum 45 kg S ha^{-1}) could be attributed to the positive effects of gypsum on plant growth and development. Gypsum may have enhanced nutrient availability, improved soil structure, and promoted overall plant health, leading to a faster rate of crop growth in this treatment.

Conversely, the lower recording for crop growth rate in T_4 (S_2L_1 Iron Pyrite 15 kg S ha^{-1}) may be a result of the negative impacts of iron pyrite on plant growth. Iron pyrite can adversely affect soil quality, inhibit nutrient uptake, and hinder plant growth, resulting in a slower rate of crop growth in this treatment compared to others (Hitsuda *et al*., 2015) [5].

Table 5: Effect of different sources and levels of sulphur on Crop Growth Rate (g m $^{-2}$ day^{-1})

Treatments	CGR (g m $^{-2}$day^{-1})	
	30-60DAS	**60-90DAS**
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	0.25	0.14
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	0.39	0.27
T_3 S_1L_3- Gypsum 45 kg S ha^{-1}	0.49	0.36
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	0.20	0.11
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	0.23	0.13
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	0.31	0.19
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	0.34	0.23
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	0.37	0.25
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	0.40	0.29
F test	S	S
SEm±	0.02	0.01
CD (P=0.05)	0.04	0.03

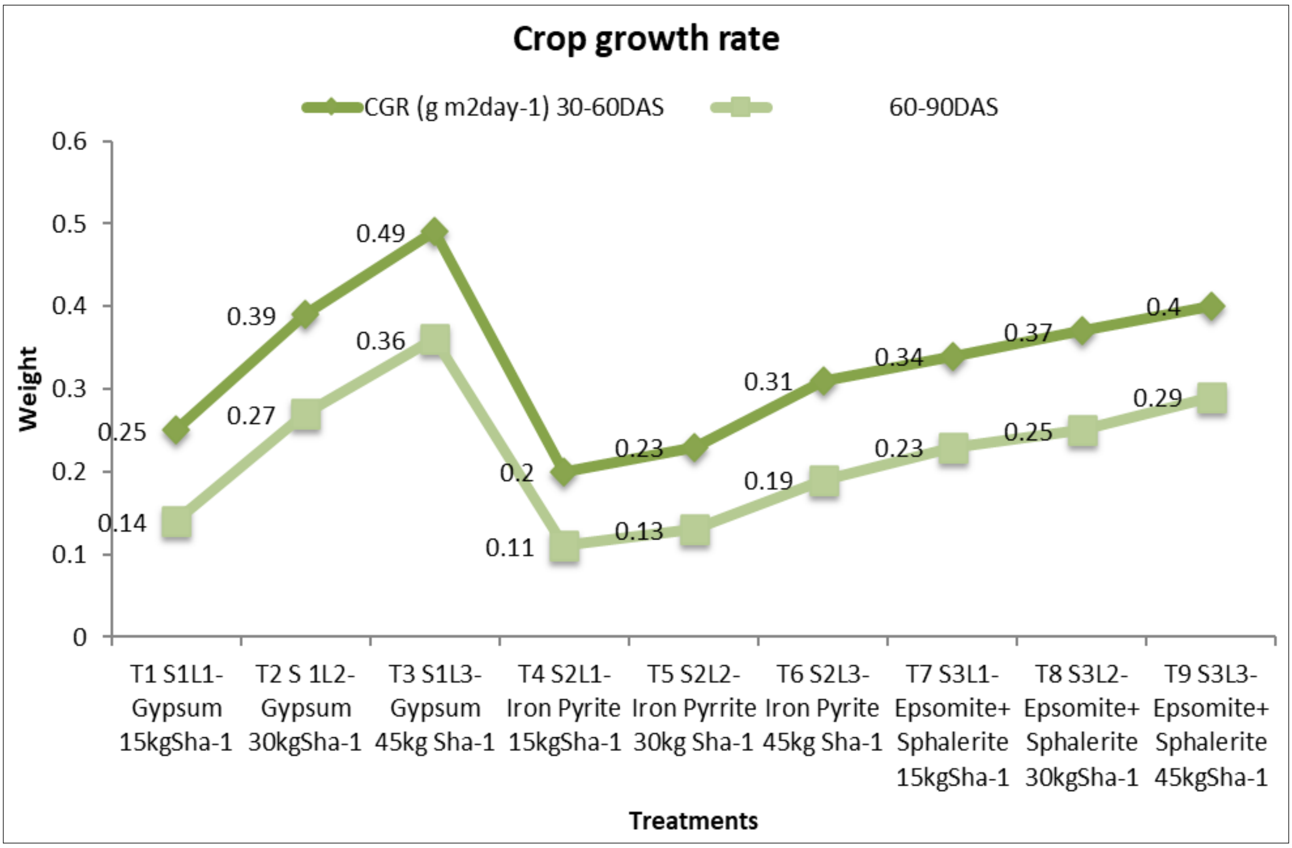

Fig 1: Effect of different sources and levels of sulphur on Crop Growth Rate (g m^{-2} day^{-1})

7. Relative Growth Rate (g m^{-2} day^{-1})

The observations on realtive growth rate (g m^{-2} day^{-1}) of black soybean recorded at different intervals (30-60, and 60-90) was statistically analysed and is being presented in table no.7 and graphically depicted in figure no.2

A sigmoidal but marginal decrease in RGR was observed during the successive growth intervals.

