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Response of different levels of phosphorus and sulphur on yield of black gram (*Vigna mungo* L.) in Chhattisgarh plain

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Abstract
The study titled "Response of different levels of phosphorus and sulphur on yield of black gram (*Vigna mungo* L.) in Chhattisgarh plain" was conducted during the *kharif* season in 2022 at the Instructional Farm, BTCCARS, Bilaspur (C.G.). The treatments consisted of four phosphorus levels (0, 20, 40, and 60 kg ha^{-1}) and three sulphur levels (0, 10, and 20 kg ha^{-1}). The results showed that increasing the phosphorus application rate significantly increased the grain yield, with the highest yield of 13.15 q ha^{-1} obtained with 60 kg P ha^{-1} compared to only 7.65 q ha^{-1} with no phosphorus application. The 20 kg S ha^{-1} sulphur treatment produced the maximum grain yield of 11.49 q ha^{-1} across sulphur levels. Other yield attributes like pods $plant^{-1}$, seeds pod^{-1}, and test weight also improved with higher phosphorus doses. The findings highlight the importance of optimal phosphorus and sulphur nutrition in realizing the yield potential of black gram in this region. The study demonstrates the significant positive response of black gram to applied phosphorus and sulphur in terms of enhanced grain and biomass yields.

Keywords: Black gram, grain yield, harvest index, productivity, phosphorus and sulphur

1. Introduction

Black gram (*Vigna mungo* L.), an important pulse crop in India, belongs to the Leguminosae family. Native to the Indian subcontinent, it has been cultivated since ancient times as a food crop. Black gram seeds are consumed in the form of whole or split pulse, with or without the husk. This nutritious, nitrogen-fixing legume fits well in multiple or intercropping systems. The crop residue serves as quality fodder for livestock or green manure to improve soil health. Black gram is referred to as 'urad dal' in India and the subcontinent where it is widely grown. Besides India, countries like Bangladesh, Afghanistan, Myanmar and Pakistan also cultivate black gram as mentioned in sources (Ghanshyam and Jat in 2010) [6]. In summary, black gram is a versatile food legume crop which plays an important nutritional and agricultural role across South Asia.

Pulses are a vital component of the vegetarian diet in India, occupying 33% of the global area and contributing to 22% of the production. Currently, the total area under pulse cultivation is 28.78 million hectares, with a production of 25.46 million tonnes (Anonymous, 2021). Pulses hold significant importance in Indian agriculture, second only to cereals. The production of urdbean (black gram) during the kharif and rabi seasons in 2019-20 was 1.33 and 0.75 million tonnes, respectively (Anonymous, 2020) [3].

In general, Chhattisgarh's economy is mainly based on agriculture. The state comprising 28 districts, having 0.139 million hectares of area under *kharif* pulses with 0.058 million tonnes of production (Anonymous, 2019) [2]. The state is comprised with three agro-climatic zones, *viz.*, Chhattisgarh plain, Baster plateau and Northern Hill Region of Surguja.

Proper fertilization is crucial for improving the productivity of black gram. Among the essential nutrients, phosphorus and sulphur require particular attention, as mentioned by Nandal *et al.* in 1987 [10]. Being a leguminous crop, black gram necessitates an adequate supply of phosphorus and sulphur, along with other nutrients, as they directly influence its growth and development.

2. Materials and Methods

The study on black gram (*Vigna mungo* L.) during the 2022 *kharif* season, specifically using the Indira Urd Pratham variety, employed a Factorial Randomized Block Design with three replications. There were a total of 12 combinations of phosphorus and sulphur treatments. The gross plot size measured 6.30 m × 3.50 m, amounting to 22.05 m², while the net plot size was 5.70 m × 2.90 m, covering an area of 16.53 m². The crop was spaced at 30 cm × 10 cm, and sowing took place on 2nd August 2022.

For fertilizer application, nitrogen and potassium were used at a rate of 25 kg ha^{-1} and 20 kg ha^{-1}, respectively. The phosphorus and sulphur levels were varied based on the different treatments. The seed rate employed was 18 kg ha^{-1} to establish the crop successfully in the experimental plots.

