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Optimizing phosphorus and sulphur fertilizers for enhanced summer mungbean cultivation: Insights from Dehradun, Uttarakhand, India

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Abstract
This study explores the impact of phosphorus and sulphur fertilizers on summer mungbean cultivation in Dehradun, Uttarakhand, India. Utilizing a Randomized Block Design with varying nutrient levels, the research reveals that meticulous nutrient management significantly enhances key growth parameters, seed characteristics, and overall yield. Phosphorus positively influences vegetative growth and reproduction, while sulphur plays a crucial role in growth, nodulation, and seed development. Elevated phosphorus and sulphur levels not only improve vegetative growth but also positively influence nodulation, essential for nitrogen fixation. In the context of rising fertilizer costs, determining the optimal dosage of these nutrients becomes imperative for economic feasibility and enhanced productivity. This study provides practical insights for sustainable and economically viable nutrient management practices, contributing to improved crop yields and the well-being of farming communities in Uttarakhand.

Keywords: Summer mungbean cultivation, phosphorus fertilization, sulphur fertilization, nutrient management, crop productivity, nodulation, sustainable agriculture, Dehradun, Uttarakhand, India

1. Introduction

Pulses, exemplified by greengram (*Vigna radiata* L. Wilczek), and are crucial for global nutrition, offering essential nutrients such as protein, vitamins, fibers, iron, zinc, and magnesium (Yadav *et al*., 2017) [6]. Recognized as the second most critical food crop worldwide, pulses play a key role in ensuring food security, particularly in regions like India (Statistical Year Book India, 2016) [5]. Beyond their nutritional significance, pulses contribute substantially to soil health through symbiotic nitrogen fixation, benefiting both human nutrition and agricultural sustainability.

In Dehradun, Uttarakhand, the focus on summer cultivation of mungbean has gained momentum due to favorable conditions such as controlled pest and disease levels, lower rainfall, and reduced humidity. Greengram, occupying a substantial area in India, has become a staple crop in arid and semi-arid regions, making a significant contribution to pulse production. However, challenges, such as suboptimal yields, persist, attributed to factors like the absence of improved varieties, dominance of dryland agriculture, and insufficient application of fertilizers.

Among the crucial nutrients influencing pulse production, phosphorus stands out as a critical element responsible for vegetative growth, reproduction, and overall yield (Singh *et al*., 2017) [3-4]. The significance of phosphorus in legume crops, particularly its impact on root development, nodulation, and energy transfer, underscores its vital role in biological nitrogen fixation. Studies have demonstrated the positive impact of phosphorus application on mungbean yields, necessitating the determination of optimal dosages for economic feasibility and increased productivity.

Sulphur, another essential nutrient, plays a key role in the growth and development of pulses, influencing nodulation activity and nutritional quality (Kumar *et al*., 2012) [1]. Given the considerable portion of Indian soils identified as sulphur-deficient, understanding the impact of sulphur on greengram's dry matter accumulation, phosphorus uptake, and overall crop performance becomes imperative (Singh *et al*., 2017) [3-4]. Additionally, sulphur's role in amino acid synthesis and its association with protein production further underscore its significance in pulse crops. In the current agricultural landscape marked by intensive chemical practices, rising fertilizer costs present economic challenges to farmers. Consequently, determining the optimal requirements of phosphorus and sulphur fertilizers for summer mungbean cultivation becomes imperative, not only for economic feasibility but also to enhance factor productivity, ensuring nutritional and economic security for farming communities.

This paper addresses the knowledge gap regarding the optimal application of phosphorus and sulphur fertilizers in summer mungbean cultivation, considering the specific agro-climatic conditions of Dehradun, Uttarakhand. Through an exploration of the intricate relationship between phosphorus, sulphur, dry matter production, and yield, the research aims to provide valuable insights guiding sustainable agricultural practices, improving crop yields, and contributing to the overall well-being of farming communities.

2. Material & Methods

A field trial was conducted at Department of Agronomy, SAI Institute of Paramedical and Allied Sciences, Dehradun in *summer* season 2019

2.1 Treatments

A description of methods and materials used, experimental procedure followed throughout course of study is mentioned in this section. The experiment employed a Randomized Block Design with a 3x3 factorial arrangement, involving two factors: phosphorus and sulfur levels. Three levels of phosphorus (45 kg/ha, 60 kg/ha, 75 kg/ha) and three levels of sulfur (15 kg/ha, 30 kg/ha, 45 kg/ha) constituted the nine treatment combinations.

