RESPONSES OF SULFUR AND PHOSPHORUS DOSES ON THE YIELD AND QUALITY OF FENUGREEK (*Trigonella foenum-graecum* L.)

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Abstract. This study was conducted to determine the effects of sulfur and phosphorus doses on the yield and quality of fenugreek in Siirt, Turkey, in the 2016-2017 and 2017-2018 growing seasons. Field trials were designed in a factorial complete block design with three replications at the experimental fields of the Agricultural Faculty of Siirt University. In the study, plant height (cm), first pod height (cm), the number of pods (pod plant^{-1}), the number of seeds in the pod (seed pod^{-1}), pod length (cm), thousand-seed weight (g), seed yield (kg ha^{-1}), protein content (%) and trigonelline content (%) were determined. All of the growth and yield parameters, except for plant height and pod length, were significantly affected by sulfur fertilization. All the parameters were affected by phosphorus fertilization. The highest seed yield (2224 kg ha^{-1}) and trigonelline content (1.26%) were obtained under 30 kg S ha^{-1} and 90 kg P ha^{-1} applications.
Keywords: *Trigonella foenum-graecum, fertilizer, medicinal plants, seed yield, trigonelline*

Introduction

Nowadays, due to the many side effects of synthetic and chemical drugs, trending towards alternative medicine or complementary medicine is gradually increasing. Medicinal and aromatic plants used for this purpose can be found in Turkey among many other countries, mainly by gathering from the natural flora. Therefore, medicinal plants of the desired quantity and quality cannot be obtained. This situation brings up the production of medicinal and aromatic plants with increasing the usage area.

Fenugreek (*Trigonella foenum-graecum* L.) which is grown for its seeds, fresh shoots, and leaves and is an important multi-purpose plant, one of the oldest known to have medicinal and aromatic properties. It has Mediterranean and Asian origin, and is an annual plant belonging to the Leguminosae family (Baldemir and İlgün, 2015; Bienkowski et al., 2016), containing about 50 species, and 45 of these species are found in the natural flora of Turkey (Davis, 1982; Beyzi et al., 2010). India is the world's largest producer of fenugreek, and it is also grown in South Asia, the Middle East, Far East, China, Iran, Pakistan, Turkey, the Mediterranean region, Europe, North Africa, Australia, Canada, the USA, and Argentina (Basu et al., 2019).

Fenugreek is a plant that has economic value in food, feed, medicine, and cosmetics. Fenugreek seeds are used in traditional medicine in the treatment of diabetes and cancer, as a natural dyestuff in the cosmetics industry, in animal feeding, as a coating material of some products in the food industry, and in making spices (Boeker, 1963; Baytop, 1984; Arslan et al., 1989; Hornok, 1992; Akgül, 1993; Küçük and Gürbüz, 1999; Soylu et al., 2000; Kızıl and Arslan, 2003; Tunçtürk et al., 2011; Abd Elhamid et al., 2016). It is also used as a green manure plant since it is a legume plant, and it has been reported to play a role in improving the physical and chemical properties of the soil (Abdelgani et al., 1999).

Phosphorus (P), which fulfills many functions related to plant growth, development, and metabolism and is essential for young tissues and cannot be renewed, is the most crucial macronutrient element after nitrogen. It is also called the key to life because it regulates many metabolic activities of plant life. If sufficient P is given to the plant, it causes rapid growth and increases plant resistance. In the case of P deficiency, plants stop and slow down the growth of the above-ground organs and accelerate the root growth. P, which also plays an essential role in increasing the yield of legumes by increasing biological activities such as nodulation, nitrogen fixation, nutrient uptake in the soil and in the rhizosphere environment, alleviates adverse effects of drought on physiological parameters in plants (Kacar and Katkat, 2007; Turan and Horuz, 2012; Yadav et al., 2014; Singh and Singh, 2016; Gezgin, 2018).

Generally, the properties of soils in Turkey affect the uptake of soil phosphorus by plants negatively (high pH, high lime content, low organic matter content, high clay content). It is very important to apply appropriate amounts of P to legume plants or to increase the availability of soil phosphorus, according to the results of soil analysis (Gezgin, 2018). Legumes' benefiting from soil phosphorus also differs according to its species and varieties (Gökmen Yılmaz et al., 2017).

Elemental sulfur (S) is a natural material and can be applied to increase the availability of plant nutrients and to reduce deficiencies in calcareous and alkaline soils (Manesh et al., 2013). Sulfur has vital importance in the activation of the process of photosynthesis, carbohydrate metabolism, and certain enzyme systems in plants; it can increase plants' seed and oil yields and protein contents. It is considered to be an essential nutrient in the vitamin and amino acids synthesis of legume plants. Sulfur is found in cysteine, cystine, and methionine, among the amino acids, and in the composition of proteins. It is necessary for chlorophyll formation (Lal et al., 2015). It accelerates root growth and nodule formation (Tonguç et al., 2017; Bolat and Kara, 2017). It has been reported that the amount of nitrogen fixed by legumes increases with the treatment of sulfur, and as a result of this, soil fertility improves (Mohamed El-Sayed Ali, 2018).