2.1 Treatment Details

The experiment included 04 levels of phosphorus (P_2O_5) and 03 levels of sulphur (S). The phosphorus treatments were as follows:

P_0: 0kg ha^{-1}, P_1: 20kg ha^{-1}, P_2: 40kg ha^{-1} and P_3: 60kg ha^{-1}

The sulphur treatments were as follows:

S_0: 0kg ha^{-1}, S_1: 10kg ha^{-1} and S_2: 20kg ha^{-1}

These different levels of phosphorus, sulphur was applied to the black gram crop during the experiment to assess their impact on various parameters and yield.

A study was undertaken to evaluate the effects of different phosphorus and sulphur fertilization levels on several yield attributes and productivity of black gram. The parameters analyzed after crop harvest included pods per plant, pod length, seeds per pod, test weight, biological yield, grain yield, stover yield and harvest index. The objective was to determine the response of black gram to varying nutrient levels in terms of measurable yield components. Data analysis helped understand the influence of phosphorus and sulphur application on optimizing the yields and harvest index of black gram. The post-harvest observations generated useful information for identifying the ideal fertilizer doses to obtain maximum black gram productivity under the given growing conditions. The findings provide guidance for enhancing nutrient management strategies for this important legume crop.

3. Result

The study data presented in Tables 1 and 2 analyzes the influence of different phosphorus and sulphur fertilization treatments on key yield attributes and productivity parameters in black gram. The attributes measured include pods per plant, pod length, seeds per pod, test weight, grain yield, stover yield, biological yield and harvest index. The results help evaluate the effect of varying phosphorus doses (0, 20, 40 and 60 kg ha^{-1}) and sulphur levels (0, 10 and 20 kg ha^{-1}) on these parameters. The data provides insights into the response of black gram to applied phosphorus and sulphur in terms of measurable yield components. Analysis of these yield parameters is critical for determining the optimal nutrient doses for maximizing black gram yields and harvest index. The tabulated data forms the basis for developing fertilizer recommendations aimed at improving black gram productivity.

3.1 Number of pods (plant^{-1})

The study found that increasing application rates of phosphorus had a significant positive impact on the number of pods plant^{-1} in black gram. The treatment with the highest level of phosphorus at 60 kg ha^{-1} (P_3) recorded the maximum number of pods plant^{-1} at 36.85, which was statistically on par with the 40 kg P ha^{-1} (P_2) treatment. The P_3 treatment significantly outperformed the lower phosphorus levels of 20 kg P ha^{-1} (P_1) and 0 kg P ha^{-1} (P_0). The lowest phosphorus treatment P_0 resulted in the minimum number of pods plant^{-1} at 24.27. Overall, the data indicates a significant beneficial response of number of pods per black gram plant to increasing doses of applied phosphorus up to 60 kg ha^{-1}. The findings will help determine the optimal phosphorus levels for maximizing pod production in black gram.

Sulphur levels showed a positive trend in influencing the significantly no. of pods plant^{-1}. Treatment S_2 (20 kg ha^{-1}) had the highest no. of pods plant^{-1} (33.32), which was slightly higher than S_1 (10 kg ha^{-1}) and statistically significant higher than S_0 (0 kg ha^{-1}). This suggests that higher levels of sulphur positively affected pod formation in the crop, resulting in more pods plant^{-1}.

The statistical analysis of the data showed no significant interaction between phosphorus and sulphur fertilizer levels in their effect on number of pods per plant in black gram. The response to increasing phosphorus rates for pod number remained consistent across the sulphur treatments tested. Similarly, the influence of different sulphur levels on pods per plant did not vary significantly at different phosphorus application rates. This suggests the effects of phosphorus and sulphur on pod production were additive rather than synergistic or antagonistic. The results indicate phosphorus and sulphur can be managed independently as per crop requirements to optimize black gram yield through their influence number of pods per plant.

Higher levels of phosphorus and sulphur positively affected the number of pods plant^{-1} in a crop. Treatment P_3 with the highest phosphorus level and treatment S_2 with the highest sulphur level recorded the highest no. of pods plant^{-1}. Adequate levels of these nutrients can increase pod formation, resulting in higher yield. These outcomes are consistent with the findings of Singh *et al*. (2006) [13].

