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The Effect of Agricultural Sulfur Levels on the Growth and Yield of Six Genotypes of Sorghum (*Sorghum bicolor* L.) in Salah al-Din Governorate.

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Abstract

The experiment was conducted in Al-Mutasim Subdistrict, Samarra District, Salah al-Din Governorate, during the autumn agricultural season of 2024. Six genotypes of Sorghum (Kafir, Enqaz, Giza, Babel, Tabat, and Hamam) were used, along with four sulfur levels (0, 400, 800, and 1600 kg ha^{-1}). The experiment was implemented according to a randomized complete block design (RCBD) in a split-plot arrangement with three replicates. The results showed that increasing the sulfur level led to a significant improvement in plant growth, with the average plant height increasing from 154.44 cm at the base level to 173.85 cm at the highest level. Leaf area also increased from 4095.50 cm^2 to 4734.65 cm^2/plant. Genotypes also had a significant impact, with the Giza genotype recording the highest average plant height (243.28 cm) and leaf area (6001.46 cm^2 $plant^{-1}$), while genotypes such as Tabat and Hamam had the least response. As for yield characteristics, the number of grains per head increased from 1756.37 grains $head^{-1}$ at zero sulfur levels to 2229.32 grains $head^{-1}$ at 1600 kg ha^{-1}, and the thousand-grain weight increased from 30.39 g to 40.26 g. Meanwhile, the Babel genotype recorded the highest thousand-grain weight (38.71 g), while the Hamam genotype recorded the lowest (31.87 g). Total Sorghum yield also increased from 3.05 tons ha^{-1} to 3.93 tons ha^{-1}, and the biological yield increased from 5.25 tons ha^{-1} to 7.74 tons ha^{-1} at the highest sulfur level. The effect of sulfur was also evident on grain protein content, increasing from 5.25% to 7.74% at 1,600 kg ha^{1}. Pairwise combinations of sulfur levels and genotypes showed that some cultivars, such as Kaffir and Giza, respond better to higher sulfur levels, and increasing yield.

Keywords: Agricultural sulfur, Sorghum , genetic combinations, Salah El-Din.

Introduction:

Sorghum (*Sorghum bicolor* L. Moench) is a strategic grain and forage crop worldwide due to its high nutritional value and multiple agricultural and industrial uses. It plays an important role in enhancing local food security through the production of animal feed and silage, especially in food-scarce areas [1]. It has also recently been exploited for biofuel production, where its biomass—stems, leaves, and grains—is converted into bioethanol, biodiesel, biooil, and biochar, enhancing its economic value as a multi-use crop [2]. Globally, the crop is primarily used as animal feed due to its high productivity under water-limited conditions. It is also used in the preparation of concentrated poultry feed due to its high protein content. It can also be used as green fodder or silage in Iraq, where proper irrigation management, the selection of climate-resistant varieties, and high-yielding genetic combinations contribute to increased productivity and improved utilization of this vital crop. This makes it a key pillar for enhancing sustainable agricultural productivity and diversifying food and bioenergy sources in the country [3].

The genetic makeup of Sorghum (*Sorghum bicolor*) plays a pivotal role in determining its response to different environmental conditions and production efficiency. These combinations influence growth traits such as plant height, leaf number, and plant vigor. It also affects yield and grain protein concentration, making it essential for selecting varieties best suited to local conditions and increasing their tolerance to environmental stresses such as drought, salinity, and temperature changes, as well as improving nutritional quality and productivity. A recent study demonstrated that Sorghum genetics significantly influence drought tolerance during the germination and seedling stages, with a clear impact on growth rate, yield, and grain protein concentration [4]. Genetic diversity among varieties enhances productivity, carbon storage, and protein concentration, offering significant potential for improving these traits through breeding programs [5]. Therefore, studying genotypes is essential for developing environmental stress-resistant varieties with high yields and improved protein quality, supporting sustainable agricultural production.

