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Effect of Boron on Growth, Forage Yield and Quality of Some Legume Forage Crops

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ABSTRACT

Background: The objective of this study was to evaluate the effect of boron (B) fertilizer application on the growth, forage yield, quality and nutritive element content of legume forage crops.

Methods: The field experiment was conducted during season of 2023-24 at the Siirt University Faculty of Agriculture Research and Experiment Land, Türkiye. In the study, narbon vetch (*Vicia narbonensis* L.) (NV), forage pea [*Pisum sativum* ssp. *arvense* (L.) Poir.] (FP), berseem clover (*Trifolium alexandrinum* L.) (BC) and Persian clover (*Trifolium resupinatum* L.) (PC) species were examined. Treatments included five pureboron concentrations (0, 1, 2, 3 and 4 kg ha^{-1}) applied on before sowing. Boron experiments were set up separately for each legume species.

Result: Boron treatments increased legume forage crops species productivity relative to the control. When plant growth characteristics, forage yield and quality parameters were evaluated together, it was concluded that 1 kg ha^{-1} B application for NV and PC, 2 kg ha^{-1} B application for FP and BC were the most effective doses.

Key words: Berseem clover, Forage pea, Narbon vetch, Persian clover.

INTRODUCTION

The deficit of quality roughage is among the most important problems of agriculture in many countries. Forage crops grown in field agriculture are one of the most important sources of quality roughage. In cases where the area allocated to forage crops and production are insufficient, it is essential to obtain the highest yield and quality of fodder from the unit area. In this sense, cultural practices are an important factor in increasing the yield and quality per unit area. Within the scope of these applications, providing plants with appropriate amounts of the plant nutrients that are deficient is of great importance. For the development of plant resistance mechanisms and healthy plant development, macronutrients as well as microelements must be present in the soil in sufficient quantities and, more importantly, in an absorbable form. Therefore, as in many other crops, balanced plant nutrition practices should be given importance in order to increase the yield and quality of forage crops.

Today, the focus in animal husbandry is generally on high forage yield. Feed quality is of secondary importance. However, this situation not only causes significant problems in the nutrition of animals but also results in the production of poor quality animal products. For this reason, importance should be given to studies on plant nutrients to increase feed quality as well as feed efficiency. While research focuses more on macronutrients, microelements that play a role in many physiological processes in both plants and animals are neglected. This study is an original study in this sense.

Boron (B) is feeding the soil and the crops grown with B has gained great importance in cultivation systems where chemical fertilizers and high-yielding varieties are used intensively. Boron application is the second most important micronutrient in crop production after zinc and plays a critical role in plant growth and development (Safdar *et al*., 2023). Boron plays a role in cell wall formation, sugar transport, nucleic acid and carbohydrate metabolism and nitrogen (N) fixation in plants (Rahman *et al*., 2020; Ati *et al*., 2024). In addition, B has an effect on germination, flower formation, pollen formation, fruit set (Mathew *et al*., 2013; Panda *et al*., 2024), seed yield (Ullah *et al*., 2024) and dry matter (Nagar and Kumar, 2022) increase. Considering these functional functions of the B element in plants, forage crops, mostly used in their vegetative parts, can be affected positively or negatively depending on the dose applied from B used as fertilizer. Additionally, legumes are a plant group that is more sensitive to B deficiency. In some studies, it has been reported that B applications positively affect growth, yield and quality in soybean (Nagar and Kumar, 2022), groundnut (Kumar *et al*., 2022) and lentil (Nema *et al*., 2022). There are very limited number of studies on B application in forage legumes. From this perspective, this

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study examining the B responses of legume forage crops is the most comprehensive study.

While the uptake of B by plants depends on the physical (such as clay mineralogy, temperature and moisture) and chemical (such as soil B content, organic matter and pH) contents of the soil (Nagar and Kumar, 2022), responses to B fertilization may naturally vary among plant species, with some plants being more sensitive to B deficiency and toxicity than others. Moreover, the inadequate availability of B minerals in the soil may limit plant growth and also affect forage crops (Naik *et al*., 2025). Therefore, the responses of different legume forage plant species to B doses in the same ecology constitute another important unique value of this study. The aim of this study was to determine the effects of B fertilization applied at different doses on forage yield, quality and mineral content of different legume forage crop species in B deficient soil.

