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Research article

Efficiency of phosphorus and nitrogen fertilization on improving steppe rangeland in semi-arid ecology

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Abstract

In this study, the effects of phosphorus and nitrogen fertilization on the successful improvement of a semi-arid steppe rangeland were recorded, which was in fair condition. The study was conducted in 2017 by using a 50 kg ha^{-1} P_2O_5, and different dosages (30, 60, 90, 120 kg ha^{-1}) of nitrogen fertilizers and observations were recorded during 2018-2019 (2 years). Dry matter yield and forage quality parameters such as crude protein, neutral and acid detergent fiber contents were recorded to evaluate the performance of rangelands. All the fertilizers significantly increased dry matter yield; it was nearly doubled when P_2O_5 was applied and tripled when 90 or 120 kg ha^{-1} nitrogen was applied. Crude protein (CP) content was also affected by the fertilizers, but the effect of nitrogen was greater on CP content, which was four times higher (33.5–129.3 kg ha^{-1} CP) under 120 kg ha^{-1} nitrogen application when compared to a control group. Phosphorus slightly affected NDF content but had no significant effect on ADF content. Nitrogen fertilization did not affect NDF content but the ADF content was slightly decreased. Results indicated both phosphorus and nitrogen fertilization increased the yield and quality of forage. Hence, semi-arid steppe rangelands, which are in fair condition, need to be fertilized using 50 kg ha^{-1} phosphorus and 60 to 90 kg ha^{-1} nitrogen to improve their performance.

Keywords: Fertilization, Forage quality, Forage yield, Rangeland improvement, Semi-arid

Introduction

The climate-based reasons such as drought, rising temperature, and CO_2 elevation could cause significant variations in rangeland ecosystems, including vegetation, and it is almost impossible to avoid interference (Polley *et al*., 2013; Holechek *et al*., 2020). Human impact is mostly due to allowing heavy grazing by animals, which degrades rangeland vegetation and consequently could cause a significant decrease in desirable plant density and production, carrying capacity, plant reproduction, and an increase in soil erosion (Zhao *et al*., 2007; Surmen and Koc, 2016; Pulido *et al*., 2018; Husain *et al*., 2019, Shinde and Mahanta, 2020). Vegetation is developed under the effect of grazing pressure along with climate and soil characteristics (Gokkus, 2020). Therefore, any changes in one of these factors significantly affect the vegetation positively or negatively depending on the movement shift (Khojasteh *et al*., 2022; Yildiz and Cacan, 2023). Improving degraded rangeland vegetation is harder in arid and semi-arid regions, and researchers all over the world reported this problem (Havstad *et al*., 2007; Holechek *et al*., 2011; Li *et al*., 2013; Louhaichi *et al*., 2016; Mureithi *et al*., 2016; Gokkus, 2020). Suggestions include ceasing heavy grazing and then enabling the recovery of vegetation naturally. However, using proper range improvement techniques could accelerate the recovery processes (Holechek *et al*., 2011; Ram and Sannagoudar, 2023). Rangeland improvement methods consist of many techniques, such as reseeding, burning, fertilization, aeration, irrigation, tilling, etc. Fertilization, especially phosphorus and nitrogen, is widely used among other techniques for the improvement of degraded vegetation (Snyman, 2002; Mut *et al*., 2010; Carpici, 2011). Depending on the annual precipitation, the yield of rangeland is increased through fertilization (Comakli *et al*., 2005; Koc *et al*., 2005; Balabanli *et al*., 2010; Mut *et al*., 2010). Besides, forage quality (Wallace *et al*., 2019), soil microbial activity (Kowaljow *et al*., 2010), and species richness (Laliberte *et al*., 2010) are increased by fertilization in rangelands. For example, phosphorus fertilization enhances the growth of legumes (Snyman, 2002) and significantly increases the yield of rangeland (Zhou *et al*., 2016). Johnson *et al*. (2001) determined a 129% increase in forage yield by the fertilization of rangeland with an amount of 78 kg ha^{-1} nitrogen. However, fertilizers may negatively affect the botanical composition. Aydin and Uzun (2005) reported that the legume ratio was decreased by nitrogen fertilization, which consequently changed crude protein content negatively.

In Central Anatolia, overgrazing has a long history and therefore, most of the rangelands are degraded. Moreover, extreme droughts have great adverse pressure on the vegetation. Indeed, there were significant reductions in forage quality and yields at the regional rangelands. This study aimed to record the effects of phosphorus and nitrogen fertilization on improving the steppe rangelands under moderate conditions, where arid and semi-arid conditions prevail, such as the rangelands in Central Anatolia.