Sulfur is an essential nutrient for plants, contributing to the synthesis of amino acids such as methionine and cysteine, and the formation of proteins, enzymes, and chlorophyll, thus supporting plant and root growth and increasing productivity [6]. Sulfur also plays an important role in metabolic processes and improving the efficiency of nitrogen and phosphorus use, enhancing crop quality. Sulfur also plays an important role in metabolic processes and improving the efficiency of nitrogen and phosphorus use, which enhances crop quality [7]. Sulfur in plants undergoes a cycle that includes its absorption from the soil in the form of sulfate (SO_4^{2-}) and its distribution in the leaves, stems, and grains [8]. In the soil, sulfur contributes to improving soil fertility, increasing microbial activity, and enhancing the plants ability to absorb other elements by lowering pH [9]. Sulfur deficiency also leads to poor growth, yellowing of leaves, and low protein content in grains [10]. Therefore, adding sulfur fertilizers is an important foundation for achieving high productivity and improving crop quality. Given the limited studies on the effect of sulfur on plant growth and productivity, this study aimed to investigate the effects of different sulfur levels and genetic makeup of sorghum on growth, productivity, and quality traits in Salah al-Din Governorate.

Materials and Methods

Study Factors

1. Six sorghum genotypes were obtained from the Department of Field Crops, College of Agriculture, University of Anbar: (Kafir, Inqaz, Giza, Babel, Tabat, and Hamam).

2. Sulfur Level: Sulfur was used at three levels of fertilization. Foamed sulfur (90% sulfur) was obtained and added at rates of (0, 400, 800, and 1600) kg ha-1.

Experiment Implementation

A field experiment was conducted during the autumn agricultural season of 2024 AD in Al-Mutasim sub-district/Samarra district, Salah al-Din Governorate. The land used for the experiment was identified, and five random samples were taken to a depth of (0-30 cm). These samples were then mixed and ground with a wooden hammer, passed through a 2 mm sieve, and air-dried. They were then placed in plastic containers for chemical and physical analysis. The field experiment was conducted according to a randomized complete block design (R.C.B.D.) with a split-plot arrangement. The experimental land was prepared after plowing, leveling, and dividing it into three replicates, each with (24) experimental units. Each experimental unit contained four rows, with a spacing of 70 cm between rows and 20 cm between holes. The experiment was fertilized with NPK (18:46:0) at a rate of 200 kg ha-1 before planting. Urea fertilizer (46% N) was added at a rate of 390 kg ha-1 in two batches, the first at planting and the second 40 days after planting [11]. Planting was completed on July 15, 2024. Seeds were sown at a rate of 2-3 seeds per hole to ensure germination. Plants were thinned to one plant per hole one month after planting. After the heads were removed and flowering was complete, the plant heads were covered with paper bags to prevent birds from attacking them. Weeding and control were carried out manually. Corn stem borer (Sesamia cricaled) was treated with 10% granular diazinon as the active ingredient, at a rate of 6 kg/ha. This was done by grafting the growth tip twice, the first as a preventative treatment at the 4-5 leaf stage, and the second 15 days after the first treatment [12]. Sulfur was also added to each plant upon grafting. Irrigation was done by drip irrigation and using well water.

Table (1) Physical and chemical properties of the experimental soil for the agricultural season (2024) AD

Trait	Unit	Value
pH	-	7.81
EC	$dS\cdot m^{-1}$	2.42
Organic matter	$g\cdot kg^{-1}$	0.84
Available nitrogen	$mg\cdot kg^{-1}$	19.5
Available phosphorus	$mg\cdot kg^{-1}$	6.02
Available potassium	$mg\cdot kg^{-1}$	120.14
Sand	$g\cdot kg^{-1}$	529
Silt	$g\cdot kg^{-1}$	241
Clay	$g\cdot kg^{-1}$	230
Texture	-	S.C.L (Sandy Clay Loam)
Gypsum	$g\cdot kg^{-1}$	56.23
Lime	$g\cdot kg^{-1}$	211.01

*Soil analysis was performed in the laboratory of the College of Agriculture, Department of Soil and Water Resources, Tikrit University.

Traits studied:

Plant height (cm)

The height of ten protected plants was measured from the midlines of each experimental unit, starting from the soil surface to the top of the spike at maturity, and the mean was taken.

•**Leaf area (cm^2 $plant^{-1}$)**

Calculated according to the equation: leaf length × maximum leaf width × 0.75 [13].

•**Number of grains per spike.**

The number of seeds per spike was counted after the spike was dried, separated, and counted.

•**Weight of 1,000 grains (g).**

1,000grains of overwintered spikes from each experimental unit were manually counted and weighed using a sensitive electronic balance.

•**Total grain yield (tons ha^{-1}).**

The seeds of the ten plants taken from the two intermediate lines were separated and weighed. The total weight was then divided by ten plants to obtain the average yield per plant per unit.