MATERIALS AND METHODS

The experiment was carried out in the 2023-2024 vegetation period in the Research and Experiment Land of the Faculty of Agriculture of Siirt University (37°58′13.20″N-41°50′43.80″E, 887 m), located in the Southeastern Anatolia Region of Türkiye, which has semi-arid climate conditions. During the period in which the research was conducted (December 2023-June 2024), the average temperature was recorded as 14.0°C and the total rainfall was 553.0 mm. The soil of experimental site was clay loam in texture, salt-free (electrical conductivity= 0.05 dS m^{-1}) and slightly alkaline (pH= 7.80) in reaction. The trial soils are in the calcareous class in terms of lime content (1.98%) and the organic matter content (0.60%) is very low. Soil was poor in available phosphorus (P) (55 kg P_2O_5 ha^{-1}), calcium (Ca) (1110 ppm) and B (0.82 ppm) while high in potassium (K) (440 kg K_2O ha^{-1}) and magnesium (Mg) (259 ppm). In the study, narbon vetch (*Vicia narbonensis* L. cv. Görkem) (NV), forage pea [*Pisum sativum* ssp. *arvense* (L.) Poir. cv. Özkaynak] (FP), berseem clover (*Trifolium alexandrinum* L. cv. Derya) (BC) and Persian clover (*Trifolium resupinatum* L. cv. Demet-82) (PC) species were examined. Etidot-67 (Disodium Octaborate Tetrahydrate, $Na_2B_8O_{13}.4H_2O$) with 20% pure B content was used as boron fertilizer.

The experiment was laid out in randomized block design consisting of 5 B doses treatment (B_0= 0, B_1= 1, B_2= 2, B_3= 3 and B_4= 4 kg ha^{-1}) with four replications. The field trial was planned and carried out separately for 4 plant species. Boron fertilizer was applied to the soil before sowing. In addition, nitrogenous (urea, 46% N) and phosphorous (triple super phosphate, 43-44% P_2O_5) fertilizers were applied to each plot in homogeneous amounts according to the soil analysis results before planting. During sowing, the sowing norm was applied as 100 live seeds per m^2 for NV and FP, 25 kg ha^{-1} for BC and 15 kg ha^{-1} for PC. Sowing of all species was done on December 20, 2023. Plants were harvested at full flowering stage (between April 30-June 2, 2024).

The number of days to flowering was calculated in days from the sowing date until the date when flowering was observed in 50% of the plants in the plot. Morphological measurements were made on 10 plants randomly selected from the 4 rows in the middle of each plot before harvesting. Natural plant height was determined by measuring the height between the soil surface and the top point of the plant, without disturbing the natural state of the plant or removing the plant. Natural plant height was measured on lodging-prone NV and FP plants. For plant height, the distance from the soil surface to the top of the plant was measured. Plant height measurements were made on BC and PC, which have no lodging problems. The main stem length was determined by lifting and straightening the plant and measuring the distance between the soil level of the main stem and the tip of the main stem with the help of a meter. The main stem length was also determined in plants whose natural plant height was measured. Main stem thickness was measured with a digital caliper 10 cm above the soil surface. Green forage yield was determined by mowing and weighing the remaining part of each plot after removing the edge effects and green forage yields per hectare were determined by taking into account the harvest area. At the end of the cutting, a random sample of 500 g green fodder was taken from each plot in a paper bag and dried in sun and then in an oven for final drying at a temperature of 65°C to a constant dry weight. Hay yields per hectare were determined by determining the dry herbage ratio of the dried herbage samples and multiplying it by the green forage yields of the parcels. Forage quality analyses such as crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), P, K, Ca and Mg were determined using the #IC-0904FE calibration set (WinISI, 2024) with the Near Infrared Reflectance Spectroscopy device (Brogna *et al*., 2009). The CP yield (kg ha^{-1}) was calculated by multiplying the CP content (%) with hay yield. Relative feed value (RFV) was determined according to the method reported by Van Dyke and Anderson (2000). The classification reported by Rohweder *et al*. (1978) was used to evaluate the quality grade of the forage according to the CP, ADF, NDF and RFV data determined in the dry matter of legume species.