Materials and Methods

***Study area*:** The experiment was conducted at Aslanbeyli rangeland of Eskisehir district, Türkiye (Fig 1). The rangeland is located at an altitude of 1075 m above sea level, and semi-arid climatic conditions prevail in the region. Vegetation is typical steppe vegetation; it mostly consists of perennial grass species (i.e., *Festuca valesiaca*) and some invasive species, such as *Asphodeline taurica*. Rangeland's condition was determined in 2016 as 'fair' using the transects method and the experimental area was fenced to control animal grazing to avoid the grazing effects. Small ruminants mostly graze the rangeland.

***Soil characteristics and meteorological data*:** At the beginning of the experiment, the soil samples were taken from a depth of 0 to 30 cm and the soil characteristics were determined at the laboratory of the Research Institute for Forest, Soils and Ecology. According to the report, the

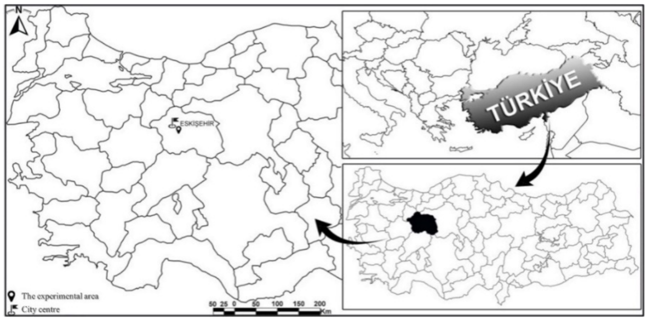

Fig 1. Location of the experimental area in the region

soil was loamy, pH was 8.38, lime content was 20%, and nitrogen and phosphorus contents were 0.12% and 10.87 ppm, respectively. Soil salinity was < 2 mS cm^{-1} and the organic matter content was 2.16%. Meteorological data were obtained from Seyitgazi Meteorological Station, which is in the range of 7 km from the experimental area. Annual total precipitation was 404.8 and 360.8 in the years of 2018 and 2019, respectively. The long-term average (LTA) of annual precipitation was 352.6 mm. Annual temperature averages were 12.1 and 11.8ºC in 2018 and 2019, but the LTA was lower (10.1ºC) when compared to the experimental years.

Experimental method: The area was fenced in 2016, before setting up the experiment to avoid the effect of grazing. The experiment was established using a split-plot arrangement in a randomized complete block design with three replications. While main plots consisted of two doses of phosphorus (0 or 50 kg P_2O_5 ha^{-1}) as triple super phosphate form, subplots consisted of five doses of nitrogen (0, 30, 60, 90, and 120 kg N ha^{-1}) as ammonium sulfate. In the early spring of 2017, triple super phosphate (TSP 42% P_2O_5) was applied to the main plots, and nitrogen fertilizer was applied as urea at the end of April when the vegetation growth started. Sampling was carried out in June for both years by clipping 1-m^2 area of every plot when the common grasses were in the blooming stage. Clipped samples were oven-dried at 60ºC until they reached constant weight and then weighed to determine the dry matter production. These dry samples were used to determine forge quality characteristics such as NDF, ADF contents, and CP yield. NDF and ADF contents were determined using an ANKOM fiber analyzer. For CP yield, firstly nitrogen concentrations of the samples were determined in the Kjeldahl method and multiplied by 6.25 for CP content estimation. After that, crude protein yield was obtained by multiplying the CP content and dry matter yield.

***Statistical analysis*:** All data were subjected to analysis of variance in the mixed model for repeated measurements in SAS statistical software (SAS Institute, 2011). The year factor was considered random in the analysis and the means were compared using the Tukey test.

Results and Discussion

Dry matter yield: On an average, dry matter yield was 921.1 kg ha^{-1} and it did not change significantly between the years (Table 1). Phosphorus fertilization increased dry matter yield by nearly 50% and this variation was statistically significant (p <0.01). Nitrogen fertilization gave better results in dry matter yield and the highest yields were recorded at 90 and 120 kg ha^{-1} nitrogen fertilization (1220.9 and 1242.0 kg ha^{-1}, respectively).