•**Biological yield (tons ha^{-1}) :** The weight of leaves and stems was calculated by adding them together and dividing them by the number of plants. Leaves were dried naturally, while stems were dried in an electric oven at 65-70°C until constant weight. The average dry matter yield per plant was calculated.

•**Protein content (%):** The nitrogen content of the seeds was calculated using a Kjeldahl macro, then the following equation was applied:

$$\%protein = \%\ nitrogen \times 6.25$$

Statistical Analysis

Data were collected and statistically analyzed using SAS software (SAS Institute,

2011) according to factorial experiments in a randomized complete block design with a single-panel system. Duncans multiple range test was used to compare means at the 0.05 probability level [14].

Results and Discussion:

•Plant Height (cm)

The results of Table (2) showed that sulfur levels, Sorghum genotypes, and their interactions had a significant effect on plant height. The results showed that increasing the level of added sulfur from zero to 1600 kg ha^{-1} resulted in a gradual increase in average plant height. The lowest average height was recorded in the control treatment (154.44 cm), while the highest average (173.85 cm) was recorded at the 1600 kg ha^{-1} level. This is attributed to the important physiological role of sulfur in the formation of sulfur amino acids (methionine and cysteine), proteins, and enzymes, in addition to its contribution to improving photosynthesis and increasing the efficiency of nitrogen and phosphorus uptake [15]. Sulfur availability also improves soil microbiological activity and enhances nutrient availability, which positively affects plant growth and stem elongation [9]. The results also revealed significant differences between Sorghum genotypes. The Giza genotype significantly outperformed the other cultivars in average plant height (243.28 cm), followed by the Kafir genotype (168.53 cm). Meanwhile, the Enqath, Babel, Tabat, and Hamam genotypes recorded the lowest heights, with averages ranging from 143.25 to 149.57 cm. These differences are attributed to genetic factors, as some cultivars possess distinct traits associated with increased plant height due to the inclusion of genes responsible for vegetative growth and stem elongation, enabling them to utilize environmental resources more efficiently [16]. The interaction between sulfur levels and genotypes was also significant. The Giza cultivar recorded the highest plant height at all sulfur levels, clearly outperforming the other cultivars, reaching a maximum height of 253.74 cm at the 1600 kg ha^{-1} level. Meanwhile, the Tabat and Hamam cultivars showed the lowest response to sulfur levels, not exceeding 152.14 cm at the same level. This suggests that some genotypes have a higher capacity to utilize fertilizer additives, reflecting differences in the physiological and genetic efficiency of cultivars in absorbing and utilizing nutrients to enhance growth.

Table 2. Effect of sulfur levels, Sorghum genotypes, and their interactions on plant height (cm).

Genotypes	Sulfur level (kg ha^{-1})				Mean of Genotypes
	0	400	800	1600	
Kafeer	155.21 d	170.12 c	173.11 bc	175.68 ab	168.53 bc
Inqadh	139.99 f	150.19 e	153.00 de	155.08 d	149.57 e
Giza	229.17 a	241.00 a	249.22 a	253.74 a	243.28 a
Babel	135.88 f	146.00 e	153.14 de	156.01 d	147.76 d

Tabat	133.37 f	142.17 f	147.00 e	150.47 e	143.25 e
Hammam	133.00 f	144.27 f	149.00 de	152.14 d	144.60 e
Mean of Sulfur levels	**154.44 d**	**165.63 c**	**170.75 bc**	**173.85 ab**	

Leaf area (cm² plant^{-1})