The reduced use of fossil fuels in the world and in Turkey and the widespread use of sulfur-free fertilizers have caused sulfur deficiency to emerge as a factor limiting the yield in plant production. Sulfur affects nitrogen utilization efficiency, and adverse effects of sulfur deficiency are observed on the growth of plants, chlorophyll amount, photosynthesis capacities, yield, and yield parameters (Tonguç et al., 2017). Sulfur positively affects not only the above-ground organs of plants but also the root growth, just like phosphorus. As a matter of fact, in the soybean plant given sulfur, the number and weight of side roots, the number and weight of nodules in which nitrogen fixation occurred were reported to increase significantly (Zhao et al., 2008). In beans, plant weight, the number of branches, the number of pods, the number of grains per plant, thousand-seed weight, harvest index, and yield were indicated to significantly increase in comparison with unfertilized plants (Tonguç et al., 2017).

This study was conducted to determine the effects of sulfur and phosphorus doses on the yield and quality characteristics of fenugreek (*T. foenum-graecum* L.).

Materials and methods

The study was carried out between 2016-2018 under the ecological conditions of Siirt province located in the Southeastern Anatolia Region of Turkey, which has a

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semi-arid climate. Siirt is located at 37° 58' 7.37" N and 41° 51' 3.87" E coordinates with 894 m altitude (*Figure 1, Figure 2*).

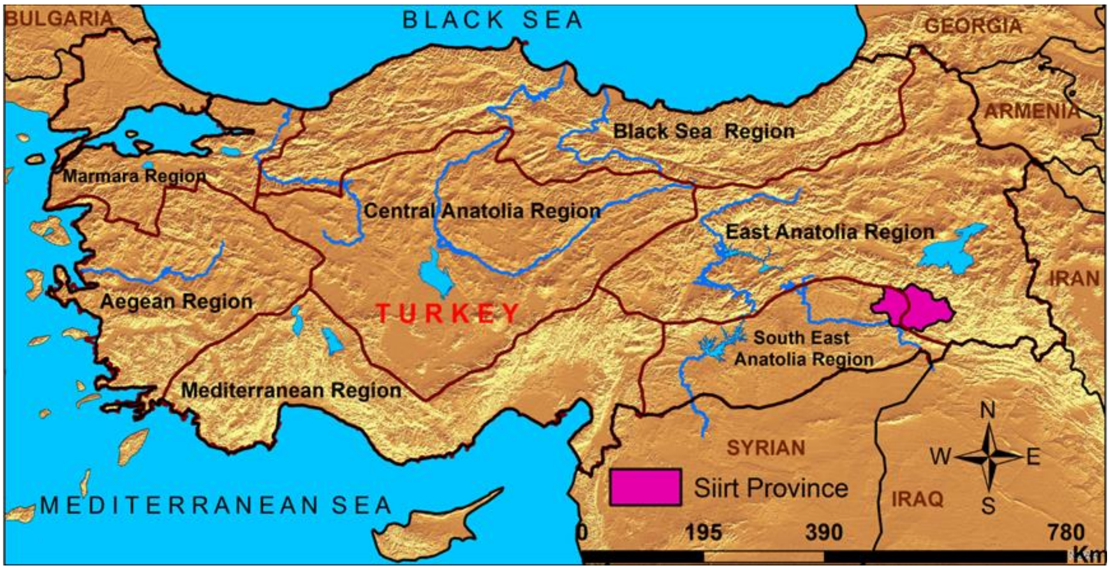

Figure 1. *Location of the study area in Turkey*

Figure 2. *A photo of the research area*

In the second year of the study, less precipitation (522.8 mm) occurred in comparison with the first year (574.2 mm), while the long-term annual precipitation was 634.1 mm. While the highest precipitation occurred in March and April during the 2016-2017 vegetation period, the highest precipitation was recorded in May during the 2017-2018 vegetation period (*Table 1*). The mean temperature during the study years and the long-term mean temperature (38 years) were 11.2 ^oC, 13.8 ^oC, and 11.4 ^oC, respectively *Table 1* (Anonymous, 2018).