Treatment combinations

Treatment No.	Treatment combination	Treatment Description
T1	P1 S1	P1=45 × S1=15
T2	P1 S2	P1=45 × S2=30
T3	P1 S3	P1=45 × S3=45
T4	P2 S1	P2=60 × S1=15
T5	P2 S2	P2=60 × S2=30
T6	P2 S3	P2=60 × S3=45
T7	P3 S1	P3=75 × S1=15
T8	P3 S2	P3=75 × S2=30
T9	P3 S3	P3=75 × S3=45

Detail of field layout

S. no.	Particulars	Contents
1.	Number of replications	3
2.	Total number of plots in one replication	10
3.	Total number of experimental plots	30
4.	Experimental design	Randomized Block Design (Factorial)
5.	Gross plot size	4.5 m x 4.0 m
6.	Net plot size	3.30 m x 3.6 m
7.	Spacing	30 cm x10 cm
8.	Fertilizer application	As per treatment
9.	Year	*summer* season of 2019

2.2 Crop Variety

- Used HUM-16 greengram variety from Banaras Hindu University.
- Suited for North East Plain Zone, resistant to MYMV.
- Maturity in 55 days, ideal for rice-wheat cropping.

2.3 Sowing Operations

- Treated seeds with capton and rhizobium culture.
- Prepared fields with ploughing and harrowing.
- Sowed greengram seeds manually, 30 cm apart, at 5 cm depth.

2.4 Nutrient and Weed Management

- Applied calculated fertilizer doses uniformly before sowing.
- Used urea, DAP, MOP, and phosphogypsum.
- Weed control with pendimethalin 30 EC pre-emergence spray.

2.5 Calendar of field operations

a) Pre-Sowing Operations

S. No.	Field operations	Date
1	Preparatory tillage	11.04.2021
2	Harrowing cum levelling	11.04.2021
3	Layout	12.04.2021
4	Seed sowing	16.04.2021
5	Urea, DAP, MOP, Phosphogypsum application	16.04.2021

b) Post-sowing Operations

	Irrigation	Dates	Operations
1	a. First (23 DAS)	08.05.2021	Irrigation was applied as per treatment
	b. Second (45 DAS)	30.05.2021	Irrigation was applied as per treatment
	c. Thinning	1.05.2021	Manually
2	**Weeding**		
	Chemical weeding	16.04.2021	Pendimethalin @ 0.75 kg/ha
3	Harvesting	2.07.2021	
	1st Picking	23.06.2021	Manually
	2nd Picking	1.07.2021	Manually
4	Threshing	08.07.2021	Manually

3. Results

3.1 Plant Dry Matter Production

- Dry matter production, recorded at 20, 40, and 60 DAS, is presented in Table 1.
- Dry matter increases with growth stages, peaking at 60 DAS.

20 DAS

- Phosphorus levels significantly boost dry matter, with the highest level (7.38) outperforming others.
- Both 30 kg and 20 kg sulphur ha^{-1} show significant effects over 10 kg sulphur ha^{-1}.

40 DAS

- 60 kg phosphorus ha^{-1} significantly enhances dry matter over 40 kg and 20 kg phosphorus ha^{-1}.
- 30 kg and 20 kg sulphur ha^{-1} significantly outperform 10 kg sulphur ha^{-1}.
- Control plots accumulate significantly lower dry matter than the lowest levels of phosphorus and sulphur.

3.2 Crop Growth Rate (CGR)

CGR, outlined in Table 2, peaks at 40 DAS.

0-20 DAS: 60 kg phosphorus ha^{-1} and highest sulphur level exhibit the best CGR.

20-40 DAS: 60 kg and 40 kg phosphorus ha^{-1}, 30 kg sulphur ha^{-1}, and 20 kg sulphur ha^{-1} show superior CGR.

40 DAS to Harvest: Higher phosphorus and sulphur levels enhance CGR significantly.
Control consistently records lower CGR compared to nutrient-treated plots.

3.3 Leaf Area Index (LAI)
LAI data, in Table 3, highlights phosphorus and sulphur's significant impact on growth stages.

20 DAS
LAI slightly increases with higher phosphorus and sulphur but lacks significance. Max LAI with highest P (0.34) and S (0.34), minimum at lowest levels.

40 DAS
Significant phosphorus effect on LAI, peaking at 60 kg P ha^{-1} (2.71).
30 kg S ha^{-1} reports the highest LAI (2.41), on par with 20 kg S ha^{-1}, both significantly surpassing 10 kg S ha^{-1}.
Control significantly lower than other doses (0.98).

