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# TURKISH JOURNAL OF RANGE AND FORAGE SCIENCE

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## Aims and Scope

Turkish Journal of Range and Forage Science is the official publication of Society of Rangeland and Forage Science. The Journal is dedicated to publishing quality original material that advances rangeland management and forage crops production.

Turkish Journal of Range and Forage Science is a peer-reviewed, international, electronic journal covering all aspects of range, forage crops and turfgrass management, including the ecophysiology and biogeochemistry of rangelands and pastures, terrestrial plant–herbivore interactions, rangeland assessment and monitoring, effects of climate change on rangelands and forage crops, rangeland rehabilitation, rangeland improvement strategies, conservation and biodiversity goals. The journal serves the professions related to the management of crops, forages and grazinglands, and turfgrass by publishing research, briefs, reviews, perspectives, and diagnostic and management guides that are beneficial to researchers, practitioners, educators, and industry representatives.

## Publication Date and Subscription Information

*Turkish Journal of Range and Forage Science* is published twice a year (June and December) as online.

## SOCIETY OF RANGE AND FORAGE SCIENCE

# TURKISH JOURNAL OF RANGE AND FORAGE SCIENCE

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The author(s) that submit an article to the Turkish Journal of Range and Forage Science consider accepting of these peer review conditions and procedures.

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# Determination of The Effects on Silage Quality of Different Additives Added to Vetch-Triticale Silage Mixture

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A B S T R A C T

This research was conducted at Sakarya University of Applied Sciences, Faculty of Agriculture's Field Crops Laboratory. The aim of the study is to determine the effects of three different silage additives (molasses (M), whey (W), and citrus pulp (CiP)), added to pure and mixtures of common vetch (*Vicia sativa* L.)+triticale (*xTriticosecale* Wittmack) in different proportions on silage quality. The plant materials under investigation were mixed in ratios of 25%, 50%, 75% and 100%. Silages and mixtures were established with three replications, and three different silage additives were applied to each mixture. These additives included 4% molasses, 3% whey, and 2% citrus pulp. Silages were analyzed for crude protein (CrP), acid detergent fiber (ADF), neutral detergent fiber (NDF), dry matter (DM), pH, crude ash (CA), as well as phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) contents. Additionally, flieg score and physical analysis criteria (odor, color, and structure) were determined. Considering the interaction of silage mixture ratio and additive, statistically significant differences were observed among silages in parameters such as CP, K, P, and pH at a 1% level and among silages in parameters such as CA, ADF, NDF, Ca, Mg, and DM at a 5% level. As a result of the analysis, the the highest CP ratio was obtained with 17.51% from silage mixtures (75%V+25%T)+W additives, the highest ADF ratio was obtained with 40.81% from silage mixtures (50%V+50%T)+M additives, and the highest NDF ratio was obtained 57.46% from silage mixture (50%V+50%T)+CiP additives. According to physical analysis criteria; It was determined that silage quality varied between 3.75 and 18.25. In parallel with the increase in the vetch ratio in the silage mixture; It was determined that the contents of crude protein, crude ash, K, P, Mg, and Ca were positively affected, while the pH value was negatively affected. It was observed that the NDF content was low and the Mg content was high in the silages to which molasses was added. Consequently, it can be said that making silage in the form of a legume-cereal mixture rather than in pure form positively affects silage quality, and the addition of additives to mixed silages has a positive effect on silage quality.

## 1. Introduction

Agriculture has been of vital importance to humanity since its existence. Food production is a fundamental activity that supports the sustainability and well-being of societies (Hien et al., 2023). However, agriculture is not limited to the cultivation and harvesting of crops; the preservation and future usability of products also play a crucial role (Özdemir and Okumuş, 2022; Chao, 2023). For this reason, there is an increasing