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Table 1. *Climate characteristics of trial area*

Climate parameters	Research years	Months								
		Nov	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**Mean/Sum**
Average temparature (ºC)	2016-2017	10.4	3.3	3.0	2.7	9.6	14.0	19.5	26.9	11.2
	2017-2018	11.2	8.0	5.7	8.2	13.7	16.8	19.8	27.4	13.8
	Long term*	10.3	4.9	3.0	4.5	8.8	14.3	19.5	26.2	11.4
Monthly precipitation (mm)	2016-2017	55.4	116.6	46.4	29.2	119.2	132.8	74.6	0.0	574.2
	2017-2018	86.0	47.4	56.4	74.2	47.6	61.6	139.6	10.0	522.8
	Long term*	85.1	91.1	82.2	96.6	108.7	96.3	64.3	9.8	634.1

*: 1980-2018

In the study, some physical and chemical analysis results of the soils taken before establishing the field trial were presented in *Table 2*. In the first year (2016-2017), the trial area soils were loamy textured, and they were clay-loam textured in the second year (2017-2018); both trial area soils were slightly alkaline, salt-free, their lime content was "medium calcareous," the organic matter content was "low," and the available potassium (K) content was "sufficient". The available P content of the soils in the first year was determined to be "very little," and the available P content of the soils in the second year was determined to be "low" (*Table 2*).

Table 2. *Some physical and chemical properties of the study area soils (0-20 cm)**

Properties	Value	
	2016-2017	**2017-2018**
Clay, %	47.56	34.16
Silt, %	12.11	26.00
Sand, %	40.33	39.84
pH	7.72	7.53
Electrical conductivity (EC), mS cm^{-1}	0.363	0.150
Lime ($CaCO_3$), %	12.0	8.2
Organic matter, %	1.31	1.78
Available phosphorus, kg P_2O_5 ha^{-1}	24	49
Available potassium, kg K_2O ha^{-1}	1430	1250

*: Analyses were carried out in Siirt University, Science and Technology Application and Research Center Laboratory

As the plant material in the study, fenugreek (*T. foenum-graecum* L.) seeds, belonging to the "Konya population" and seeded locally in the Central Anatolia Region of Turkey, were used.

In this study, the field trial was established as three replications in randomized blocks according to the factorial trial design. In the study, 4 different sulfur doses (S_0= 0, S_{10}= 10, S_{20}= 20, and S_{30}= 30 kg S ha^{-1}) and 4 different phosphorus doses (P_0= 0, P_{30}= 30, P_{60}= 60, and P_{90}= 90 kg P_2O_5 ha^{-1}) constituted the subject of the study. Elemental sulfur was used as the source of sulfur fertilizer, and triple superphosphate (43-44% P_2O_5) was used as the source of phosphorus fertilizer. According to the

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research subjects, both fertilizer forms were mixed by applying them to the soil before seeding.

The seeding process was performed manually on 14 November 2016 in the first year and on 17 November 2017 in the second year on the grooves opened with the help of a marker. In the study, row distance was 30 cm and parcel distance was 100 cm. Each parcel constituted from four rows, while length and width of the parcels were 3 meter by 1.2 meter each with a total area of 3.6 m^2 per parcel. Sowing norm was 30 kg ha^{-1}, and sowing was done manually in rows opened with the help of a marker. Weed control was performed mechanically by hand several times in both years. At the harvest, two border rows and 50 cm from each side were excluded to eliminate border effects.

Plant height, first pod height, pod length, the number of pods per plant, and the number of seeds per pod were determined in 10 plants randomly selected in each parcel before harvest. The harvest was carried in the entire plot area, excluding borders in the first week of July in both years. The harvested plants were dried in the shade for 3-4 days, and seed yields were calculated per hectare. Crude protein determination in seeds was performed by the Kjeldahl nitrogen determination method, and trigonelline analysis was performed by the HPLC method. In trigonelline analysis was used Agilent TC-C18 (ODS 25 cm * 4.6 mm) column. Column temperature was maintained at 27 °C and the flow rate of the mobile phase was kept at 1 ml per min. The changes in absorbance at wavelength 210 nm were recorded with UV detector. The peak area was calibrated to trigonellin content with a standard.

The data were analyzed by JMP statistical software. A homogeneity test was applied to the data obtained from the study. According to the results of the homogeneity test, they were subjected to combined variance analysis (ANOVA) according to the factorial trial design in randomized blocks. According to the F-test results, differences between the groups were determined by the LSD multiple comparison test. In the study, the correlation coefficients of the pairwise relationships between the examined properties were calculated (Yurtsever, 1984; Düzgüneş et al., 1987).

Results and discussion

Plant height

In the study, the effect of S doses on the plant height of fenugreek was statistically insignificant, and according to S doses, plant height varied between 62.4-65.2 cm as the mean of P doses and years. The effect of phosphorus doses on plant height was determined to be statistically significant at the $p<0.01$ level. This difference occurred between the P_0 and P_{30} doses of phosphorus and its P_{60} and P_{90} doses. In this study, in which plant height increased according to P doses, the highest plant height was determined in P_{60} (65.2 cm) and P_{90} (66.3 cm) P doses. When the interaction of SxP was examined, the highest plant height was determined in the S_0P_{90} application as 70.1 cm, but no statistically significant difference was found between it and S_0P_{60}, $S_{10}P_{60}$, $S_{10}P_{90}$, $S_{30}P_0$, and $S_{30}P_{90}$ applications. The lowest plant height was measured in unfertilized parcels (control). SxP interaction was determined to be statistically significant ($p<0.01$) (*Table 3*). When the studies on this subject were reviewed, increasing P applications were reported to increase plant height, similarly to the results of our study (Halesh et al., 2000; Khiriya et al., 2001; Nehara et al., 2006; Meena et al., 2012; Mehta et al., 2012; Verma et al., 2014; Srivastava et al., 2015; Ahmad, 2017; Basu et al., 2019).