3.2 Pod length (cm)

Pod length also significantly increased with increasing phosphorus levels. Treatment P_3 exhibited the longest pods (6.13 cm), which were significantly longer compared to the pods from lower phosphorus levels and at par with the treatment P_2 (40 kg ha^{-1}). The shortest pod length (5.00 cm) was recorded with the lowest phosphorus level P_0 (0 kg ha^{-1}).

Pod length was statistically significantly affected by the different sulphur levels. All three sulphur treatments (S_0, S_1, and S_2) resulted in similar pod lengths (around 5.77 cm). Which was statistically significant at par with the treatment S_1 (10 kg ha^{-1}). The lowest pod length (5.38 cm) was recorded with the lowest sulphur level S_0 (0 kg ha^{-1}).

The statistical analysis revealed no significant interaction effect between applied phosphorus and sulphur levels on pod length in black gram. The response to increasing phosphorus rates for pod length remained unchanged across the different sulphur treatments. Similarly, the impact of varying sulphur levels on pod length was consistent at the different phosphorus application rates tested. This additive nature of phosphorus and sulphur effects suggests their fertilizer doses can be optimized independently to maximize pod size and growth in black gram. The lack of any synergistic or antagonistic interaction simplifies nutrient management strategies for improving this yield attribute. The results indicate phosphorus and sulphur can be managed as per crop needs to enhance pod development without any interaction influences.

The study was indicated that pod length is positively correlated with phosphorus levels. This is likely due to the fact that phosphorus is an plant essential nutrient for plant growth and development. Phosphorus is involved in a number of cellular processes, including photosynthesis, respiration, and protein synthesis. It is also essential for the formation of cell walls and the transport of water and nutrients within the plant. Therefore, it is not surprising that pod length would be increased in plants that are receiving adequate amounts of phosphorus. The results of this study were also suggested that pod length is significantly affected by sulphur levels. This is likely due to the fact that sulphur is not as essential for plant growth and development as phosphorus. Sulphur is involved in a number of cellular processes, including protein synthesis and the formation of amino acids. These outcomes are consistent with findings of Tomar *et al*. (2013) [15].

3.3 Number of seeds (pod^{-1})

Higher phosphorus levels led to an increase in the no. of seeds pod^{-1}. Treatment P_3 had the highest no. of seeds pod^{-1} (6.65 seeds), significantly higher than the lower phosphorus levels. Which was at par with the treatment P_2 (40 kg ha^{-1}). The lower no. of seeds pod^{-1} (5.11 seeds) was observed with the lowest phosphorus level P_0 (0 kg ha^{-1}).

Sulphur levels also had a slight positive effect on the no. of seeds pod^{-1}. Treatment S_2 (20 kg ha^{-1}) recorded the highest no. of seeds pod^{-1} (6.12 seeds), Which was statistically significant at par with the treatment S_1 (10 kg ha^{-1}) and lowest was (5.04 seeds) recorded in treatment S_0 (0 kg ha^{-1}). While the differences between the treatments were not large, it suggests that higher sulphur levels might contribute to a slightly higher number of seeds pod^{-1}.

The results of the statistical analysis revealed no significant interaction effect between phosphorus and sulphur fertilizer levels on the number of seeds per pod in black gram. The influence of increasing phosphorus doses on seeds per pod remained consistent across the different sulphur treatments tested. Similarly, the impact of varying sulphur levels did not change significantly with different phosphorus application rates. This suggests the individual effects of phosphorus and sulphur on seed development were additive rather than synergistic or antagonistic. The lack of interaction indicates phosphorus and sulphur can be independently optimized as per crop requirements to maximize number of seeds per pod and boost yield potential in black gram. This simplifies nutrient management strategies for improving this key yield component.

Higher phosphorus fertilizer markedly improved pod length in cm and seeds pod^{-1} in the legume crop, with up to 24% longer pods and 29% more seeds at the maximum dose. In contrast, sulphur fertilizer had a more moderate positive effect, increasing pod length by up to 7% and seeds per pod by 21% at the highest dose. The results highlight the greater constraint that phosphorus deficiency imposes compared to sulphur deficiency on pod development and seed set in this legume crop. Also, similar study was report by Bairwa *et al*. (2012) [5].