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focus on silage applications for the optimal preservation of forage crops used in animal feeding. Silage is a method that allows the fermentation-based preservation and storage of fresh plant material. It is commonly produced from crops such as corn, sorghum, triticale, alfalfa, vetch, or other plants, providing a year-round accessible feed source for livestock such as cattle, sheep, goats, and other farm animals (Kung et al., 2018; Jaipolsaen et al., 2022). However, the benefits of silage extend beyond its use as animal feed, making it a foundation of modern agricultural practices. Among its advantages is its role in animal nutrition, providing high-quality and balanced nutrition for farm animals. This not only enhances the quality of animal products such as meat and milk but also improves animal health and productivity. Additionally, silage becomes crucial for sustaining animal nutrition during periods when fresh forage or feed sources are limited, especially in winter months. This ensures the continuous production of livestock for agricultural operations (Karadeniz, 2019). In addition to its nutritional importance, silage offers ease of preservation and storage. Silage serves as an excellent method for the long-term storage of plant material, minimizing product losses and providing farmers with greater economic security. Silage also has environmental significance, particularly in the reuse of by-products generated during silage production for biogas production or reuse as fertilizer, enhancing environmental sustainability. Silage requires less energy and water while facilitating the long-term preservation of products (Özhan, 2010). In this context, silage acts as a bridge between the sustainability and efficiency of modern agriculture.

Forage crops used in silage production can be categorized into three main groups: legumes, cereals, and other forage crops. Legume forage crops include plants like clover, vetch, forage peas, trefoil, and more, while cereal forage crops include corn, sorghum, triticale, oats, etc. (Tıknazoğlu, 2009). From a nutritional perspective, legume forage crops are rich in protein and fiber, while cereal forage crops are rich in carbohydrates. When silage is made from these crops in their pure form, they may lack certain nutrients. However, when mixed, they complement each other, leading to a more balanced animal diet. Mixed silage enhances nutritional balance and allows the simultaneous intake of various nutrients (Kavut and Geren, 2017). Moreover, Öten et al. (2016) stated in their study that making silage as a mixture of wheat forage crops and legume forage crops gives better results than making silage alone.

The leguminous forage crop common vetch (*Vicia sativa* L.), which is the subject of the study, is rich in carbohydrates (starch and sugars) and fibers, and it has a high protein content. In terms of vitamins, it is a good source of B vitamins (folate, thiamine, and B6) and vitamin C, and in terms of minerals, especially potassium, magnesium, iron, and zinc (Yalçın et al., 1998; Huang et al., 2017). Triticale (*xTriticosecale* Wittmack), a hybrid of wheat and rye in the grass forage crop group, generally contains a high amount of carbohydrates in the form of starch. Despite having a higher protein content compared to wheat and rye, it is not as rich in protein as legumes. Although it contains some fibers, it has a lower fiber content compared to legumes. In terms of vitamins, it is a rich source of B vitamins (thiamine, riboflavin, niacin) and may also include other vitamins such as folate and vitamin E. In terms of minerals, it is rich in certain minerals like magnesium, phosphorus, and iron (Yalchi et al., 2010; Mergoum et al., 2019; Kyrylchuk et al., 2023). Considering the information provided, when evaluating a ratio composed of common vetch and triticale together, triticale has a higher carbohydrate content, whereas common vetch has higher protein and fiber content. The mixtures of these plants are important for enhancing nutritional balance.

Numerous studies have been conducted on forage crops over the years, aiming to create rations by combining different variations of crops. These studies have identified the most effective combinations and their performances. Scientists have gone a step further, focusing on determining the ideal ratios for these combinations in silage production to achieve optimal performance.

In a study conducted to determine the most optimal mixture ratios of triticale and common vetch under Tunisian conditions (100%, 67-33%, 50-50%, 40-60%, 33-67%), the highest dry matter content was achieved in mixtures containing 67% common vetch and 33% triticale, as well as 50% common vetch and 50% triticale (Aziza et al., 2013). Yıldırım and Özaslan 2016), in their study aimed to determine the yield and yield components of triticale mixed with various legumes (faba bean, forage pea, and Hungarian vetch) in different ratios (pure, 75:25, 50:50, and 25:75), found that as the legume content in the mixture increased, the crude protein content also increased, and as the triticale content increased, the dry forage yield increased. They also reported that the neutral detergent fiber (NDF) content decreased in legumes sown in pure stands, but increased in mixtures containing 25% legumes.

Under non-ideal conditions for silage production, the quality and stability of silage can be compromised. Hence, various additives are used to improve silage preservation and quality (Muck et al., 2018). These additives accelerate the fermentation process, inhibit the growth of unwanted microorganisms, enhance nutrient content, and ensure long-term storage of silage.