3.4 100-Seed Weight (g)
Maximum 100-seed weight observed at 60 kg phosphorus ha^{-1} (3.94), on par with 40 kg ha^{-1} (3.61), significantly higher than 20 kg ha^{-1} (3.0).
Sulphur at 30 kg ha^{-1} records the highest weight (3.89), significantly surpassing 20 kg ha^{-1} (3.59) and 10 kg ha^{-1} (2.97).
Control has a significantly lower 100-seed weight (1.6) than nutrient-treated plots.

3.5 Grain Yield and HI
3.5.1 Grain Yield (kg/ha): Data on summer moong bean seed yield, detailed in Table 5, underwent statistical analysis. Phosphorus application significantly influenced seed yield, with the highest at 60 kg P/ha (914.66kg/ha), significantly surpassing 40 kg P/ha (880.28) and 20 kg P/ha (803.96kg/ha). No significant difference between 40 and 60 kg P/ha. Sulphur application up to 20 kg/ha impacted seed yield; 30 kg S/ha (902.67) and 20 kg S/ha (879.54) significantly surpassed 10 kg S/ha (816.68). Control had significantly lower grain yield (577.0) than nutrient-treated plots

3.5.2 Harvest Index (%)
Data on summer green-gram's Harvest Index (H.I.), outlined in Table 5 indicates notable impacts of phosphorus and sulphur levels. The highest H.I. occurred with 60 kg P/ha (38.49), on par with 40 kg P/ha (37.71) and significantly higher than 20 kg P/ha (36.89). Sulphur application up to 30 kg/ha influenced H.I., with the maximum at 30 kg S/ha (38.27), on par with 20 kg S/ha (37.83), significantly surpassing 10 kg S/ha (36.99). Control had a significantly lower H.I. (32.66) than the lowest P and S levels.

3.6 No. of Nodules per Plant
20 DAS: At 20 DAS, higher phosphorus (60 kg/ha) and sulphur (30 kg/ha) levels resulted in the maximum nodules, significantly surpassing lower doses (10 kg/ha) and the control.

40 DAS: By 40 DAS, both phosphorus (60 kg/ha) and sulphur (30 kg/ha) levels exhibited a significant increase in nodules compared to lower doses (20 kg/ha, 10 kg/ha) and the control. The study highlights the positive impact of elevated phosphorus and sulphur levels on nodulation in summer moong bean plants

Table 1: Plant dry matter (g m^{-2}) as influenced by various levels of phosphorus and sulphur at various growth stages

Treatment	20 DAS	40 DAS	Harvest
(A) Phosphorus levels (kg ha^{-1})			
20	5.94	60.59	149.98
40	6.73	62.10	158.04
60	7.38	63.01	163.97
SEm±	0.38	0.51	0.62
CD (P=0.05)	0.80	1.08	1.32
(B) Sulphur levels (kg ha^{-1})			
10	5.93	60.82	155.88
20	6.82	62.22	157.65
30	7.29	62.67	158.47
SEm±	0.38	0.51	0.62
CD (P=0.05)	0.80	1.08	1.32
(C) Control *vs* treatment			
Control vs Rest	5.50	53.34	133.0
SEm±	0.48	0.66	0.81
CD (P=0.05)	1.03	1.39	1.71

Table 2: CGR ($g/m^2/day^1$) as affected by different levels of phosphorus and sulphur at various growth stages.

Treatment	0-20 DAS	20-40 DAS	Harvest
(A) phosphorus levels (kilogram per hectare)			
20	1.11	7.88	2.80
40	1.90	9.01	3.73
60	2.62	9.59	4.52
SEm±	0.37	0.41	0.37
CD (P=0.05)	0.88	0.86	0.78
(B) sulphur levels (kilogram per hectare)			
10	1.19	8.13	2.96
20 kg	1.99	8.96	3.82
30 kg	2.44	9.39	4.27
SEm±	0.41	0.41	0.37
CD (P=0.05)	0.88	0.86	0.78
(C) Control *vs* treatment			
Control vs Rest	0.17	6.13	1.60
SEm±	0.53	0.52	0.47
CD (P=0.05)	1.13	1.11	1.00

Table 3: LAI as influenced by different doses of phosphorus and sulphur at various growth stages

Treatment	20 DAS	40 DAS
(A) phosphorus levels (kilogram per hectare)		
20	0.32	1.05
40	0.33	1.91
60	0.34	2.71
SEm±	0.12	0.33
CD (P=0.05)	0.28	0.71
(B) sulphur levels (kilogram per hectare)		
10	0.32	1.18
20	0.33	2.08
30	0.34	2.41
SEm±	0.12	0.33
CD (P=0.05)	0.28	0.71
(C) Control *vs* treatment		
Control vs Rest	0.29	0.98
SEm±	0.16	0.43
CD (P=0.05)	0.27	0.92

Table 4: Yield attributing character (Seed Weight-100 seeds) as influenced by different phosphorus and sulphur levels.