3.4 Test weight (g)

The study found that increasing levels of both phosphorus and sulphur fertilization had significant positive effects on the test weight of black gram grains. The highest phosphorus level of 60 kg ha^{-1} (P_3) resulted in the maximum test weight of 45.22 g, statistically similar to 40 kg P ha^{-1} (P_2) and superior to the lower P_1 and P_0 treatments. Similarly, the highest sulphur application of 20 kg ha^{-1} (S_2) recorded higher test weight of 43.57 g compared to 10 kg S ha^{-1} (S_1) and 0 kg S ha^{-1} (S_0). The minimum test weight of 38.27 g and 40.41 g was observed in the lowest phosphorus (P_0) and sulphur (S_0) treatments, respectively. The data indicates the beneficial response of black gram grain test weight to increasing levels of phosphorus up to 60 kg ha^{-1} and sulphur up to 20 kg ha^{-1}. The results will help identify optimal nutrient doses for improving grain quality in terms of higher test weight.

The statistical analysis showed no significant interaction effect between the applied phosphorus and sulphur levels on test weight of black gram grains. This indicates the influence of increasing phosphorus rates on grain test weight remained consistent across the different sulphur treatments. Similarly, the impact of varying sulphur levels did not change significantly at the different phosphorus application rates. The additive nature of the individual phosphorus and sulphur effects suggests their fertilizer doses can be optimized independently to improve black gram grain test weight and quality. The lack of any synergistic or antagonistic interaction effect simplifies nutrient management strategies for achieving higher grain density and test weight in this crop.

The study found that application of higher sulphur level at 20 kg ha^{-1} (S_2) significantly increased number of pods per plant, number of seeds per pod, pod length and test weight compared to lower S_1 and S0 treatments. The results highlight the beneficial effects of adequate sulphur nutrition in improving these key yield-contributing parameters in black gram. Sulphur application enhanced pod and seed development, resulting in higher grain yields. This indicates the importance of proper sulphur management for realizing the yield potential of black gram. Further field experiments to assess responses to sulphur beyond 20 kg ha^{-1}, and its interactions with other nutrients like phosphorus, would help refine fertilizer recommendations for optimizing black gram productivity. The findings underscore the need for ensuring adequate sulphur availability to support reproductive growth and grain filling processes in black gram for maximum yields. These outcomes are consistent with findings of Niraj and Prakash (2015) [11].

3.5 Grain yield (q ha^{-1})

The study found that increasing application rates of phosphorus had a significant positive effect on grain yield of black gram. The treatment with the highest phosphorus level at 60 kg ha^{-1} (P_3) recorded the maximum grain yield of 13.15 q ha^{-1}, which was statistically similar to 40 kg P ha^{-1} (P_2). P_3 significantly out yielded the lower phosphorus treatments of 20 kg P ha^{-1} (P_1) and 0 kg P ha^{-1} (P_0). The minimum grain yield of 7.65 q ha^{-1} was observed under the P_0 treatment. Similarly, application of the highest sulphur level at 20 kg ha^{-1}

(S_2) resulted in the highest grain yield of 11.49 q ha^{-1}, comparable to 10 kg S ha^{-1} (S_1) but superior to 0 kg S ha^{-1} (S_0) which recorded the lowest yield of 9.88 q ha^{-1}.
The statistical analysis showed non-significant interaction between applied phosphorus and sulphur for grain yield. The results highlight the substantial positive response of black gram grain productivity to increasing levels of both phosphorus up to 60 kg ha^{-1} and sulphur up to 20 kg ha^{-1}.
Phosphorus fertilization proved highly effective at increasing grain yield in the legume crop, with applications of (60 kg ha^{-1}) raising yield by over 71% compared to the control treatment. Meanwhile, sulphur fertilization had a more moderate impact, increasing yield by up to 16% with the highest dose of (20 kg ha^{-1}). The findings demonstrate that ensuring adequate phosphorus supply through fertilizers is crucial for maximizing yields, with phosphorus deficiency representing a more serious limitation than sulphur deficiency under the given conditions. These outcomes are consistent with findings of Kumar *et al.* (2023) [7] and Naik *et al.* (2022) [9].

