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Growth, yield, quality, nutrient content, uptake and economics of fenugreek affected by levels of phosphorus and Sulphur in alluvial soil

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Abstract
An experiment was conducted at College Agronomy Farm, B.A. College of Agriculture, Anand Agricultural University, Anand 388110 during *rabi* 2022-2023 to study the effect of phosphorus and Sulphur on fenugreek under loamy sand soil of middle Gujarat. There was total sixteen treatment combinations, four levels of phosphorus (0, 20, 30 and 40 kg P_2O_5/ha) and four level of Sulphur (0, 20, 30 and 40 kg S/ha). In fenugreek, growth and growth attributing characters are more important in respect to higher seed yield. Plant height at 30 DAS (14.50 cm) and at harvest (64.58 cm), number of branches per plant (6.08) was significantly higher by application of 40 kg P_2O_5/ha, same treatment reported higher dry weight of nodules per plant (9.79 mg). Significant response of phosphorus (40 kg P_2O_5/ha) on number of pods per plant (20.25), pod length (12.83 cm) and test weight (13.35 g) at harvest. Higher level of phosphorus application (40 kg P_2O_5/ha) reported 25.31 and 11.45% more seed (1515 kg/ha) and straw (3261 kg/ha) over control treatment (0 kg P_2O_5/ha). Phosphorus content (0.458 and 0.196%, seed and straw respectively), uptake (6.96 and 6.42 kg/ha) and sulphur uptake (4.70 and 6.55 kg/ha) higher in treatment where 40 kg P_2O_5/ha was applied. Non-significant response of phosphorus on harvest index, protein content, sulphur content. Sulphur is also responsible for synthesis of certain vitamins (biotin and thiamine), proteins, fats and metabolism of carbohydrates. Role of sulphur on growth parameters found significant, application of 40 kg S/ha reported significantly higher plant height (14.50 and 64.16 cm, at 30 DAS and harvest, respectively), number of branches per plant (6.33). Increasing dry weight of nodules (9.38 mg) with increasing rate of sulphur up to 40 kg S/ha. Significantly the maximum number of pods per plant (20.66), test weight (13.30 g) and higher pod length (12.66) reported in treatment S_3 (40 kg S/ha), but pod length was remain at par with the rest of sulphur levels except control. Application of 40 kg S/ha reported 20.39 and 8.90% higher seed (1476 kg/ha) and straw (3258 kg/ha) yield over control treatment. Sulphur content (0.319 and 0.213% in seed and straw, respectively), phosphorus uptake (6.45 and 5.92 kg/ha, by seed and straw, respectively) and sulphur uptake (4.72 and 6.94 kg/ha, by seed and straw, respectively) were reported maximum in treatment S_3 (40 kg S/ha). Protein content, phosphorus content and harvest index did not show response of sulphur. Levels of phosphorus and sulphur significantly effected economics of fenugreek. Higher net realization (76271 and 73348 ₹/ha, respectively) was reported in treatment P_3 (40 kg P_2O_5/ha) and S_3 (40 kg S/ha).

Keywords: Fenugreek, phosphorus, sulphur, loamy sand soil

Introduction
India is largest producer, consumer and exporter of seed and spices among the spices, fenugreek (*Trigonella foenum-graecum* L.) locally known as '*methi*' under the family *Fabaceae*, self-pollinated, crop grown in India as well as many countries. Due to the high concentration of vitamins, proteins, and minerals it contains, this priceless fragrant and medicinal plant is used for its nutritional and healthful properties. It is used as leafy vegetable as well as dry seed use for spices purpose, so role of fenugreek is multipurpose. Fenugreek seeds can be a good supplement to cereals because of its high protein (25%), lysine (5.7 g/16 g N), soluble (20%) and insoluble (28%) dietary fiber besides being rich in calcium, iron and beta carotene (NIN 1987).

In India this crop is grown on area of about 1,46,363 ha with the production of about 2,26,305 tones and productivity 1546 kg/ha in 2022-23 (Anon., 2022-23). Fenugreek occupies third place in area and fourth in production among all the major seed spices grown in India.