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Table 3. *Means of yield components at different sulfur and phosphorus doses in fenugreek*

S doses	P doses	Plant height (cm)			First pod height (cm)			Pod length (cm)		
		2017	**2018**	**Mean[1]**	**2017**	**2018**	**Mean[1]**	**2017**	**2018**	**Mean[1]**
S_0	P_0	59.8	57.8	58.8 e	36.4	46.2	41.3	14.4	13.3	13.8
	P_{30}	63.8	61.4	62.6 cde	44.5	50.1	47.3	14.5	14.6	14.6
	P_{60}	69.9	68.8	69.4 ab	43.5	48.9	46.2	14.8	15.3	15.0
	P_{90}	69.0	71.1	70.1 a	42.3	52.7	47.5	15.4	16.4	15.9
S_0 Mean		65.6	64.8	65.2	41.7	49.5	45.6 A	14.8	14.9	14.8
S_{10}	P_0	60.7	56.9	58.8 e	41.3	38.2	39.8	14.1	14.5	14.3
	P_{30}	60.8	62.4	61.6 de	40.3	42.6	41.4	14.7	15.4	15.1
	P_{60}	65.1	66.5	65.8 a-d	43.1	42.7	42.9	15.2	15.7	15.4
	P_{90}	66.3	68.53	67.4 abc	40.4	44.7	42.5	17.7	16.3	17.0
S_{10} Mean		63.2	63.6	63.4	41.3	42.1	41.7 B	15.5	15.5	15.5
S_{20}	P_0	61.7	64.5	63.1 cde	39.9	36.1	38.1	14.2	14.2	14.2
	P_{30}	62.6	60.1	61.4 de	39.1	40.0	39.6	15.9	15.8	15.8
	P_{60}	61.7	65.7	63.7 cde	43.1	43.2	43.1	15.2	15.2	15.2
	P_{90}	62.6	60.1	61.4 de	40.9	42.4	41.7	16.2	16.3	16.3
S_{20} Mean		62.2	62.6	62.4	40.7	40.4	40.6 B	15.4	15.4	15.4
S_{30}	P_0	64.4	67.1	65.8 a-d	35.2	35.5	35.4	14.2	14.5	14.4
	P_{30}	64.1	64.3	64.2 b-d	43.4	40.3	41.8	15.3	15.5	15.4
	P_{60}	61.3	62.5	61.9 de	46.3	48.3	47.3	15.9	16.1	16.0
	P_{90}	66.4	66.1	66.3 a-d	41.8	44.6	43.2	15.2	15.6	15.4
S_{30} Mean		64.1	65.0	64.5	41.7	42.2	41.9 B	15.2	15.4	15.3
Phosphorus mean										
P_0		61.7	61.6	61.6 b	38.2	39.0	38.6 b	14.3	14.2	14.2 c
P_{30}		62.8	62.1	62.5 b	41.8	43.3	42.6 a	15.1	15.3	15.2 b
P_{60}		64.5	65.9	65.2 a	43.9	45.8	44.9 a	15.3	15.6	15.4 b
P_{90}		66.1	66.5	66.3 a	41.3	46.1	43.7 a	16.1	16.2	16.1 a
Means		63.8	64.0		41.3	43.5		15.2	15.3	
CV (%)		7.2			10.8			6.5		
Year (Y)		ns			*			ns		
Sulfur (S)		ns			**			ns		
Phosphorus (P)		**			**			**		
SxP		**			ns			ns		
SxPxY		ns			ns			ns		

S_0= Control, S_{10}= 10 kg ha^{-1} sulfur, S_{20}= 20 kg ha^{-1} sulfur, S_3= 30 kg ha^{-1} sulfur, P_0= Control, P_{30}= 30 kg ha^{-1} phosphorus, P_{60}= 60 kg ha^{-1} phosphorus, P_{90}= 90 kg ha^{-1} phosphorus, [1]: The difference between the means indicated by the same letter in the same column and group is not significant, CV: Coefficient of variation, ns: Not significant, *: p<0.05, **: p<0.01

First pod height

In the fenugreek plant, S and P doses had a statistically significant effect on the first pod height at the p<0.01 level. The highest first pod height was measured in plants in parcels not treated with S, and no statistically significant difference was found between the other S doses. In other words, increased S doses did not affect the first pod height (*Table 3*). Tunçtürk et al. (2011) reported that the highest first pod height was obtained in the dose of 40 kg S ha^{-1} and that contrary to the results of our study, the first pod height increased with increasing S doses. It is thought that seeding time and genotype differences may be effective in this difference in the literature. As a matter of fact, Babagil (2010) stated that the first pod height is a property that is significantly affected by genotype and environmental factors. When the results of phosphorus doses were examined, as the mean of years and S doses, the lowest first pod height (38.6 cm) was

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measured in parcels not treated with phosphorus fertilizer, while the P_{30}, P_{60}, and P_{90} doses of phosphorus were statistically in the same group and yielded the highest values (*Table 3*). In the studies conducted on fenugreek, the highest first pod height was determined in 40 kg P ha^{-1} by Khiriya and Singh (2003) and in 30 kg P ha^{-1} doses by Tunçtürk (2011), Nehara et al. (2006) reported that increased phosphorus doses increased yield properties.