Variance analysis was performed on the obtained data according to the randomized complete block design, separately for each forage legume species (Yurtsever, 1984).

RESULTS AND DISCUSSION

Yield attributes and forage yield

The number of flowering days did not vary according to B doses in legume forage plant species. The flowering date of 50% of the plants in the plot was recorded as May 15, 2024 in NV, April 28, 2024 in FP, April 26, 2024 in BC and May 26, 2024 in PC.

The growth and yield of forage legume species were generally significantly affected by B doses. Data regarding to the yield attributes and yields of NV, FP and BC species were significantly increased with increasing levels of B up to 2 kg ha^{-1}. However, the effect of B doses on PC was seen starting from 1 kg ha^{-1} dose. The highest values in terms of natural plant height in NV and FP species (47.0 and 86.1 cm, respectively) and plant height in BC (82.6 cm) were determined at the B_2 dose. Unlike these three species, the highest plant height in PC was determined at B_1 and B_2 doses; however, the difference between these doses and the control and B_3 doses was insignificant. The highest main stem length in the NV was determined at the B_2 dose with 71.7 cm, while in the FP, it was determined at the B_2 (110.4 cm) and B_3 (109.1 cm) doses. The effect of B doses on main stem thickness was significant ($p<0.05$) in FP and BC, while NV and PC were not affected by B doses. The highest stem thickness was determined at B_2 dose (4.25 mm) in FP and B_3 dose (4.47 mm) in BC (Table 1).

The highest green forage yield was determined in the NV, FP and BC at the B_2 dose (16903, 46373 and 23583 kg ha^{-1}, respectively), while in PC, it was obtained at the B_1 (11945 kg ha^{-1}) and B_2 (11795 kg ha^{-1}) doses. The lowest green forage yields were found in NV and PC at B_4 doses and in other species at B_0, B_1, B_3 and B_4 doses. Hay yield showed the same pattern as that of green forage yield. The highest hay yield was obtained in NV at B_1 (3093 kg ha^{-1}), B_2 (3243 kg ha^{-1}) and B_3 (3167 kg ha^{-1}) doses, while it was determined as B_2 treatment (7911 and 5932 kg ha^{-1}, respectively) for FP and BC and B_1 (2660 kg ha^{-1}) and B_2 (2578 kg ha^{-1}) doses for PC. The lowest hay yield was determined as B_0 and B_4 for NV, B_0, B_1, B_3 and B_4 for FP and BC and B_4 for PC (Table 1).

Boron determines plant growth and yield by influencing various physiological processes, including pigment

Table 1: Effect of B on plant growth attributes and forage yield of legume forage plant species.*

Boron levels (kg ha^{-1})	Natural plant height (cm)	Main stem length (cm)	Main stem thickness (mm)	Green forage yield (kg ha^{-1})	Hay yield (kg ha^{-1})
		Narbon vetch			
B_0	31.5d	46.4d	3.36	14590c	2812b
B_1	40.6b	53.0c	3.76	16073b	3093a
B_2	47.0a	71.7a	3.76	16903a	3243a
B_3	38.6bc	61.3b	3.67	16548ab	3167a
B_4	37.0c	56.6c	3.52	13648d	2627b
Mean	38.9	57.8	3.61	15552	2988
P value	0.0001	0.0001	0.592	0.0001	0.0003
		Forage pea			
B_0	71.7c	94.4c	4.03abc	41792b	6801b
B_1	76.8bc	107.0ab	4.19ab	43017b	7155b
B_2	86.1a	110.4a	4.25a	46373a	7911a
B_3	83.4ab	109.1a	3.80c	41352b	6867b
B_4	81.0ab	98.7bc	3.98bc	41075b	6704b
Mean	79.8	103.9	4.05	42722	7087
P value	0.020	0.010	0.023	0.007	0.001