The common method to increase fenugreek productivity is to improve soil fertility status by supplying required amount of plant nutrients such as phosphorus and sulphur. Phosphorus (P) plays vital role in production of fenugreek as its availability not only improves the growth and yield but also enhances the symbiotic N-fixation. Phosphorus is essential nutrient for determining plant growth and productivity. The common role of phosphorus in plant metabolism is known to enhance the grain quality, imparts hardiness to shoot, helps root enlargement and governs biochemical processes. Sulphur is fourth most important nutrient after nitrogen, phosphorus and potassium. Sulphur is one of the essential nutrients that is vital for the ample growth and development of plants. It is essential for the synthesis of proteins and enzymes. It is an integrant of S-containing amino acids *viz*. methionine, cysteine and cystine which are the building blocks of protein. In plant bodies it triggers several enzymes. It is an integral part of photosynthesis and plant respiration biochemical processes. It is a precursor of photosynthesis which in turn produces sugars, starch, oils, fats and vitamins. It plays an important role in chlorophyll formation. Sulphur is crucial for the formation of essential oils which give spices their characteristic aroma and flavor.

Materials and Method

Experiment site and climate

One year field experiment was carried out to study the effect of phosphorus and Sulphur on fenugreek under loamy sand soil of Agronomy Farm, Department of Agronomy, B.A. College of Agriculture, Anand Agricultural University, Anand during *rabi* 2022-2023. Mean weekly weather parameters data was collected from Department of Agricultural Meteorology, B.A. College of Agriculture, Anand Agricultural University, Anand for the growing period (Fig. 01). Before sowing the experiment in the field, collected composite soil sample (0-15 cm) depth according to standard soil sampling process. The sample was used for analysis of initial status of soil. The experiment soil was low in organic carbon (0.45%), available nitrogen (205.75 kg/ha), medium in available phosphorus (48.90 kg/ha), available potassium (238.45 kg/ha) and available Sulphur (14.95 ppm).

Map 1: Agronomy Farm, Department of Agronomy, B.A. College of Agriculture, Anand Agricultural University, Anand 388001 (Gujarat) 22°32'25.4"N 72°58'53.0"E

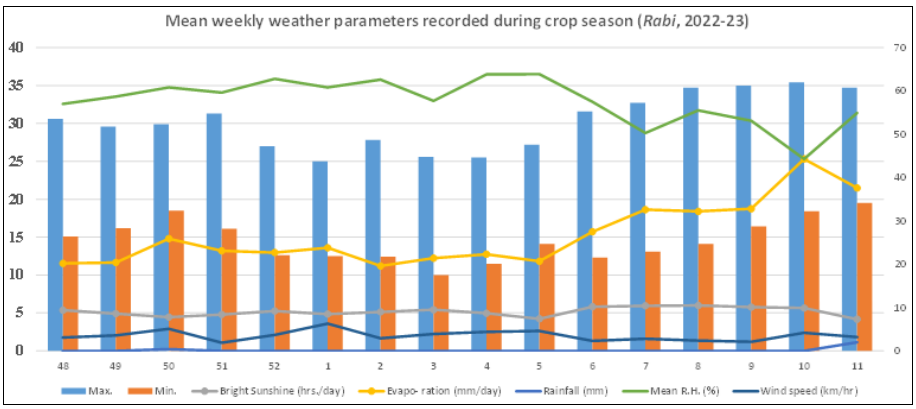

Fig 1: Mean weekly weather parameters during crop season

Experiment design, treatment and crop husbandry

Evaluation was carried out on fenugreek with four levels of phosphorus (0,20,30 and 40 kg/ha) and four levels of Sulphur (0,20,30 and 40 kg/ha), there were total sixteen treatment combination replicated thrice. Fenugreek was sown 30 cm apart in plot size 3.60 × 5.0 m plot. Statistical analysis of mean data was carried out by using Randomized complete Block design (Factorial). Full dose of nitrogen and according to treatment phosphorus and Sulphur were applied by urea, diammonium phosphate (DAP) and bentonite Sulphur, respectively.