Pod length

While the effects of S doses on pod length were statistically insignificant in the fenugreek plant, the effects of P doses were significant at the $p<0.01$ level. The pod length varied between 14.8-15.5 cm according to sulfur doses. The pod length was observed to increase in parallel with the increasing P doses. The highest pod length was measured to be 16.1 cm at P_{90} dose, and the lowest value was measured in the control parcel (14.2 cm) (*Table 3*). Similarly to our results, Khiriya et al. (2001), Khiriya and Singh (2003), Bhunia et al. (2006), and Meena et al. (2012) reported that increased P doses increased the pod length.

Number of pods

The statistical analysis results demonstrated that S and P doses and SxP interaction had significant effects on the number of pods per plant at the $p<0.01$ level. In the study, the number of pods was determined to increase in the fenugreek plant depending on the increase in S and P doses. In both fertilizer applications, the highest values were determined at the highest fertilizer doses (*Table 4*). In the studies conducted by Kumar (2011) on pea and by Nawange et al. (2011) on chickpeas, it was reported that increasing phosphorus and sulfur applications increased the number of pods.

The number of pods per plant was reported to vary between 7.7-8.5 by Tunçtürk (2011), between 30.6-33.0 by Meena et al. (2012), between 46.73-50.72 by Lal et al. (2015), between 6.4-8.6 by Srivastava et al. (2015), and between 11.6-23.1 by Mitoo et al. (2018). The reason for the number of pods per plant obtained in this study to be higher than these values in the literature may be differences in genotype, soil, climate, and cultural practices.

When the SxP interaction was examined, the highest number of pods was obtained from $S_{30}P_{60}$ and $S_{30}P_{90}$ applications, while the lowest number of pods was obtained from the S_0P_0 application (*Table 4*).

Number of seeds per pod

When sulfur applications were examined, it was observed that the number of seeds per pod increased up to S_{20} dose (15.59 seeds) depending on the increase in S doses, and after this dose, it was observed that it decreased statistically significantly. This difference between sulfur doses was statistically significant at the $p<0.01$ level. In terms of phosphorus doses, the number of seeds per pod increased with increasing P doses. Although the highest value was obtained to be 15.85 seeds at P_{90} dose, the difference between P_{90} and P_{60} doses (15.62 seeds) was statistically insignificant. This difference between phosphorus doses was determined to be statistically significant at the $p<0.01$ level. According to the sulfur x phosphorus interaction, the lowest number of seeds per pod was in S_0P_0 interaction (12.40), and the highest values were determined in $S_{20}P_{90}$, $S_{20}P_{30}$, $S_{20}P_{60}$, $S_{30}P_{60}$, $S_{30}P_{90}$, S_0P_{90}, $S_{10}P_{90}$, $S_{10}P_{60}$, and S_0P_{60} interactions. SxP

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interaction was determined to be very important in terms of the number of seeds per pod ($p<0.01$) (*Table 4*). Srivastava et al. (2015) reported that the number of seeds per pod varied between 13.20-16.60 and that the application of phosphorus increased the number of seeds per pod in the fenugreek plant. Mitoo et al. (2018) stated that the number of seeds per pod varied between 11.67-15.07 and increased with increasing phosphorus and sulfur applications.

Table 4. *Means of yield components at different sulfur and phosphorus doses in fenugreek*