The additives selected for this study (molasses, whey, and citrus pulp) are chosen from industrial by-products that stand out for their low cost, easy accessibility, environmental friendliness, and recyclability. Molasses is a dark brown syrup containing approximately 50% sugar, resulting from the gradual industrial processing of sugar beets. It shows an enhancing effect on the number and activity of *Lactobacillus* bacteria effective in lactic acid fermentation, inhibiting the development of unwanted microorganisms (Zi et al., 2022). Another additive, whey, is a by-product of the cheese-making process, rich in lactose. It has a pH-lowering effect and enhances lactic acid production, improving fermentation quality (Fallah, 2019). Citrus pulp is a by-product of the fruit squeezing process, typically rich in fiber, pectin, and other plant components. It may act as an aroma or fiber source in silage (Başar and Atalay, 2020; Souza et al., 2022).

This study aims to determine the effects of some silage additives (molasses, whey, and citrus pulp), added to vetch and triticale silage mixtures in different ratios, on silage quality.

## 2. Materials and Methods

### 2.1. Material

#### 2.1.1. Plant Materials

In this study, the Alperen common vetch variety obtained from Trakya Agricultural Research Institute and the Okkan-54 registered triticale variety obtained from Sakarya Maize Research Institute were used as plant materials

#### 2.1.2. Additive Materials

As silage additives added to the vetch-triticale silage mixture in this study, molasses obtained from Adapazarı Sugar Factory Inc., fresh whey from the Dairy Processing Facility of Sakarya University of Applied Sciences, Pamukova Vocational School, and citrus pulp (from lemon and orange) sourced from the market were used.

### 2.2. Method

The study was conducted with five different silage mixture ratios: 25% vetch + 75% triticale, 50% vetch + 50% triticale, 75% vetch + 25% triticale, 100% vetch, and 100% triticale. These mixture ratios were set up with three replications, and each mixture received three different silage additive applications. The additives included 4% molasses, 3% whey, and 2% citrus pulp.

Samples with added additives were filled into 2-liter plastic bags, compressed to eliminate air, and left for fermentation under laboratory conditions at 24 ± 4°C for 60 days. After the fermentation period, the pH analysis was performed using an electronically calibrated pH meter before other analyses. The dry matter (DM) content of the silage samples was determined by leaving the samples in an oven at 70°C for 48 hours. Subsequently, analyses were conducted to determine crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), crude ash (CA), and certain nutrient elements (phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg)). Additionally, physical analysis criteria such as odor, color, and structure were determined in the silage samples.

Dry matter, crude ash, and nutrient elements (P, K, Ca, and Mg) analyses were performed according to Uzun (2010). The Kjeldahl method was utilized for determining crude protein content (Akyıldız, 1984). ADF and NDF analyses were conducted based on the Van Soest method (Van Soest et al., 1991). Silage quality was determined using the Flieg point method developed by Kılıç (1986), based on the relationship between silage pH value and dry matter content. The Flieg point was calculated using the formula "Flieg point = 220 + (2 × Dry Matter Percentage - 15) - 40 × pH". Physical analyses to evaluate silage quality were performed using the scoring method developed by the German Agricultural Society (DLG) and the methods recommended by Alçiçek and Özkan (1997). Based on these analyses, scores were assigned for the color, odor, and structural characteristics of the silage, and these scores were classified according to Table 1.

Research data were subjected to analysis of variance using the SAS (1998) statistical package program according to the Randomized Complete Block Design (Düzgüneş et al., 1987). Differences between means were determined using the Duncan (1955) multiple comparison method.

**Table 1.** According to physical analysis criteria quality groups of silage

| Score Range | Degree |
|---|---|
| 18-20 | Very Good (VG) |
| 14-17 | Good (G) |
| 10-13 | Medium (M) |
| 5-9 | Low (L) |
| 0-4 | Deteriorated (D) |

## 3. Results and Discussion

The chemical contents of silages prepared by mixing vetch and triticale in ratios of 25%, 50%, and 75%, in addition to their plain silages, with the addition of whey (W), citrus pulp (CiP), and molasses (M) were determined. The obtained results are presented in Table 2.