Fenugreek variety Gujarat Methi 2 was sown using 20 kg seed per hectare. Weed control is necessary operation, twice hand weeding and one interculturing operation was carried out during growth period. Light irrigation was given immediately after sowing to facilitate uniform germination and plant population, during whole growth period five irrigation was applied for successful crop production. Plant protection measures were carried out as and when required to protect crop against insect and pest. From net plot area, select five plants randomly for taking biometric observation. Chemical analysis of fenugreek seed and straw were carried out by taking representative sample from each net plot at harvest of crop. The samples were oven dried at 60±5 °C for 48 hours and then powdered by using stainless steel mill.

Statistical analysis

Data on different aspects of fenugreek like growth, yield and other parameters was subjected to statistical analysis as per procedure of Randomized Block Design (factorial). The data was generated through computer software following the procedure prescribed by Cochran and Cox (1967). The variances of different sources of variation in ANOVA were tested by "F test" and compared with the value of Table F at 5% level of significance. S.Em ±, critical differences (C.D.) and coefficient of variation (CV%) were also worked out. The critical difference was calculated to determine the significance of treatment mean, whenever the "F test" was found significant at 5% level of probability. To explicate the nature and the magnitude of effect, treatment summary tables along with S.Em ± and C. D. were prepared and are given in the next chapter "Results and Discussion" and their analysis of variance are given in the appendices at the end.

Results and discussion

Effect of phosphorus on growth parameters

Phosphorus plays a general role in plant metabolism, regulating physic-bio-chemical processes, hardening shoots, enhancing symbiotic nitrogen fixation, improving grain quality, and regulating photosynthesis. Application of phosphorus increased all growth attributes of fenugreek. Response of periodical plant height significantly effect by application of phosphorus. Significantly higher plant height at 30 DAS (14.50 cm) and at harvest (64.58 cm) was observed in treatment P_3 (40 kg P_2O_5/ha) than rest of treatment except control treatment (0 kg P_2O_5/ha). No application of phosphorus (P_0: 0 kg P_2O_5/ha) reported significantly lower plant height (12.66 and 59.33 cm, respectively). Growth parameter horizontally in terms of number of branches per plant at harvest (Table). Increasing number of branches per plant with increasing levels of phosphorus, treatment P_3 (40 kg P_2O_5/ha) reported significantly higher number of branches per plant (6.08) at harvest. Application of 40 kg P_2O_5/ha reported significantly the maximum dry weight of nodules per plant (9.79 mg) over the rest of phosphorus levels. Minimum dry weight of nodules per plant (7.55 mg) was observed in control treatment (P_0: 0 kg P_2O_5/ha). Phosphorus has an important role in several of physiological and biochemical processes that are essential to the growth and development of plants, which may account for the general increase in fenugreek growth observed with elevated phosphorus levels. Application of phosphorus may have stimulated plant metabolic processes, leading to enhanced meristematic activity and apical development. One major aspect contributing to the formation of dry matter is the rate of phosphorus absorption and translocation to the leaves (Singh *et al*., 2010 and Jat *et al*., 2012) [9, 4].

Effect of phosphorus on yield attributes and yield

Phosphorus application to fenugreek up to 40 kg/ha reported significant response on yield attributes and yield. Number of pods per plant (20.25) and pod length (12.83 cm) reported significantly higher in treatment P_3 (40 kg P_2O_5/ha), it was 11.51 and 10.03% higher over control treatment, respectively. Significantly increasing yield attributes like number of pods per plant and pod length might be due to all metabolic processes, especially respiration, glycolysis and photosynthesis, depend on the activity of phosphorus-dependent coenzymes like NAD and NADP (Detroja *et al.*, 1995 and Jat and Shektawat, 2001) [2, 3].