3.6 Stover yield (q ha^{-1})
The study observed that increasing levels of phosphorus and sulphur fertilization significantly increased the stover yield of black gram. The highest phosphorus level of 60 kg ha^{-1} (P_3) resulted in the maximum stover yield of 32.08 q ha^{-1}, which was statistically comparable to 40 kg P ha^{-1} (P_2) but superior over lower P_1 and P_0 levels. The minimum stover yield of 24.42 q ha^{-1} was recorded under the 0 kg P ha^{-1} (P_0) treatment. Similarly, the highest sulphur application of 20 kg ha^{-1} (S_2) produced significantly higher stover yield of 30.40 q ha^{-1} over the 10 kg S ha^{-1} (S_1) and 0 kg S ha^{-1} (S_0) treatments. The lowest stover yield of 26.87 q ha^{-1} was observed with 0 kg S ha^{-1} (S_0). The data indicates the positive influence of increasing phosphorus up to 60 kg ha^{-1} and sulphur up to 20 kg ha^{-1} in improving black gram stover output. Optimal P and S nutrition can maximize biomass production for higher stover yields.
The statistical analysis of the data showed non-significant interaction between applied phosphorus and sulphur levels in terms of their effects on stover yield of black gram. This indicates the response to increasing phosphorus doses for stover yield remained consistent across the different sulphur treatments tested. Similarly, the influence of varying sulphur levels on stover yield did not change significantly with different phosphorus application rates. The additive effects imply phosphorus and sulphur can be managed independently to optimize black gram biomass production and stover yields. The lack of any synergistic or antagonistic phosphorus-sulphur interaction effect simplifies nutrient management strategies for improving stover output in this crop.
The study highlights the importance of providing adequate levels of essential nutrients to the crop for achieving higher stover yield and better sustainability. Further research can focus on optimizing the levels of phosphorus and sulphur for specific crop varieties and growing conditions to maximize yield and improve soil health. These outcomes are consistent with findings of Mahesh *et al.* (2021) [8] and Abraham *et al.* (2021) [1].

3.7 Biological yield (q ha^{-1})
The study found that increasing levels of both phosphorus and sulphur fertilization significantly increased the biological yield of black gram. The highest phosphorus rate of 60 kg ha^{-1} (P_3) resulted in the maximum biological yield of 45.23 q ha^{-1}, comparable to 40 kg P ha^{-1} (P_2) but superior over lower P_1 and P_0 levels. The minimum biological yield of 32.07 q ha^{-1} was observed under the 0 kg P ha^{-1} (P_0) treatment. Similarly, application of the highest sulphur level at 20 kg ha^{-1} (S_2) recorded the highest biological yield of 41.89 q ha^{-1}, statistically similar to 10 kg S ha^{-1} (S_1) but significantly higher than 0 kg S ha^{-1} (S_0) which had the lowest biological yield of 36.75 q ha^{-1}. The data indicates the positive influence of increasing phosphorus and sulphur levels in improving overall biomass production and biological yield of black gram.
The statistical analysis of the biological yield data revealed non-significant interaction between applied phosphorus and sulphur levels. This indicates the response to increasing phosphorus rates for biological yield remained consistent across the different sulphur treatments. Similarly, the influence of varying sulphur levels did not change significantly with different phosphorus application rates. The additive effects of phosphorus and sulphur suggest their levels can be optimized independently to maximize the total biomass production and biological yield of black gram. The lack of any synergistic or antagonistic interaction effect simplifies nutrient management strategies for improving biological yield in this crop.
The application of higher levels of phosphorus and sulphur demonstrated a positive impact on the biological yield of the crop. Treatment P_3 and S_2 showed the highest biological yield, significantly higher than the lower levels of the respective nutrients. Adequate levels of these nutrients can increase the overall productivity of the crop and improve soil health. These outcomes are consistent with findings of Singh and Singh (2012) [12].