	Plant height (cm)	Main stem thickness (mm)	Green forage yield (kg ha^{-1})	Hay yield (kg ha^{-1})
		Berseem clover		
B_0	72.8b	3.30c	17558b	4193b
B_1	78.0ab	3.92abc	19185b	4628b
B_2	82.6a	4.28ab	23583a	5932a
B_3	74.1b	4.47a	18018b	4294b
B_4	73.6b	3.55bc	17180b	4202b
Mean	76.2	3.90	19105	4650
P value	0.009	0.039	0.005	0.0007
		Persian clover		
B_0	53.1ab	4.83	9074b	2024bc
B_1	55.9a	4.99	11945a	2660a
B_2	56.2a	5.42	11795a	2578a
B_3	53.6ab	4.97	8908b	2068b
B_4	47.0b	4.76	7548c	1692c
Mean	53.2	4.99	9854	2205
P value	0.013	0.105	0.0001	0.001

*: The difference between means indicated with the same letter in the same group is not statistically significant.

contents. Boron fertilization significantly increased the forage yield and yield-effective plant growth parameters in all species considered in the present study compared to the control. These effects of the B element varied according to some species. It was also reported by Rodrigues *et al*. (2024) that B requirements differ among species. When the forage yield and growth factors were evaluated together, 2 kg ha^{-1} B application gave the highest values in NV, FP and BC species, while PC responded positively to B application up to 1 kg ha^{-1} dose. The positive effect of B on growth characteristics and forage yield may be due to its role in cell elongation, nitrogen fixation capacity, formation of meristematic tissues, transport of sugars, photosynthesis and carbohydrate metabolism and nucleic acid synthesis (Rahman *et al*., 2020; Abdelwanis *et al*., 2022). The beneficial effect of B on yield was consistent with the results of others in BC (Sidhu and Kumar, 2018), alfalfa (Taherian *et al*., 2019), sainfoin (Chen *et al*., 2024) and grass pea (Sayed *et al*., 2024).

Providing B in appropriate doses has a positive and significant effect on plant growth, development and yield as it positively promotes physiological events in the plant. Excessive application of B may cause deterioration in meristematic tissues and deformations in plant development. In fact, it was observed that the forage yields decreased significantly in the B_4 dose in the NV and in the B_3 dose in the FP, BC and PC. Similar finding was reported Sheoran (2020) and Petrová and Soudek (2022). The different responses to B in the species considered in the present study indicate that there is a very narrow range between B deficiency and toxicity, as stated by Al-Amery and Khrbeet (2025). Therefore, application B requires careful consideration. Because available B in the soil that is deficient in one crop may have toxic effects on another crop (Geng *et al*., 2023).

Forage nutritive value and mineral content

CP, ADF and NDF concentrations are the main quality indicators of roughage. In the present study, the CP content

Table 2: Effect of B on some forage quality parameters of legume forage plant species.*

Boron levels (kg ha^{-1})	CP (%)	CP yield (kg ha^{-1})	ADF (%)	NDF (%)	RFV
		Narbon vetch			
B_0	21.60ab	606.8b	29.77	37.83	162.3
B_1	22.91a	707.9a	29.46	38.32	161.0
B_2	21.64ab	700.9a	28.75	39.19	157.8
B_3	21.13b	668.9a	28.25	39.52	157.9
B_4	20.87b	548.4c	28.17	39.86	156.8
Mean	21.63	646.6	28.88	38.94	159.2
P value	0.047	0.0002	0.679	0.786	0.968
		Forage pea			
B_0	23.57	1604.0c	27.92	38.40	162.9
B_1	25.24	1810.0b	27.83	36.45	172.0
B_2	25.65	2030.0a	27.36	36.06	174.7
B_3	24.31	1670.0bc	27.10	35.94	176.2
B_4	24.25	1625.0bc	26.94	35.26	179.7
Mean	24.60	1748.0	27.43	36.42	173.1
P value	0.133	0.003	0.707	0.324	0.386
		Berseem clover			
B_0	18.28	765.9b	32.02	41.54	143.3
B_1	18.72	865.9b	31.85	40.93	145.7
B_2	18.74	1113.0a	32.01	41.62	143.1
B_3	18.92	811.5b	31.96	41.84	143.4
B_4	17.93	753.4b	31.84	41.14	145.2
Mean	18.52	861.9	31.94	41.41	144.1
P value	0.523	0.001	0.999	0.972	0.992
		Persian clover			
B_0	21.97	445.2bc	28.67	33.77	183.4
B_1	22.33	593.5a	29.22	34.54	178.2
B_2	22.09	570.4a	29.02	34.60	178.4
B_3	22.06	455.9b	28.22	34.77	179.1
B_4	22.03	372.8c	28.17	34.82	178.9
Mean	22.10	487.6	28.66	34.50	179.6
P value	0.767	0.0003	0.099	0.265	0.412