Treatment	100 Seed weight (g)
Phosphorus Levels (kilogram per hectare)	
20	3.0
40	3.61
60	3.89
SEm±	0.28
CD (P=0.05)	0.60
Sulphur Levels (kilogram per hectare)	
10	2.97
20	3.59
30	3.94
SEm±	0.28
CD (P=0.05)	0.60
Control v/s Treatment	
Control vs Rest	1.6
SEm±	0.37
CD (P=0.05)	0.77

Table 5: Grain yield and H.I. as affected by different phosphorus and sulphur levels.

Treatment	Grain yield (kg/ha)	Harvest index (%)
(A) Phosphorus Levels(kg ha^{-1})		
20 kg ha^{-1}	803.96	36.89
40 kg ha^{-1}	880.28	37.71
60 kg ha^{-1}	914.66	38.49
SEm±	20.37	0.41
CD (P=0.05)	43.18	0.88
(B) Sulphur Levels (kg ha^{-1})		
10 kg ha^{-1}	816.68	36.99
20 kg ha^{-1}	879.54	37.83
30 kg ha^{-1}	902.67	38.27
SEm±	20.37	0.41
CD (P=0.05)	43.18	0.88
(C) Control *vs* treatment		
Control vs Rest	577.0	32.66
SEm±	26.29	0.53
CD (P=0.05)	55.74	1.13

Table 6: Number of nodules affected by levels of phosphorus and sulphur

Treatment	Numbers of nodules/plant	
	20 DAS	40 DAS
(A) Phosphorus Levels (kg ha^{-1})		
20	12.77	19.75
40	13.70	20.54
60	14.40	21.41
SEm±	0.37	0.38
CD (P=0.05)	0.78	0.81
(B) Sulphur Levels (kg ha^{-1})		
10	12.89	20.02
20	13.74	20.59
30	14.24	21.10
SEm±	0.37	0.38
CD (P=0.05)	0.78	0.80
(C) Control *vs* treatment		
Control	12.17	18.75
SEm±	0.46	0.49
CD (P=0.05)	1.01	1.04

4. Conclusion

4.1 Plant Dry Matter Production: Phosphorus and sulphur positively influenced dry matter production at various growth stages, with the highest impact observed at 60 DAS. Optimal levels significantly outperformed lower doses and the control, emphasizing their essential role in enhancing plant biomass.

4.2 Crop Growth Rate (CGR): CGR peaked at 40 DAS, showcasing significant improvements with elevated phosphorus and sulphur levels. The study underscores the crucial role of these nutrients in promoting sustained crop growth and development.

4.3 Leaf Area Index (LAI): Phosphorus and sulphur levels significantly affected LAI, demonstrating their impact on the plant's foliage. Higher doses led to increased LAI, with implications for overall plant health and photosynthetic efficiency.

4.4 100-Seed Weight: Elevated phosphorus and sulphur levels positively influenced 100-seed weight, indicating their role in seed development. The study highlights the importance of nutrient management in achieving desirable seed characteristics.

4.5 Grain Yield: Phosphorus and sulphur application significantly increased grain yield, with the highest values recorded at 60 kg P/ha and 30 kg S/ha. This reinforces the pivotal role of these nutrients in maximizing crop productivity.

4.6 Harvest Index (%): The harvest index exhibited notable improvements with higher phosphorus and sulphur levels, emphasizing their impact on resource allocation towards grain production. Optimal nutrient management enhances the efficiency of assimilate utilization.

4.7 No. of Nodules per Plant: Phosphorus and sulphur levels positively influenced nodulation, crucial for nitrogen fixation. Higher doses resulted in a significant increase in nodules at both 20 DAS and 40 DAS, highlighting their role in supporting legume-microbe symbiosis.

In conclusion, the study underscores the significance of phosphorus and sulphur management in achieving optimal plant performance, seed characteristics, and overall crop productivity in summer moong bean cultivation.

5. Discussion

The study underscores the positive impact of phosphorus and sulphur levels on various growth parameters in summer mungbean cultivation. Optimal nutrient levels significantly enhance dry matter production, Crop Growth Rate (CGR), Leaf Area Index (LAI), 100-Seed Weight, grain yield, Harvest Index (%), and nodulation. The findings emphasize the crucial role of nutrient management in promoting robust vegetative growth, seed development, and overall crop productivity. This knowledge offers practical insights for farmers aiming to adopt sustainable and economically viable nutrient management practices in agriculture.

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