3.8 Harvest index (%)
Harvest index, which represents the proportion of grain yield to the total biological yield, also increased with increasing phosphorus levels. Treatment P_3 had the highest harvest index (29.07%), indicating efficient allocation of resources towards grain production. The lowest harvest index (23.85%) was recorded with the lowest phosphorus level P_0 (0 kg ha^{-1}).
Harvest index, which represents the proportion of grain yield to the total biological yield, also increased with increasing sulphur levels. Treatment S_2 had the highest harvest index (27.92%), indicating efficient allocation of resources towards grain production. The lowest harvest index (26.88%) was recorded with the lowest phosphorus level S_0 (0 kg ha^{-1}).
The statistical analysis revealed that the interaction (P×S) between phosphorus and sulphur levels did not have a significant effect on the harvest index.
The results indicate that higher levels of phosphorus (60 kg ha^{-1}) and sulphur (20 kg ha^{-1}) positively influenced grain yield, stover yield, and biological yield. Adequate phosphorus and sulphur application can lead to increased crop productivity and overall yield. Additionally, higher phosphorus and sulphur levels resulted in improved harvest index, indicating efficient resource allocation towards grain production. Proper nutrient management practices, including phosphorus and sulphur application, are crucial for optimizing crop productivity and achieving higher yields. These outcomes are consistent with findings of Tejaswini and Rajesh (2023) [14].

Table 1: Effect of different phosphorus and sulphur levels on pods plant^{-1}, pod length, seeds pod^{-1} and test weight in black gram

Treatment Details	Number of pods plant^{-1}	Pod length (cm)	Number of seeds pod^{-1}	Test weight (g)
4 levels of phosphorus (P_2O_5)				
P_0 0 kg ha^{-1}	24.27	5.00	5.11	38.27
P_1 20 kg ha^{-1}	30.99	5.47	5.74	41.45
P_2 40 kg ha^{-1}	35.12	5.87	6.24	44.63
P_3 60 kg ha^{-1}	36.85	6.13	6.65	45.22
S.Em±	0.878	0.126	0.158	1.048
CD (P=0.05)	2.576	0.370	0.464	3.073
3 levels of sulphur (S)				
S_0 0 kg ha^{-1}	29.86	5.38	5.64	40.41
S_1 10 kg ha^{-1}	32.24	5.71	6.06	43.20
S_2 20 kg ha^{-1}	33.32	5.77	6.12	43.57
S.Em±	0.760	0.109	0.137	0.908
CD (P=0.05)	2.230	0.321	0.402	2.662
Interaction (P × S)				
S.Em±	1.52	0.22	0.27	1.82
CD (P=0.05)	NS	NS	NS	NS

Table 2: Response of different levels of phosphorus and sulphur on grain yield (q ha^{-1}), stover yield (q ha^{-1}), biological yield (q ha^{-1}) and harvest index (%)

Treatment Details	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest index (%)
4 levels of phosphorus (P_2O_5)				
P_0 0 kg ha^{-1}	7.65	24.42	32.07	23.85
P_1 20 kg ha^{-1}	9.94	27.66	37.60	26.43
P_2 40 kg ha^{-1}	12.22	31.22	43.44	28.13
P_3 60 kg ha^{-1}	13.15	32.08	45.23	29.07
S.Em±	0.357	0.886	1.009	-
CD (P=0.05)	1.047	2.600	2.960	-
3 levels of sulphur (S)				
S_0 0 kg ha^{-1}	9.88	26.87	36.75	26.88
S_1 10 kg ha^{-1}	10.85	29.26	40.11	27.56
S_2 20 kg ha^{-1}	11.49	30.40	41.89	27.92
S.Em±	0.309	0.768	0.874	-
CD (P=0.05)	0.906	2.252	2.563	-
Interaction (P × S)				
S.Em±	0.62	1.54	1.75	-
CD (P=0.05)	NS	NS	NS	-

4. Conclusion

The study revealed that increasing phosphorus application rates positively influenced several black gram yield parameters including number of seeds per pod, pods per plant, pod length, test weight, grain yield, stover yield, biological yield and harvest index. The treatment with the highest phosphorus level of 60 kg ha^{-1} (P_3) consistently recorded the best performance across most parameters compared to the lower phosphorus treatments. This demonstrates the significant yield enhancing response of black gram to phosphorus fertilization up to 60 kg ha^{-1}.

Similarly, increasing sulphur levels showed beneficial effects on certain yield attributes like number of pods per plant and number of seeds per pod. The highest sulphur level of 20 kg ha^{-1} (S_2) resulted in maximum values for these two parameters highlighting the importance of adequate sulphur nutrition.

The findings highlight the crucial role of phosphorus in enhancing crop productivity and yield, indicating that adequate phosphorus supply is essential for maximizing black gram yields. On the other hand, sulphur application showed a less pronounced effect, suggesting that under the given conditions, the available sulphur levels were sufficient to support crop yield.

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