At 30-60 DAS the maximum increase in RGR was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) *i,e.* 0.043 g m^{-2} day^{-1} and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.,* 0.042 g m^{-2} day^{-1} was found to be statistically at par with T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}). Lowest RGR was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i,e.,*0.29 g m^{-2} day^{-1} .

At 60-90 DAS the maximum increase in RGR was observed and recorded in treatment T_3 S_1L_3 (Gypsum 45 kg Sha^{-1}) *i,e.* 0.0143 g m^{-2} day^{-1} and T_9 S_3L_3 (Epsomite+ Sphalerite 45 kg S ha^{-1}) *i,e.,* 0.0136 g m^{-2} day^{-1} was found to be statistically at par with T_3 S1L3 (Gypsum 45 kg S ha^{-1}). Lowest RGR was observed in treatment T_4 S_2L_1- (Iron Pyrite 15 kg S ha^{-1}) *i,e.,*0.0094 g m $^{-2}$ day^{-1}.

The probale reason for higher relative growth rate in T_3 S_1L_3 (Gypsum 45 kg S ha^{-1}) may be due to the positive impact of gypsum on plant growth. Gypsum could have improved nutrient availability, enhanced soil moisture retention, and stimulated overall plant development, leading to a faster relative growth rate in this treatment.

Conversely, the lower recording for relative growth rate in T_4 S_2L_1 (Iron Pyrite 15 kg S ha^{-1}) could be attributed to the adverse effects of iron pyrite on plant growth. Iron pyrite may have inhibited nutrient uptake, caused soil toxicity, and restricted plant development, resulting in a slower relative growth rate in this treatment compared to others (Hitsuda *et al*., 2015) [5].

Table 6: Effect of different sources and levels of sulphur on Relative Growth Rate (g m $^{-2}$day^{-1})

Treatments	RGR (g m^{2}day^{-1})	
	30-60DAS	60-90DAS
T_1 S_1L_1- Gypsum 15 kg S ha^{-1}	0.033	0.0102
T_2 S $_1L_2$- Gypsum 30 kg S ha^{-1}	0.041	0.0134
T_3 S_1L_3- Gypsum 45 kg S ha^{-1}	0.043	0.0143
T_4 S_2L_1- Iron Pyrite 15 kg S ha^{-1}	0.029	0.0094
T_5 S_2L_2- Iron Pyrite 30 kg S ha^{-1}	0.031	0.0099
T_6 S_2L_3- Iron Pyrite 45 kg S ha^{-1}	0.037	0.0113
T_7 S_3L_1- Epsomite+ Sphalerite 15 kg S ha^{-1}	0.039	0.0126
T_8 S_3L_2- Epsomite+ Sphalerite 30 kg S ha^{-1}	0.040	0.0130
T_9 S_3L_3- Epsomite+ Sphalerite 45 kg S ha^{-1}	0.042	0.0136
F test	S	S
SEm±	0.00027	0.00014
CD (P=0.05)	0.00059	0.00030