Increasing application of phosphorus up to 40 kg P_2O_5/ha significantly improved the seed, stover and biological yield of fenugreek. Higher level of phosphorus application (P_3: 40 kg P_2O_5/ha) reported higher seed (1515 kg/ha), straw (3261) and biological (4776 kg/ha) yield, improvement of phosphorus application over no application was 25.31 and 11.45 percent higher in seed and straw yield, respectively. Higher yield of fenugreek might be because of better plant absorption and enhanced phosphorus availability in the soil (Meena, 2003, Nehara *et al*., 2006, Sammauria and Yadav, 2008) [5, 6, 8]. A significant regulating role of the intricate process of yield production is played by photosynthesis in conjunction with the availability of assimilates (source) and storage organs (sink). It also might be due to improvement in yield might be due to nutritional condition. Response of phosphorus levels on the harvest index was found non-significant.

During investigation, effect of levels of phosphorus on protein content, Sulphur content in seed and straw were found non-significant. One of the main nutrients in the soil for plants is phosphorus. It is a component of plant cells and is necessary for the growth of the plant's growing tip and cell division. Application of 40 kg P_2O_5/ha (P_3) reported significantly higher phosphorus content in seed and straw (0.458 and 0.196%, respectively). Phosphorus and Sulphur uptake significantly influenced by application of phosphorus to fenugreek. Significantly maximum phosphorus uptake by seed (6.96 kg/ha), straw (6.42 kg/ha) and Sulphur uptake by seed (4.70 kg/ha) by application of 40 kg P_2O_5/ha (P_3) while significantly higher Sulphur content by straw (6.55 kg/ha) was reported in treatment P_3 (40 kg P_2O_5/ha), it remain at par with other levels of phosphorus except control (0 kg P_2O_5/ha) treatment.

Effect of Sulphur on growth parameters

The significant role that Sulphur plays in energy transformation, the activation of several enzymes and carbohydrate metabolism may be the cause of the rise in these yield-related characteristics. When enough Sulphur is present, they aid in the flower's reproductive parts' primordial initiation, which in turn controls the quantity of pods per plant and seeds per pod. It is inferred from the data presented in Table 1 indicated that growth attributes of fenugreek were found significant. Periodical plant height at 30 DAS and at harvest was found significant, application of 40 kg S/ha reported significantly higher plant height at 30 DAS and at harvest, respectively (14.50 and 64.16 cm) and number of branches per plant (6.33). Improvement in growth parameters might be because of Sulphur play crucial function in controlling the physiological and metabolic systems of plants may account for the increase in crop growth following its application. At higher Sulphur levels, meristematic tissue activity increased promoted chlorophyll synthesis, which turn increased dry matter production (Jat *et al.*, 2012) [4]. Application of Sulphur as a basal application dose in soil significantly influenced dry weight of nodules per plant. Increasing levels of

Sulphur up to 40 kg S/ha reported significantly higher dry weight of nodules per plant (9.38).

Yield attributes and yield of fenugreek were significantly varied due to different levels of Sulphur. Number of pods per plant and pod length of fenugreek was significantly affect by levels of Sulphur. Application of higher levels of Sulphur (40 kg S/ha) reported significantly the highest number of pods per plant (20.66) and higher pod length (12.66 cm). Fenugreek pod length had remained statistically at par with rest of treatments except control treatment S_0 (0 kg S/ha). Statistically significant variation was observed in the test weight due to different level of Sulphur (Table 01). Results of experiment showed that at harvest, test weight (13.30 g) was reported significantly higher in treatment S_3 (40 kg S/ha) than rest of treatments except control treatment (S_0: 0 kg/ha). Seed, straw and biological yield of fenugreek was significantly affected by Sulphur levels (Table 01). Increasing fenugreek seed (1476 kg/ha), straw (3258 kg/ha) and biological yield (4734 kg/ha) with increasing levels of Sulphur up to 40 kg S/ha (S_3). Seed and straw yield of fenugreek was comparatively 20.39 and 8.90% higher over control treatment. Increasing yield of fenugreek by application of Sulphur might be due to by enhancing both the vegetative and reproductive stages of crop development, Sulphur application appears to have preserved the equilibrium between source and sink, which eventually led to an increase in seed output. Levels of Sulphur did not show its significant response on harvest index of fenugreek (Table 01).