Table (3) shows a significant effect of sulfur levels, genotypes, and their interaction on plant leaf area. It clearly shows that increasing sulfur levels from 0 to 1600 kg ha¹ increased the average leaf area from 4095.50 to 4734.65 46 cm² plant^{-1}, reflecting a generally positive response across all genotypes. This is explained by the vital role of sulfur in photosynthesis, which increases the plants ability to absorb nutrients, which is reflected in an increase in the area exposed to sunlight. Moreover, when sulfur is available, the plants physiological ability to produce sulfur amino acids (methionine and cysteine) and synthesize proteins and enzymes associated with photosynthesis improves. It also plays a role in supporting the synthesis of chlorophyll and antioxidants, which contributes to the formation of larger, more light-efficient leaves [10] Previous studies have shown that appropriate sulfur addition leads to a significant increase in leaf mass compared to the control treatment [17]. recorded an increase of approximately 47.5%, consistent with the current results. Sulfur also plays an important role in enhancing the activity of microorganisms that convert sulfur from its unavailable form to the sulfate form (SO_4^{-2}), which is readily available for absorption. This enhances nitrogen and phosphorus availability and supports vegetable growth [9]. Furthermore, the table shows that the Giza genotype clearly outperformed the other genotypes, recording the highest leaf area both at the zero level (5300.55 cm² plant^{-1}) and at the higher level (6001.46 cm² plant^{-1}). Meanwhile, genotypes such as Tabat and Hamam showed lower averages, reflecting differences in genetic efficiency in sulfur utilization, nutrient distribution, and cell extension efficiency. Recent evidence suggests that genetic differences between cultivars contribute to determining a plants ability to utilize nutrients and foliar growth [18]. The interaction between sulfur and genotype was significant, with Giza cultivar showing a very high response at 1600 kg ha^{-1}, with a clear increase in leaf area compared to 0 kg ha^{-1}. The response was weaker for other cultivars, such as Tabat and Hamam, indicating that some genotypes possess a higher physiological and genetic capacity to utilize sulfur to enhance foliar growth.

Table 3. Effect of sulfur level, Sorghum genetic compositions, and their interaction on leaf area (cm^2 plant^{-1})(

Genotypes	Sulfur level (kg ha^{-1})				Mean of Genotypes
	0	**400**	**800**	**1600**	
Kafeer	3114.14 d	3321.14 c	3445.09 bc	3517.02 ab	3349.35 bc
Inqadh	4911.97 b	5170.00 a	5385.09 a	5669.24 a	5284.83 a
Giza	5300.55 a	5511.14 a	5787.21 a	6001.46 a	5650.09 a

Babel	5074.87 a	5301.74 a	5500.47 a	5749.91 a	5406.75 a
Tabat	3071.12 d	3188.94 cd	3301.49 bc	3458.37 ab	3254.98 bc
Hammam	3100.36 d	3211.19 cd	3369.47 bc	3409.89 ab	3272.73 bc
Mean of Sulfur levels	**4095.50 d**	**4237.03 c**	**4481.15 b**	**4734.65 a**	

•Number of grains per head (grains head⁻ ¹)

The results of Table (4) indicate that sulfur levels, genetic makeup, and their interactions significantly affected the number of grains per head of Sorghum plants. The sulfur treatment at a concentration of 1600 kg ha^{-1} recorded the highest average (2229.32 grains $head^{-1}$), compared to the zero treatment, which produced 1756.37 grains per head. These results are consistent with [19] and [20].

The results also showed clear genetic variation among cultivars. For example, the Inqadh cultivar achieved a high average yield (2498.39 grains $head^{-1}$), significantly outperforming cultivars such as Kefir, Tabat, and Hammam, which recorded lower averages (1665.26, 1656.44, and 1635.31 grains $head^{-1}$) respectively. This variation can be explained by the fact that some cultivars possess genes that positively influence pollination capacity, the number of pollinable flowers, or component distribution (carbohydrate production) in grain, consistent with [21]. The interaction between sulfur levels and genotypes revealed that some cultivars benefit more from sulfur supplementation. For example, the Rescue genotype at 1600 kg recorded the highest grain number (2773.37 grains $head^{-1}$), along with Giza at the same level (2578.14 grains per $head^{-1}$), while genotypes with low responses at zero sulfur levels, such as Hamam, recorded 1417.54 grains $head^{-1}$. This reflects that the response to sulfur is not uniform across genotypes. Rather, some genotypes are more efficient at converting sulfur into physiological components that support optimal grain formation, such as improved photosynthesis, efficient source-sink distribution, and improved nutrient balance during flowering synchronization.

Table 4. Effect of sulfur levels, genotypes, and their interactions on grain number per head (grain head - 1)

Genotypes	**Sulfur level (kg ha^{-1})**				**Mean of Genotypes**
	0	**400**	**800**	**1600**	
Kafeer	1314.21 e	1598.74 d	1800.37 c	1947.70 bc	1665.26 d
Inqadh	2199.14 b	2419.87 ab	2601.18 a	2773.37 a	2498.39 a
Giza	2119.65 b	2298.04 b	2478.90 a	2578.14 a	2368.68 b
Babel	2009.10 c	2180.29 b	2281.31 b	2387.40 ab	2214.53 c
Tabat	1478.57 e	1589.74 d	1700.32 c	1857.14 c	1656.44 d
Hammam	1417.54 e	1594.21 d	1697.35 c	1832.14 c	1635.31 d
Mean of Sulfur levels	**1756.37 d**	**1946.82 c**	**2093.24 b**	**2229.32 a**	