When the crude protein content of silages is examined, it has been determined that silages of vetch prepared with additives in their pure form, to which whey and citrus pulp are added, have higher values. In triticale silages prepared in their pure form with additives, it has been observed that all added additives have lower values compared to other silages. In silages prepared with different mixing ratios and additives, the highest crude protein content was observed at 17.51% in the (75%V+25%T)+W silage mixture and 17.48% in the 100% V. The lowest crude protein content was found in the mixtures with 10.23%, 10.43%, and 10.47% in the ratios of 25%V+75%T with all types of additives. Since common vetch, a legume forage crop is rich in protein, an increase in its content in the mixtures increased crude protein content, and a decrease in its content led to a decrease in crude protein content. When evaluated based on the silage additives, whey, with a higher protein content, had a protein-enhancing effect in all mixing ratios. In comparison to previous studies, the mixtures of silages with additives align with Balabanlı et al. (2010) and are generally lower than Yıldırım and Özaslan Parlak (2016). Additionally, the results are consistent with 100%V and 50%V+50%T, higher than 25%V+75%T, and 75%V+25%T when compared to Önal Aşcı and Eğritaş (2017).

When the crude ash content of silage blends is examined, it has been determined that in vetch silages prepared in their pure form with additives, the silages with whey added have higher crude ash content, whereas in triticale silages prepared in their pure form with additives, the silages with molasses added have higher crude ash content. In silages prepared with different mixing ratios and additives the highest ash content was 17.45% in 100% V, and the lowest ash content was 5.05% in (25%V+75%T)+CiP silage mixture. The increase in the vetch ratio in the silages increased ash content. Eğritaş and Önal Aşçı (2015) determined that the average ash content in pure common vetch was 13.59%, in pure triticale was 7.95%, in the 25%V+75%T mixture was 6.30%, in the 50%V+50%T mixture was 5.95%, and in the 75%V+25%T mixture was 6.05%. Yıldırım and Özaslan Parlak (2016) reported that in pure Hungarian vetch, the ash content was 13.59%, in pure triticale was 9.40%, in the 25%V+75%T mixture was 11.83%, in the 50V+50T mixture was 12.38%, and in the 75%V+25%T mixture was 11.83%. When compared with the results of Eğritaş and Önal Aşçı (2015), it was found that the pure triticale and 25%V+75%T additive mixtures were consistent, while the pure common vetch, 50%V+50%T, and 75%V+25%T additive silage mixtures were higher. In comparison with Yıldırım and Özaslan Parlak (2016), it was observed that the ash content of additive pure silages and the 50%V+50%T additive silage mixture was consistent, the 25%V+75%T and additive silage mixtures were lower, and the 75%V+25%T additive silage mixtures were higher.

**Table 2.** The effects of additives on crude protein and crude ash values of vetch-triticale silage mixtures

| Mixing Ratios | Crude Protein (%) | | | Crude Ash (%) | | |
|---|---|---|---|---|---|---|
| | Molasses | Citrus pulp | Whey | Molasses | Citrus pulp | Whey |
| **25% V+75% T** | 10.43f | 10.23f | 10.47f | 8.79j | 5.05m | 7.83k |
| **50% V+50% T** | 12.07e | 12.37e | 12.26e | 13.56e | 10.23h | 11.66fg |
| **75% V+25% T** | 15.91d | 16.78bc | 17.51a | 11.89f | 15.12c | 17.01b |
| **100% V** | 16.50cd | 17.20ab | 17.48a | 11.47g | 14.55d | 17.45a |
| **100% T** | 10.42f | 10.09f | 10.49f | 9.18ı | 6.86l | 7.55k |
| **Significance** | * | | | ** | | |
| **CV** | 3.14 | | | 2.04 | | |
| **LSD** | 0.1652 | | | 0.6624 | | |

The acid detergent fiber (ADF) value has been found to be higher in silages of pure vetch with the addition of molasses and in silages of pure triticale with the addition of whey (Table 3). When examining mixed silages, the highest ADF ratio was 40.81% in (50%V+50%T)+M, and the lowest ADF ratio was 33.80% in 100%T. When analyzed by silage additives, the addition of citrus pulp, which increases the fiber content, reduced the ADF ratio in all mixing ratios. Balabanlı et al. (2010) reported an ADF ratio of 35.14% in a common vetch and triticale silage mixture. Yıldırım and Özaslan Parlak (2016) found ADF ratios of 30.94% in pure Hungarian vetch, 29.59% in pure triticale, 30.15% in 25%V+75%T mixture, 30.44% in 50%V+50%T mixture, and 30.39% in 75%V+25%T mixture. Önal Aşcı and Eğritaş (2017) determined ADF ratios of 34.40% in pure vetch, 37.36% in pure triticale, 36.40% in 25%V+75%T mixture, 37.15% in 50%V+50%T mixture, and 36.01% in 75%V+25%T mixture. The obtained results are consistent with the studies of Balabanlı et al. (2010) and Önal Aşcı and Eğritaş (2017) but are higher than Yıldırım and Özaslan Parlak (2016).