Table 1. Yield and quality characteristics of rangeland under different improvement methods

Attributes	DM yield (kg ha^{-1})	CP yield (kg ha^{-1})	NDF (%)	ADF (%)
Year (Y)				
2018	903.9	90.3^{A}	61.7	38.9^{B}
2019	938.4	74.0^{B}	61.2	40.3^{A}
P_2O_5 (P)				
0 kg ha^{-1}	660.7^{B}	61.3^{B}	59.2^{B}	39.7
50 kg ha^{-1}	1181.5^{A}	103.0^{A}	63.7^{A}	39.5
Nitrogen (N)				
Control	484.3^{C}	33.5^{D}	61.4	40.8^{A}
30 kg ha^{-1}	786.4^{B}	57.9^{C}	63.9	40.8^{A}
60 kg ha^{-1}	872.0^{B}	73.5^{B}	61.3	39.3^{B}
90 kg ha^{-1}	1220.9^{A}	116.5^{A}	59.3	38.8^{B}
120 kg ha^{-1}	1242.0^{A}	129.3^{A}	61.2	38.2^{B}
Mean	***921.1***	***82.1***	***61.4***	
ANOVA				
Y	ns	**	ns	**
P	**	**	**	ns
N	**	**	ns	**
Y*P	*	ns	ns	ns
Y*N	*	**	ns	ns
P*N	**	**	ns	*
Y*P*N	**	**	ns	ns

*(p <0.05); **(p <0.01); ns: Variance was not statistically significant

Three-way interaction was statistically significant because dry matter yield was differently increased by the application of fertilizer compared to sole applications in both years.

Precipitation is the most important factor in a dry environment in determining plant production in the rangelands (Polley *et al*., 2013; Palacio *et al*., 2014; Holechek *et al*., 2020). Especially drought and high temperatures could cause significant inter-annual variations. Koc (2001) recorded that dry matter (DM) production could be half in dry years at high-elevation rangelands of Türkiye. However, DM production did not change significantly between the experimental years in the present study because a similar climatic trend prevailed in both years and there was not any significant precipitation or temperature differences between the years.

Phosphorus fertilization (50 kg ha^{-1}) significantly increased DM production by more than 400 kg ha^{-1}. Other researchers also indicated a significant increase in DM production with phosphorus fertilization (Harpole *et al*., 2011; Mulloy *et al*., 2021). This probably originated from the response of forbs to the interactive effects of phosphorus and nitrogen. Since the soils of the experimental site were poor in phosphorus, forbs, especially legumes, were highly responsive to phosphorus (Aydin and Uzun, 2005; Henkin *et al*., 2010). Forbs consisted of about half of the botanical composition in the site. Again nitrogen use efficiency was also increased as the availability of phosphorus increased (Snyman, 2002; De Groot *et al*., 2003).

Nitrogen fertilizing is another method to improve rangeland conditions and DM production (Aydin and Uzun, 2005; Jaurena *et al*., 2016). Especially 90 and 120 kg ha^{-1} N fertilizing resulted in more than 150% increment in DM yield when compared to the control plots. This was an expected result because it is known that nitrogen fertilization stimulates the growth of grasses in rangeland (Holechek *et al*., 2011). Specifically, 120 kg ha^{-1} N fertilization boosted DM yield in 2018 due to higher precipitation (Fig 2) and the compensatory effect of phosphorus on nitrogen uptake (De Groot *et al*., 2003; Chen *et al*., 2017).

CP yield: Mean CP yield was 60.69 kg ha^{-1} and it significantly varied between years (p < 0.01), with P and N fertilizations (p < 0.01). Three-way interaction

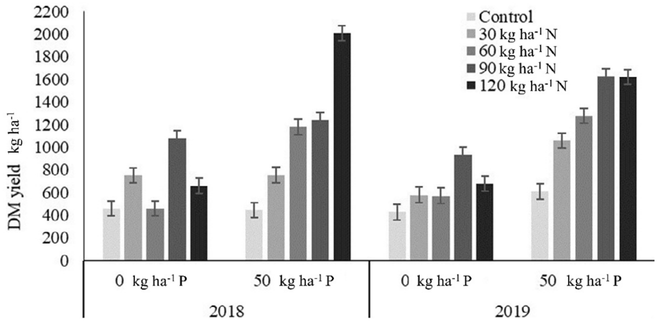

Fig 2. Three-way interaction for dry matter yield

was also significant ($p < 0.01$) (Table 1). CP yield was 90.3 kg ha^{-1} in 2018, but it significantly decreased to 74.0 kg ha^{-1} in the second year. Phosphorus fertilization (50 kg ha^{-1}) showed a 41.7 kg ha^{-1} increment in the CP yield. It was observed that CP yield increased as the nitrogen fertilization increased and the highest CP yields (129.3 and 116.5 kg ha^{-1}) were recorded when 90 and 120 kg ha^{-1} N were applied, respectively. While CP yield differences were quite higher in the plots that received 120 kg ha^{-1} N compared to the plots that received 90 kg ha^{-1} N and 50 kg P_2O_5, this huge difference disappeared in the second year (Fig 3). This was responsible for the three-way interaction.