S doses	P doses	Number of pods (pods/plant)			Number of seeds in pod (seeds/pod)			Thousand-seed weight (g)		
		2017	**2018**	**Mean[1]**	**2017**	**2018**	**Mean[1]**	**2017**	**2018**	**Mean[1]**
S_0	P_0	37.33	36.30	36.82 g	12.89	11.90	12.40 d	12.24	13.10	12.67
	P_{30}	45.70	42.57	44.13 c-f	14.57	15.07	14.82 bc	13.23	13.20	13.21
	P_{60}	43.70	45.67	44.68 cde	15.46	15.63	15.55 ab	13.07	13.42	13.25
	P_{90}	45.60	49.30	47.45 bc	15.76	16.13	15.95 a	13.52	13.30	13.41
S_0 Mean		43.08	43.68	43.27 B	14.67	14.68	14.68 C	13.02	13.25	13.14 B
S_{10}	P_0	39.33	39.73	39.53 fg	14.07	14.87	14.47 c	12.58	13.54	13.06
	P_{30}	39.93	43.13	41.53 d-g	14.73	14.77	14.75 c	13.73	13.89	13.81
	P_{60}	45.57	45.73	45.65 cd	15.40	15.73	15.57 ab	14.27	13.62	13.95
	P_{90}	44.90	48.30	46.60 bcd	15.70	15.73	15.72 a	13.42	14.12	13.77
S_{10} Mean		42.43	43.97	43.33 B	14.98	15.28	15.13 B	13.50	13.79	13.65 AB
S_{20}	P_0	39.70	38.47	39.08 fg	14.63	14.60	14.62 c	12.64	13.21	12.93
	P_{30}	43.57	45.00	44.28 cde	16.17	15.87	16.02 a	13.38	13.22	13.30
	P_{60}	48.27	46.90	47.58 bc	15.63	15.63	15.63 a	13.93	13.72	13.82
	P_{90}	51.90	50.03	50.97 b	16.00	16.20	16.10 a	14.60	15.91	15.26
S_{20} Mean		45.86	45.10	45.48 B	15.61	15.58	15.59 A	13.64	14.02	13.83 A
S_{30}	P_0	37.93	38.93	38.43 g	14.23	14.57	14.40 c	12.67	13.18	12.93
	P_{30}	39.13	41.93	40.53 efg	14.83	14.80	14.82 bc	12.88	13.32	13.10
	P_{60}	56.33	63.20	59.77 a	15.70	15.73	15.72 a	14.03	14.00	14.02
	P_{90}	56.77	55.97	56.37 a	15.63	15.67	15.65 a	15.24	15.47	15.36
S_{30} Mean		47.54	50.01	48.78 A	15.10	15.19	15.15 B	13.70	13.99	13.84 A
Phosphorus mean										
P_0		38.58	38.61	38.59 c	13.95	13.98	13.97 c	12.54	13.31	12.90 c
P_{30}		42.08	43.16	42.62 b	15.08	15.12	15.10 b	13.83	14.20	13.36 bc
P_{60}		48.47	50.38	49.42 a	15.55	15.68	15.62 a	13.26	13.41	13.76 b
P_{90}		49.80	50.90	50.34 a	15.78	15.93	15.85 a	13.69	14.70	14.45 a
Means		44.73	45.76		15.09	15.18		13.47	13.76	
CV (%)			8.9			4.6			6.6	
Year (Y)			ns			ns			ns	
Sulfur (S)			**			**			*	
Phosphorus (P)			**			**			**	
SxP			**			**			ns	
SxPxY			ns			ns			ns	

S_0= Control, S_{10}= 10 kg ha^{-1} sulfur, S_{20}= 20 kg ha^{-1} sulfur, S_{30}= 30 kg ha^{-1} sulfur, P_0= Control, P_{30}= 30 kg ha^{-1} phosphorus, P_{60}= 60 kg ha^{-1} phosphorus, P_{90}= 90 kg ha^{-1} phosphorus, [1]: The difference between the means indicated by the same letter in the same column and group is not significant, CV: Coefficient of variation, ns: Not significant, *: $p<0.05$, **: $p<0.01$

Thousand-seed weight

The results of the statistical analysis showed that S doses had a significant effect on the thousand-seed weight at the $p<0.05$ level and P doses at the $p<0.01$ level. When *Table 4* was examined, the highest thousand-seed weight among S doses was

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determined at S_{20} (13.83 g) and S_{30} (13.84 g) doses. However, no statistically significant difference was determined between them and S_{10} (13.65 g) S dose (*Table 4*). Ramkishor and Kumawat (2015) stated that different doses of S applied to the fenugreek plant had significant effects on the thousand-seed weight, and that the application of 40 and 60 kg S per hectare increased the thousand-seed weight compared to control subjects. Srivastava et al. (2015) obtained the highest thousand-seed weight to be 13.75 and 13.76 g at the 40 and 80 kg ha^{-1} P doses, respectively. Tunçtürk et al. (2011) stated that the thousand-seed weight was significantly affected by S application in the first year and that the highest thousand-seed weight was obtained to be 18.8 g at dose of 40 kg ha^{-1}. The increased P doses increased the thousand-seed weight in the fenugreek plant. While the lowest thousand-seed weight was determined at P_0 dose (12.90 g), the highest thousand-seed weight was determined at P_{90} dose (14.45 g) (*Table 4*). Tunçtürk (2011) reported that P doses increased the thousand-seed weight, and the highest thousand-seed weight was obtained from 60 and 90 kg ha^{-1} P (17.8 g and 18.0 g) applications. The highest thousand-seed weight was determined by Sammuria and Yadav (2008) from 40 and 60 kg ha^{-1} P application (11.62 g and 11.74 g, respectively), and by Mitoo et al. (2018) to be 9.98 g from 40 kg ha^{-1} P application, which was the highest dose.