•Thousand-grain weight (g)

The results of Table (5) showed that different sulfur levels had a clear effect on the thousand-grain weight of Sorghum . The highest sulfur level (1600 kg ha-1) recorded the highest average weight of 40.26 g, while the lowest weight was recorded at zero sulfur levels, with an average of 30.39 g. This effect is attributed to the role of sulfur in stimulating the formation of proteins, enzymes, and vitamins necessary to increase seed size, in addition to its positive effect on photosynthesis and improving nutrient absorption. These results are consistent with [22].

The study showed significant differences between the Sorghum genotypes in thousand-grain weight. The Babel variety recorded the highest average weight of 38.71 g, while the Hamam variety recorded the lowest average weight of 31.87 g. This variation is attributed to genetic differences between the varieties in their ability to store carbohydrates and proteins within the seed, which directly affects the final weight. This is consistent with [23].

The table results also showed that the interaction between sulfur level and genotype had a significant effect. The interaction between the Giza variety and the highest sulfur level (1600 kg ha-1) resulted in the highest 1000-grain weight, 43.58 g, while the Babylon variety achieved the lowest weight, at 26.58 g. This interaction suggests that some varieties require appropriate levels of sulfur to maximize their genetic potential, including promoting the accumulation of proteins and sugars within the grain, which is reflected in their final weight.

Table 5. Effect of sulfur level, genotypes, and their interaction on the 1000-grain weight (g) of Sorghum .

Genotypes	**Sulfur level (kg ha^{-1})**				**Mean of Genotypes**
	0	**400**	**800**	**1600**	
Kafeer	33.95 cd	37.91 bc	39.84 ab	42.55 a	38.56 ab
Inqadh	26.58 f	29.79 ef	32.95 de	36.48 b-d	31.45 d
Giza	33.00 cd	36.89 bc	40.14 ab	43.58 a	38.40 ab
Babel	34.15 c	37.88 bc	40.01 ab	42.78 a	38.71 a
Tabat	28.54 ef	31.00 de	34.56 cd	38.11 bc	33.05 c
Hammam	26.09 f	30.04 e	33.27 d	38.06 bc	31.87 cd
Mean of Sulfur levels	**30.39 d**	**33.92 c**	**36.80 b**	**40.26 a**	

- **Total grain yield (tons ha^{-1})**

The results of Table (6) showed that sulfur levels had a significant effect on the average grain yield of Sorghum . A sulfur level of 1600 kg ha-1 recorded the highest average yield, reaching 3.93 tons ha-1, while the lowest average yield was at 0 kg ha-1, reaching 3.05 tons ha-1. This is attributed to the fact that increased sulfur levels provided essential nutrients to the plant, contributing to enhanced grain growth and increased 1000-grain weight, which was subsequently reflected in total yield. These results are consistent with what [24] indicated regarding the effect of sulfur nutrition on grain yield in Sorghum . The results of Table (6) also showed clear significant differences between Sorghum genetic makeups in average grain yield. The kaffir genotype was improved, recording the highest yield of 4.17 tons ha^{-1}, followed by the babil genotype with a yield of 3.74 tons ha^{-1}, while the hamam genotype recorded the lowest yield, at 3.18 tons ha^{-1}. These differences are attributed to the different abilities of the genotypes to absorb nutrients and convert them into biomaterials usable in grain formation. These results are consistent with [23], which states that the genotype of Sorghum varied in its yield. The results of Table (6) also showed that the interaction between sulfur levels and genotypes had a significant effect on average grain yield. The interaction between the kaffir genotype and a sulfur level of 1600 kg/ha recorded the highest yield, at 4.77 tons/ha, while the interaction between the hamam genotype and a sulfur level of 0 kg/ha recorded the lowest yield, at 2.61 tons/ha. This interaction indicates that some genes respond better to the application of appropriate sulfur levels, enhancing their efficient utilization of nutritional factors.