*: The difference between means indicated with the same letter in the same group is not statistically significant.

of NV species was significantly ($p<0.05$) affected by B applications, while the effect of B was insignificant in other species. The highest CP content in the NV species was determined at the 1 kg ha^{-1} B dose (22.91%). Crude protein of this plant decreased significantly, especially after the B_2 dose (Table 2). The results obtained by Dhassi *et al*. (2021) in alfalfa support the current research findings. Additionally, Nema *et al*. (2022) reported that increases in protein content were achieved with boron application. This positive effect according to control in NV plant of B can be explained by the fact that boron, an essential component of RNA, plays a role in ribosome production and therefore protein synthesis. The role of B in protein synthesis was also reported by Akshit *et al*. (2020). CP levels of other species varied between 17.93% and 25.65% (Table 2). Values of forage protein concentrations vary considerably depending on species, soil fertility and plant maturity (Newman *et al*., 2006). When these CP values determined according to B doses are compared with the values requested for alfalfa (18-25%) (Newman *et al*., 2006), it can be said that they are in the sufficient protein range.

From the results of this study, it was evident that B application greatly affected the CP yield of legume species. The highest CP yield were determined at B_1 (707.9 kg ha^{-1}), B_2 (700.9 kg ha^{-1}) and B_3 (668.9 kg ha^{-1}) doses in NV, B_2 (2030.0 and 1113.0 kg ha^{-1}, respectively) in FP and BC and B_1 (593.5 kg ha^{-1}) and B_2 (570.4 kg ha^{-1}) doses in PC (Table 2). Maximizing yield due to B application in the plant, boron which helps protein synthesis also maximizes protein yield. In terms of CP yield similar findings were observed in fodder sorghum by Verma *et al*. (2021) and in lentil by Nema *et al*. (2022).

Quality parameters such as ADF and NDF ratio were not affected by B applications in all species considered (Table 2). The RFV is an index representing forage quality (Newman *et al*., 2006). In the present study, the variation in

Table 3: Effect of B on the mineral content of legume forage plant species (%).*

Boron levels (kg ha^{-1})	P	K	Ca	Mg
		Narbon vetch		
B_0	0.36	3.14	1.34c	0.35
B_1	0.36	3.22	1.42a	0.36
B_2	0.36	3.23	1.42a	0.35
B_3	0.36	3.19	1.40ab	0.35
B_4	0.34	3.17	1.37bc	0.36
Mean	0.35	3.19	1.39	0.35
P value	0.220	0.590	0.013	0.875
		Forage pea		
B_0	0.41	3.31	1.33	0.26
B_1	0.44	3.34	1.37	0.26
B_2	0.43	3.34	1.38	0.27
B_3	0.42	3.36	1.38	0.26
B_4	0.42	3.27	1.37	0.27
Mean	0.42	3.32	1.36	0.26
P value	0.279	0.857	0.625	0.378
		Berseem clover		
B_0	0.31	2.08 b	1.51	0.26
B_1	0.31	2.26 a	1.52	0.25
B_2	0.31	2.09 b	1.53	0.24
B_3	0.31	2.06 b	1.54	0.24
B_4	0.31	2.06 b	1.51	0.24
Mean	0.31	2.11	1.52	0.25
P value	0.920	0.0006	0.907	0.329
		Persian clover		
B_0	0.36	2.60	1.83	0.36
B_1	0.36	2.71	1.83	0.36
B_2	0.37	2.75	1.80	0.35
B_3	0.36	2.67	1.81	0.35
B_4	0.36	2.55	1.83	0.35
Mean	0.36	2.66	1.82	0.35
P value	0.145	0.139	0.147	0.906

*: The difference between means indicated with the same letter in the same group is not statistically significant.