Seed yield

The variance analysis results showed that S and P doses and SxP interaction had significant effects on seed yield at the $p<0.01$ level (*Table 5*). When *Table 5* was examined, it was determined that the highest seed yield was obtained to be 2224 kg ha^{-1} from the $S_{30}P_{90}$ application, and the lowest seed yield was obtained to be 1038 kg ha^{-1} from the S_0P_0 application. As P and S doses increased, seed yield was determined to increase in fenugreek. In both fertilizer applications, the highest seed yields were determined at the highest fertilizer doses. As the mean of years and P doses, the highest fenugreek seed yield with the sulfur application was obtained to be 1822 kg/ha (S_{30}), and as the mean of years and S doses, the highest fenugreek seed yield in phosphorus fertilizer applications was obtained to be 1810 kg ha^{-1} (P_{90}) (*Table 5*). Many researchers stated that the phosphorus element is necessary for energy transfer in plants and that the yield, and above ground and root development of the plant are adversely affected in P deficiency or excess (Kacar and Katkat, 2007; Singh and Singh, 2016). Tunçtürk et al. (2011), Lal et al. (2015), Ramkishor and Kumawat (2015), Singh Manohar et al. (2017), and Verma et al. (2017) reported that increasing sulfur doses increase seed yield, and Halesh et al. (2000), Tunçtürk (2011), and Meena et al. (2012) reported that increasing phosphorus doses increase seed yield in the fenugreek plant.

Protein content

In the study, the effects of S and P doses on the protein content of fenugreek seed were found to be statistically significant ($p<0.01$). In terms of sulfur doses, as the mean of years and P doses, the highest protein ratio was determined at S_{30} (26.0%) dose and the lowest at S_0 (25.3%) dose. In terms of phosphorus doses, increasing P doses increased protein content in fenugreek, but statistically, P doses, except for P_0, were in the same group (*Table 5*). Baldaneeya Nitesh (2018) and Tunçtürk et al. (2011) stated that they determined the highest protein content at a dose of 40 kg ha^{-1} S. Mehta et al. (2012) reported that although increasing P doses increased protein content, there was no

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difference between 20 and 40 kg ha^{-1} P doses. Tunçtürk (2011) also reported similar results.

Table 5. *Means of yield, protein and trigonelline ratio at different sulfur and phosphorus doses in fenugreek*

S doses	P doses	Seed yield (kg ha^{-1})			Protein ratio (%)			Trigonelline ratio (%)		
		2017	2018	Mean*	2017	2018	Mean*	2017	2018	Mean*
S_0	P_0	1005	1071	1038 ı	24.6	25.1	24.9	0.78	0.83	0.81 ı
	P_{30}	1121	1241	1182 h	24.9	25.5	25.2	0.88	0.91	0.90 hı
	P_{60}	1323	1432	1378 fg	25.2	25.6	25.4	0.91	0.94	0.93 gh
	P_{90}	1520	1527	1523 de	25.5	25.8	25.6	0.93	0.95	0.94 efg
S_0 Mean		1242	1318	1280 D	25.1	25.5	25.3 C	0.89	0.88	0.89 D
S_{10}	P_0	1199	1246	1223 h	25.6	24.9	25.3	0.84	0.89	0.87 h
	P_{30}	1270	1327	1299 gh	25.8	25.2	25.5	0.87	0.89	0.88 h
	P_{60}	1462	1416	1439 ef	25.7	25.5	25.6	0.92	0.94	0.93 gh
	P_{90}	1501	1559	1530 de	25.8	25.7	25.8	0.94	0.96	0.95 ef
S_{10} Mean		1358	1387	1373 C	25.7	25.4	25.5 B	0.91	0.89	0.90 C
S_{20}	P_0	1234	1283	1259 gh	25.7	25.3	25.5	0.98	0.99	0.99 e
	P_{30}	1329	1374	1351 fg	25.9	25.6	25.8	1.09	1.12	1.11 c
	P_{60}	1661	1584	1622 cd	26.0	25.8	25.9	1.10	1.14	1.12 c
	P_{90}	1902	2027	1964 b	25.7	25.6	25.9	1.19	1.22	1.21 ab
S_{20} Mean		1531	1567	1549 B	25.8	25.7	25.8 B	1.09	1.12	1.11 B
S_{30}	P_0	1428	1430	1429 ef	25.7	26.1	25.9	1.04	1.06	1.05 d
	P_{30}	1692	1687	1690 c	26.0	26.2	26.1	1.16	1.19	1.18 b
	P_{60}	1898	1989	1944 b	26.0	26.4	26.2	1.20	1.23	1.22 ab
	P_{90}	2043	2405	2224 a	25.3	26.5	25.9	1.25	1.26	1.26 a
S_{30} Mean		1765	1879	1822 A	25.8	26.3	26.0 A	1.17	1.19	1.18 A
Phosphorus mean										
P_0		1217	1258	1237 d	25.4	25.4	25.4 b	0.91	0.94	0.93 c
P_{30}		1353	1408	1380 c	25.7	25.6	25.6 a	1.00	1.03	1.02 b
P_{60}		1586	1605	1596 b	25.8	25.8	25.8 a	1.03	1.06	1.05 b
P_{90}		1741	1879	1810 a	25.6	26.0	25.8 a	1.08	1.10	1.09 a
Means		1474	1538		25.6	25.7		1.02	1.04	
CV (%)		7.0			1.6			4.1		
Year (Y)		**			ns			ns		
Sulfur (S)		**			**			**		
Phosphorus (P)		**			**			**		
SxP		**			ns			**		
SxPxY		ns			ns			ns		