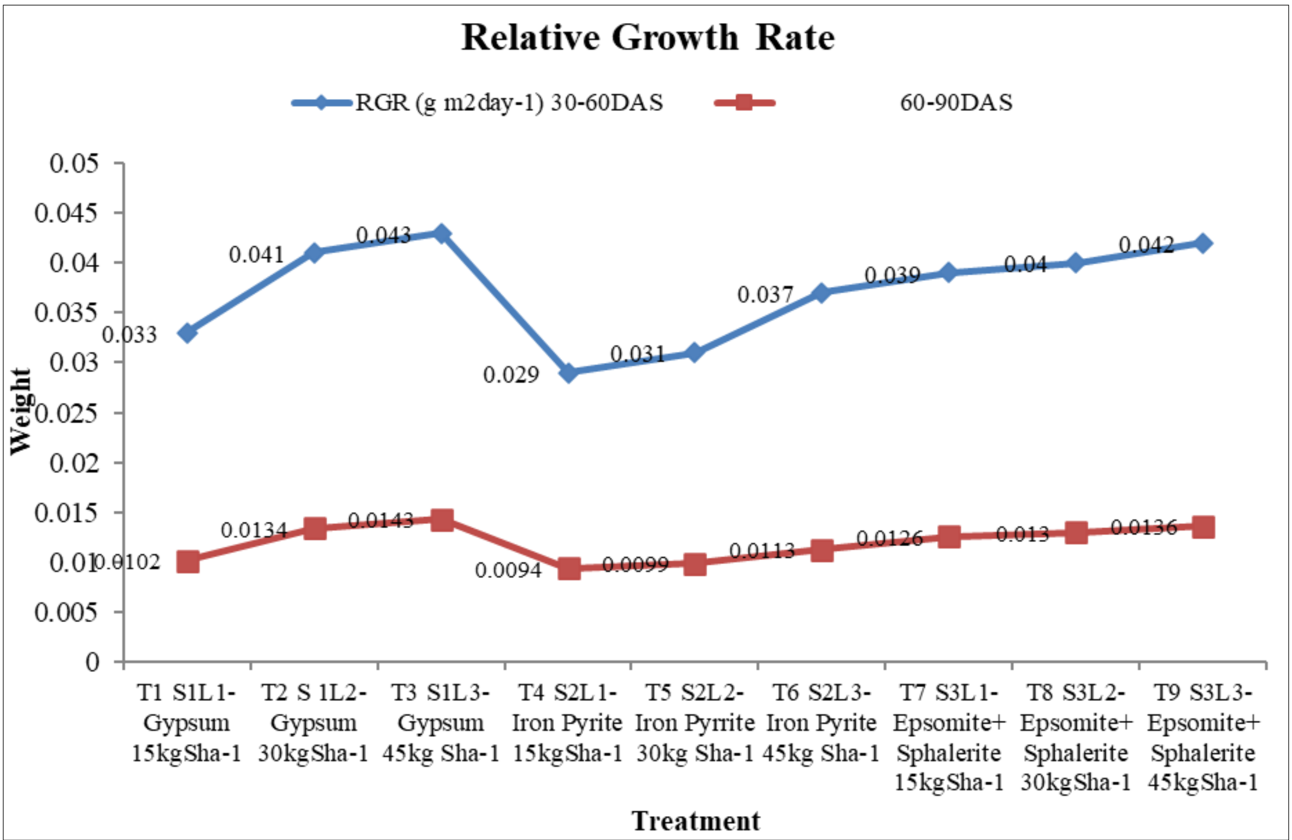

Fig 2: Effect of different sources and levels of sulphur on Relative Growth Rate (g m^{2} day^{-1})

Conclusion

Understanding the effects of different sulphur sources and levels on the productivity of black soybean is essential for agricultural practitioners seeking to maximize crop yield and quality. By discerning the nuanced interactions between sulphur availability and plant growth, farmers can make informed decisions regarding sulphur management strategies to optimize black soybean productivity. T_3 S_1L_3 (Gypsum 45 kg S ha-^{1}) showed the most notable improvements in plant height (cm),, number of leaves plant, fresh weight and dry weight (g). T_3 S_1L_3 (Gypsum 45 kg S ha-^{1}) was also observed best in CGR (g m^{-2} day^{-1}) and RGR (g g $^{-1}$ day $^{-1}$).Through further research and implementation of sustainable sulphur management practices, the cultivation of black soybean crops can be enhanced, contributing to the overall sustainability and success of agricultural systems.

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