The main determinant factor in CP yield was DM yield (Table 1), because CP yield was comprised of multiplying CP content and DM yield. The compensatory effect of phosphorus on nitrogen uptake (Chen *et al*., 2017) was more pronounced in the first year (Fig 3), possibly due to the positive effect of higher precipitation. This caused a three-way interaction for CP yield. Guevara *et al*. (2000) also recorded a similar effect of precipitation on P+N fertilizing in semi-arid rangelands.

NDF and ADF contents: Neutral detergent fibre (NDF) content was significantly increased by P fertilization (p <0.01), but no significant variations were observed between the years, by fertilizing, and for their interactions (Table 1). Mean NDF content was 61.4% and phosphorus fertilization increased it from 59.2 to 63.7% (Table 1). NDF content also varied between 59.3- 63.9% among nitrogen

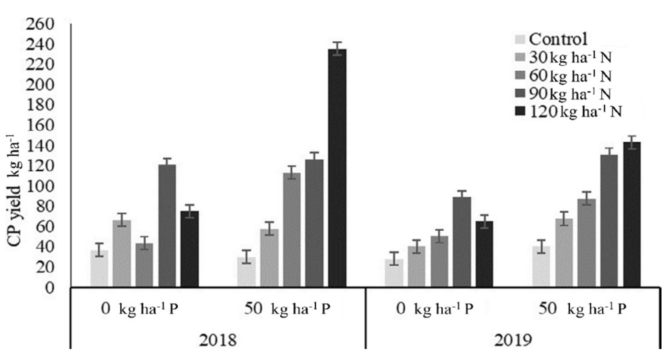

Fig 3. Three-way interaction for crude protein yield

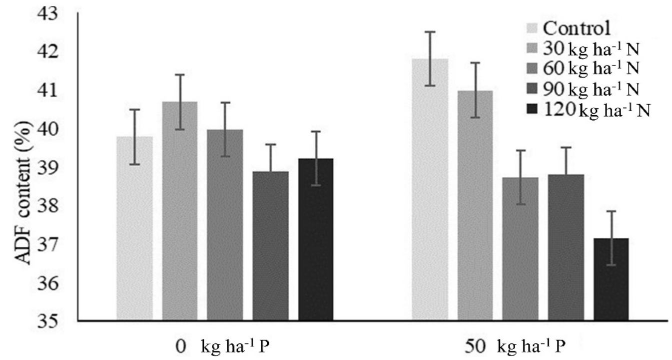

Fig 4. Phosphorus × nitrogen interaction for ADF content

applications but this variation was not significant statistically. Mean ADF content was 38.9% in 2018 and it significantly increased (p <0.01) to 40.3% in 2019 (Table 1). Phosphorus fertilization did not affect the ADF content of the rangeland hay significantly. The lowest ADF content was 38.2% and it was observed at 120 kg ha^{-1} N fertilization. ADF content showed inconsistent response to combinations of phosphorus and nitrogen fertilization (Fig 4), but P × N interaction was significant (p <0.05) (Table 1).

Changes in climatic factors affect plant production and chemical content (Severoglu and Gullap, 2020; Larsen *et al*., 2021). In the first year, the study area received more precipitation than second year. The higher precipitation might be responsible for lower ADF content since more precipitation increased young plants/tissues in the vegetation and the ADF content of young plants/tissues was much lower than the old ones (Mountousis *et al*., 2008; Koc *et al*., 2014). However, NDF content was not affected significantly by the inter-annual climatic variations of the year 2018 and 2019. While phosphorus fertilization did not affect fiber content, ADF content significantly decreased with the application of 60 kg ha^{-1} N and more (Table 1). This situation was probably related to young tissue production as fertilizer promoted new tissue production and young tissues had lower fiber content compared to old tissues (Collins and Fritz, 2003). The positive effect of increasing nitrogen rates on ADF content was more prominent by phosphorus fertilization (Fig 4) and this effect indicated P × N interaction.

Conclusion

Phosphorus and nitrogen fertilization both positively affected forage production and quality. These increments nearly reached up to 3-4 folds for DM and CP yields. Even if the digestibility of rangeland dry matter is increased by phosphorus and nitrogen fertilization, this increment will be profitable only with more precipitation. This indicated that climatic conditions had an important role in the effect of fertilization on rangeland improvement. Dosages of 50 kg ha^{-1} P_2O_5 and 60 to 90 kg ha^{-1} N could be suggested for semi-arid steppe rangelands, which are in fair condition, mostly consisting of grass species and need to be improved sustainably. However, further studies are required to understand the efficiency of these improvement methods under changing precipitation patterns.

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