Table 6. Effect of sulfur levels, genetics, and their interactions on average grain yield (tons ha-1)

Genotypes	**Sulfur level (kg ha^{-1})**				**Mean of Genotypes**
	0	**400**	**800**	**1600**	
Kafeer	3.31 d-f	4.09 a-c	4.51 ab	4.77 a	4.17 a
Inqadh	2.57 h	2.82 gh	3.03 fg	3.23 e-g	2.91 e
Giza	3.27 d-f	3.64 c-e	3.84 b-d	4.02 a-c	3.69 b
Babel	3.51 c-e	3.68 c-e	3.77 b-d	4.00 a-c	3.74 b
Tabat	3.02 fg	3.44 d-f	3.62 c-e	3.85 b-d	3.48 c
Hammam	2.61 h	3.00 fg	3.42 d-f	3.69 c-e	3.18 d
Mean of Sulfur levels	3.05 d	3.45 c	3.70 b	3.93 a	

•Biological Yield (tons ha^{-1})

The results of Table (7) indicate that the sulfur level has a clear and significant effect on the average biological yield of Sorghum . A sulfur level of 1600 kg/ha^{-1} recorded the highest yield, reaching 7.74 tons/ha^{-1}, while the lowest yield was recorded at 0 kg/ha⁻ ¹, reaching 5.25 tons/ha⁻ ¹. This is attributed to the fact that the addition of high levels of sulfur enhanced the growth of plant parts and increased biomass accumulation, which was reflected in the plants biological yield. These results are consistent with what was indicated by [25].

The results also showed significant differences between Sorghum genotypes in the average biological yield. The Kafir gene was superior, recording the highest yield of 7.54 tons ha^{-1}, followed by the Babel gene with a total yield of 7.19 tons ha^{-1}, while the Salvation gene recorded the lowest yield of 5.35 tons ha^{-1}. This disparity is attributed to the different abilities of genes to develop dense vegetative growth and accumulate more organic matter [26]. A study of five Sorghum genera grown in Basra Governorate revealed that genetic variations play a key role in determining a plants ability to produce biomass. The results of the same table also showed that the interaction between sulfur levels and genes had a significant impact on biological yield. The interaction between the Kafir genotype and a sulfur level of 1600 kg ha^{-1} recorded the highest rate (9.13 tons ha^{-1}), while the interaction between the Ingath genotype and a sulfur level of 0 kg ha^{-1} recorded the lowest rate (4.32 tons ha^{-1}). This interaction indicates that combining an appropriate genotype with an optimal sulfur level contributes to improving plant biological yield.

Table 7. Effect of sulfur level, Sorghum genotype, and their interaction on average biological yield (tons ha-1)

Genotypes	**Sulfur level (kg ha⁻ ¹)**				**Mean of Genotypes**
	0	**400**	**800**	**1600**	
Kafeer	5.89 cd	6.99 bc	8.13 a	9.13 a	7.54 a
Inqadh	4.32 e	5.21 de	5.74 d	6.13 cd	5.35 e
Giza	5.74 d	6.42 c	7.65 b	8.24 a	7.01 b
Babel	5.99 cd	7.01 b	7.64 b	8.12 a	7.19 b
Tabat	5.23 d	6.41 c	6.89 bc	7.47 b	6.50 c
Hammam	4.35 e	5.64 de	6.29 c	7.34 b	5.91 d
Mean of Sulfur levels	5.25 d	6.28 c	7.06 b	7.74 a	

Conclusions

Under the conditions of this experiment, we conclude:

1. Increasing the level of sulfur added to Sorghum enhances vegetative growth (plant height and leaf area), improves production traits (number of grains, 1000-grain weight, total and biological yield), and increases protein concentration in the grain.

2. Sorghum genotypes play a crucial role in determining their response to sulfur levels, with cultivars such as Kaffir and Giza showing greater efficiency in utilizing sulfur compared to cultivars such as Hamam and Tabat.

3. Combining sulfur levels with genotype is important for achieving maximum yield and protein quality, as some cultivars respond better to higher sulfur levels.

Recommendations

Under the conditions of this experiment, we recommend:

1. It is recommended to use high levels of sulfur (1600 kg ha-1) to improve growth, productivity, and increase protein content in Sorghum grains, especially for highly responsive cultivars.

2. Selecting appropriate genotypes, such as Kaffir and Giza, when planning cultivation with sulfur fertilizer management, maximizes nutrient utilization and achieves the highest yield.

3. Considering the combination of genotypes and sulfur levels in agricultural breeding programs to improve grain yield and protein quality.

4. Utilizing these results to develop improved fertilizer programs based on genotype characteristics, with a focus on improving the sustainable productivity and nutritional quality of Sorghum .

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