RFV according to boron doses was also found to be insignificant (Table 2). Similar findings were also reported by Konuşkan *et al*. (2020).

It is a well-known fact that animal feed must contain sufficient protein to maintain the health of animals. ADF, composed of lignin and cellulose and NDF, composed of hemicellulose, cellulose and lignin, are important indicators of feed fiber (Rohweder *et al*., 1978). The higher the percentage of ADF and NDF, the lower the value of CP that leads towards lower fodder quality (Atique-ur-Rehman *et al*., 2022). According to the classification reported by Rohweder *et al*. (1978), the species of NV, FP and PC produced forage of the "best quality" class, while BC produced forage of the "very good" class in terms of CP, ADF, NDF and RFV. Therefore, B deficiency or excess did not reduce the forage quality of the species considered.

The relationship between B and other elements is a very interesting subject in terms of plant nutrition. In the present study, B application had no significant effect on the mineral content of legume species except Ca ($p<0.05$) content of NV and K ($p<0.01$) content of BC. In the NV, Ca concentration increased significantly at B_1 and B_2 doses compared to the control and then tended to decrease. While a significant increase was detected in terms of K in the B_1 dose in BC compared to the control, other doses were in the same statistical group as the control subject. Although insignificant, changes in K and Ca in other species also showed a similar trend (Table 3). The decrease in K and Ca in plants after a certain dose can be explained by the toxic effect of B at high doses. Similar findings were reported by Kaya and Ashraf (2015) and El-Shazoly *et al*. (2019). The fact that B concentration does not have a significant effect on P and Mg accumulation can be explained by the fact that the plants were grown under optimum P conditions and that Mg in the soil was at sufficient levels. Dhassi *et al*. (2021) reported that B application had no significant effect on P, K, Ca and Mg absorption in alfalfa. While some research reports express an antagonistic relationship between B and P (Long and Peng, 2023), another report mentions a synergistic relationship (Masood *et al*., 2019). However, the B x P interaction is not yet clear (Vera-Maldonado *et al*., 2024). Similar inconsistent reports have also been reported regarding the interaction of B and Mg (Long and Peng, 2023). The interactions of B with P, K, Ca and Mg in forage plants have not been researched much. Current information does not allow the formulation of concrete hypotheses on B-macro element interactions. Further studies are needed on this subject.

Macro minerals are essential for growth and reproduction of the livestock (Talukdar *et al*., 2016). Therefore, the adequacy of roughage in terms of mineral elements is also an issue that needs to be examined. It is reported that the amounts of Ca, P and K in feeds used in rations for ruminants should be at least 0.90, 0.40 and 1.00%, respectively (Muller, 2009) and Mg should be 0.25% (NRDC, 2001). According to these limit values in the literature, while Ca, K and Mg values were at a level sufficient to meet the needs in all species, P levels were found to be insufficient in the species of NV, BC and PC.

CONCLUSION

When plant growth characteristics, forage yield and quality parameters were evaluated together, it was concluded that 1 kg ha^{-1} B application for NV and PC, 2 kg ha^{-1} B application for FP and BC were the most effective doses. Even when all other conditions such as irrigation and fertilization are at optimum levels, micro-level B applications have proven to be productive and beneficial. Therefore, it is essential to provide plants with sufficient amounts of B for optimum production under different conditions. Nowadays, in order to increase the feed efficiency per unit area, soil analyses must be carried out and fertilization programs must be arranged and when micro elements such as B are deficient, B applications must be evaluated by taking into account the differences between plant species. Similar studies are needed for different forage crop species and different soils in the future.

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Conflict of interest

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