Perusal of data presented in Table 01 indicated that levels of Sulphur did not show its significant effect on protein content and phosphorus content by seed and straw of fenugreek during experimentation. Sulphur content, uptake and phosphorus uptake was found significant due to application of Sulphur to fenugreek. Application of higher levels of Sulphur (40 kg S/ha) reported significantly the maximum Sulphur content (0.319 and 0.213% in seed and straw, respectively) and Sulphur uptake (4.72 and 6.94 kg/ha, in seed and straw, respectively), while treatment S_3 (40 kg S/ha) reported higher phosphorus uptake (6.45 and 5.92 kg/ha, respectively by seed and straw) of fenugreek.

Table 1: Effect of phosphorus and Sulphur levels on growth and yield of Fenugreek

Treatments	Plant height at 30 DAS	Plant height at harvest	No. of branches per plant at harvest	Dry weight of root nodules/ plant (mg)	No. of pods/ plant	Pod length (cm)	Test weight (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
Levels of phosphorus											
P_0=0 kg/ha	12.66	59.33	5.00	7.55	18.16	11.66	12.02	1209	2926	4135	29.20
P_1=20 kg/ha	13.50	60.58	5.08	8.93	19.75	12.00	12.85	1317	3093	4410	29.82
P_2=30 kg/ha	14.00	62.33	5.41	8.86	19.08	12.16	13.03	1434	3182	4616	31.09
P_3=40 kg/ha	14.50	64.58	6.08	9.79	20.25	12.83	13.35	1515	3261	4776	31.71
S. Em. ±	0.38	1.25	0.20	0.24	0.48	0.27	0.26	37.53	72.16	72.80	0.83
C.D. at 5%	1.11	3.62	0.58	0.71	1.38	0.80	0.75	108.38	208.39	210.25	NS
Levels of Sulphur											
S_0=0 kg/ha	12.66	59.08	4.75	8.23	18.50	11.33	12.23	1226	2992	4219	29.05
S_1=20 kg/ha	13.75	60.91	5.16	8.73	18.83	12.25	12.70	1361	3033	4394	30.97
S_2=30 kg/ha	13.75	62.66	5.33	8.80	19.25	12.41	13.01	1412	3178	4590	30.66
S_3= 40 kg/ha	14.50	64.16	6.33	9.38	20.66	12.66	13.30	1476	3258	4734	31.13
S. Em. ±	0.38	1.25	0.20	0.24	0.48	0.27	0.26	37.53	72.16	72.80	0.83
C.D. at 5%	1.11	3.62	0.58	0.71	1.38	0.80	0.75	108.38	208.39	210.25	NS
Interaction (P x S)											
S. Em. ±	0.77	2.51	0.40	0.49	0.96	0.55	0.52	75.06	144.32	145.61	1.67
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V.%	9.77	7.05	12.90	9.74	8.62	7.93	7.03	9.50	8.02	5.62	9.50

Table 2: Effect of phosphorus and Sulphur levels on quality, content, uptake of nutrient economics of fenugreek