S_0= Control, S_{10}= 10 kg ha^{-1} sulfur, S_{20}= 20 kg ha^{-1} sulfur, S_3= 30 kg ha^{-1} sulfur, P_0= Control, P_{30}= 30 kg ha^{-1} phosphorus, P_{60}= 60 kg ha^{-1} phosphorus, P_{90}= 90 kg ha^{-1} phosphorus, *: The difference between the means indicated by the same letter in the same column and group is not significant, CV: Coefficient of variation, ns: Not significant, **: p<0.01

Trigonelline content

The effects of S and P doses and SxP interaction on the trigonelline content of fenugreek seeds were found to be significant at the p<0.01 level (*Table 5*). When *Table 5* was examined, the highest trigonelline content was determined in $S_{30}P_{90}$ (1.26%), but there was no statistically significant difference between $S_{30}P_{60}$ (1.22%) and $S_{20}P_{90}$ (1.21%). On the other hand, as both S and P doses increased, trigonelline content was observed to increase (*Table 5*). Kan et al. (2007) stated that applied different phosphorous fertilizer sources did not change the trigonelline content, that trigonelline

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content varied between 0.86-1.26%, and that ecological factors might be effective on the trigonelline content. Dar et al. (2015) reported that a 40 kg P ha^{-1} application increased the trigonelline content. Mutlu (2011) reported in the study conducted in fenugreek of different origins that the trigonelline content varied between 0.66-1.40%. The trigonelline content obtained in this study was higher than the values reported by Akgül (1993) (0.36%), Mehrafarin et al. (2010) (0.20-0.36%), and Mathur and Yadav (2011) (0.27%).

Relationships between the ınvestigated properties

The simple correlation coefficients showing linear relationships between the seed yield per plant and the investigated properties were presented in *Table 6*. The correlation analysis revealed that the seed yield was positively and significantly correlated with the number of pods per plant (r= 0.703**), pod length (r= 0.334**), the number of seeds per pod (r= 0.509**), and thousand-seed weight (r= 0.571**). Increases that occurred in these properties caused significant increases in the plant seed yield. The highest correlation coefficients in terms of seed yield were determined in the relationships between the number of pods per plant, the number of seeds per pod, and thousand-seed weight. Parchin et al. (2019) stated that there was a positive relationship between the number of pods per plant and seed yield.

Table 6. *Correlation coefficients related to pairwise relations between the seed yield and other properties*

	2	3	4	5	6	7
1. Plant height	0.274**	0.094	0.218*	0.243*	0.104	0.154
2. First pod height	-	0.280**	0.080	0.068	0.110	0.078
3. Number of pods per plant^{-1}		-	0.391**	0.478**	0.436**	0.703**
4. Pod length			-	0.343**	0.321**	0.334**
5. Number of seeds per pod^{-1}				-	0.299**	0.509**
6. Thousand-seed weight					-	0.571**
7. Seed yield						-

*: Significant at the p<0.05 level, **: Significant at the p<0.01 level

A positive and significant relationship was determined between plant height and the first pod height. Positive and significant relationships were detected between the number of pods per plant and pod length and between the number of seeds per pod and thousand-seed weight. Positive and significant relationships were found between the thousand-seed weight and the number of pods per plant and between pod length and the number of seeds per pod. The number of pods per plant was stated to be the most important factor affecting seed yield in many studies (Şehirali, 1980; Pooran-Chand, 1999; Amini et al., 2002; Kumar Singh et al., 2019, Singh et al., 2019), and finding the number of pods per plant as the most leading factor in this study supports the other literature on this subject.

Conclusions

This study, which was carried out under the ecological conditions of Siirt province located in the Southeastern Anatolia Region of Turkey, which has a semi-arid climate, revealed the importance of sulfur and phosphorus fertilizers when an evaluation was

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made in terms of yield and some quality criteria. Increased sulfur and phosphorus doses positively affected all of the investigated properties. When an evaluation was made in terms of yield and yield components, 30 kg S and 90 kg P doses could be stated to be suitable for per hectare. However, it was revealed that studies involving further increasing doses of both elements should be performed due to the linear increase determined in yield and quality properties in parallel to the increasing sulfur and phosphorus doses.

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