Treatment	Protein content in seed (%)	Phosphorus content (%)		Sulphur content (%)		Phosphorus uptake (kg/ha)		Sulphur uptake (kg/ha)		Gross realization (₹/ha)	Net realization (₹/ha)	BCR
		Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw			
Levels of phosphorus												
P_0=0 kg/ha	21.55	0.381	0.156	0.291	0.189	4.61	4.58	3.52	5.55	75466	60487	5.04
P_1=20 kg/ha	21.95	0.411	0.173	0.300	0.197	5.42	5.36	3.96	6.12	82113	65484	4.94
P_2=30 kg/ha	22.14	0.441	0.180	0.301	0.199	6.32	5.73	4.31	6.32	89222	71963	5.17
P_3=40 kg/ha	22.77	0.458	0.196	0.309	0.200	6.96	6.42	4.70	6.55	94161	76271	5.26
S. Em. ±	0.30	0.007	0.003	0.005	0.003	0.17	0.17	0.12	0.15	-	-	-
C.D. at 5%	NS	0.019	0.009	NS	NS	0.51	0.50	0.37	0.43	-	-	-
Levels of Sulphur												
S_0=0 kg/ha	21.39	0.416	0.170	0.289	0.180	5.14	5.11	3.55	5.40	76552	61573	5.11
S_1=20 kg/ha	22.25	0.410	0.177	0.290	0.191	5.58	5.38	3.96	5.81	84693	67774	5.01
S_2=30 kg/ha	22.34	0.431	0.178	0.303	0.200	6.14	5.69	4.26	6.39	87898	70204	4.97
S_3= 40 kg/ha	22.42	0.434	0.180	0.319	0.213	6.45	5.92	4.72	6.94	91818	73348	4.97
S. Em. ±	0.30	0.007	0.003	0.005	0.003	0.17	0.17	0.12	0.15	-	-	-
C.D. at 5%	NS	NS	NS	0.013	0.009	0.51	0.50	0.37	0.43	-	-	-
Interaction (P x S)												
S. Em. ±	0.60	0.013	0.006	0.009	0.006	0.35	0.34	0.25	0.30	-	-	-
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-
C.V.%	4.72	5.44	5.85	5.32	5.40	10.65	10.84	10.85	8.48	-	-	-

Interaction Effect
One year experiment mean data regarding levels of phosphorus and sulphur on growth, yield attributes, economical yield, nutrient content and uptake of fenugreek was found non-significant.

Economic
The highest net realization (76271 ₹/ha) of fenugreek with BCR (5.26) was observed higher in treatment P_3 (40 kg P_2O_5/ha). Application of higher level of Sulphur (40 kg S/ha) reported the highest net realization (73348 ₹/ha) with benefit cost ratio (4.97).

Conclusion
The study conducted at the Agronomy Farm of Anand Agricultural University during rabi 2022-2023 demonstrates that phosphorus and sulphur play significant roles in enhancing the growth and yield of fenugreek (Trigonella foenum-graecum) grown in loamy sand soil of middle Gujarat.

Phosphorus Effects: The application of 40 kg P2O5/ha significantly improved fenugreek growth parameters, including plant height, number of branches per plant, and dry weight of nodules. This level of phosphorus also enhanced yield attributes such as the number of pods per plant, pod length, and test weight, leading to a substantial increase in seed (1515 kg/ha) and straw yield (3261 kg/ha) compared to the control. Furthermore, phosphorus application increased phosphorus and sulphur uptake, although it had no significant effect on harvest index or protein content.

Sulphur Effects: Sulphur application at 40 kg S/ha resulted in higher plant height, number of branches, and dry weight of nodules. This level also significantly increased the number of pods per plant, pod length, and test weight, contributing to higher seed yield (1476 kg/ha) and straw yield (3258 kg/ha) compared to the control. Sulphur improved the content and uptake of sulphur and phosphorus but did not significantly impact protein content or harvest index.

Economic Analysis
The economic evaluation reveals that the highest net realization was achieved with the application of 40 kg P2O5/ha (₹76,271/ha) and 40 kg S/ha (₹73,348/ha), indicating the profitability of these treatments. The benefit-cost ratio (BCR) was highest for phosphorus at 40 kg/ha (5.26) and slightly lower for sulphur at 40 kg/ha (4.97).
The study concludes that both phosphorus and sulphur significantly improve the growth and yield of fenugreek, with 40 kg/ha of each nutrient being optimal for maximizing productivity and profitability. These findings provide valuable insights for fenugreek cultivation practices in similar agro-ecological zones.

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Data Availability
The original contributions presented in the study are included in articles/supplementary material. Please directed to the corresponding authors.

Conflict of Interest
The authors declare that they have no known competing financial interest personal relationship that could have appeared to influence work reported in this paper.

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