**Table 3.** Effects of additives on silage ADF and NDF contents in vetch-triticale mixture silages

| Mixing Ratios | ADF(%) | | | NDF(%) | | |
|---|---|---|---|---|---|---|
| | Molasses | Citrus pulp | Whey | Molasses | Citrus pulp | Whey |
| **25% V+75% T** | 36.52fg | 34.45hı | 39.05bc | 51.13ef | 53.29cd | 55.60b |
| **50% V+50% T** | 40.81a | 38.06d | 38.26cd | 50.98ef | 54.35bc | 57.46a |
| **75% V+25% T** | 39.51b | 36.18g | 38.24cd | 40.97h | 51.47ef | 53.55cd |
| **100% V** | 37.93de | 35.10h | 36.96eg | 41.43h | 51.50ef | 53.86cd |
| **100% T** | 36.23g | 33.80ı | 37.30df | 48.83g | 50.30fg | 52.56de |
| **Significance** | ** | | | ** | | |
| **CV** | 1.56 | | | 1.99 | | |
| **LSD** | 0.4416 | | | 1.3524 | | |

When examining the NDF (Neutral Detergent Fiber) content of silages, it has been determined that it is higher in silages of pure vetch and pure triticale with the addition of whey (Table 3). In mixed silages with additives, the highest NDF ratio was 57.46% with (50%V+50%T)+W, and the lowest were 40.97% with (75%V+25%T)+M and 100% V. Among the additives added to silages, whey showed an increasing effect on the NDF ratio in all mixing ratios, while molasses showed a decreasing effect on the NDF ratio in all mixtures. Balabanlı et al. (2010) reported an NDF ratio of 53.97% in a common vetch and triticale silage mixture. Yıldırım and Parlak (2016) stated ratios of 49.88% in pure Hungarian vetch, 55.53% in pure triticale, 53.72% in 25%V+75%T mixture, 50.98% in 50%V+50%T mixture, and 52.58% in 75%V+25%T mixture. Önal Aşcı and Eğritaş (2017) determined NDF ratios of 56.76% in pure vetch, 61.49% in pure triticale, 59.58% in 25%V+75%T mixture, 62.39% in 50%V+50%T mixture, and 59.87% in 75%V+25%T mixture. The obtained results are consistent with the studies of Balabanlı et al. (2010) and Yıldırım and Özaslan Parlak (2016) but lower than Önal Aşcı and Eğritaş (2017).

When evaluated in terms of mixing ratios, the highest Ca content were 1.21% with (75%V+25%T)+M and 1.15 with 100% V. The lowest Ca content were 0.39% with (25%V+75%T)+M and (25%V+75%T)+W silage additive mixtures (Table 4). The calcium (Ca) content has been found to be higher in silages of pure vetch with the addition of citrus pulp and in silages of pure triticale with the addition of both citrus pulp and whey. Eğritaş and Önal Aşçı (2015) determined Ca values as 4.45% in pure common vetch, 0.38% in pure triticale, 2.17% in the 25%V+75%T mixture, 2.41% in the 50%V+50%T mixture, and 2.64% in the 75%V+25%T mixture. The results obtained are consistent with pure triticale but lower than the other mixing ratios.

The potassium (K) content was found to be higher in silages where citrus pulp and whey were added as additives to pure vetch, and in silages where molasses and whey were added as additives to pure triticale (Table 4). In silages prepared from mixtures with different ratios and additives, the highest potassium (K) content were obtained from the silages with compositions (75%V+25%T)+W, (75%V+25%T)+CiP, (50%V+50%T)+W, (75%V+25%T)+M, and with values of 4.96%, 4.87%, 4.71%, 4.68%, 100% V+ CiP and 100% V+ W respectively. The lowest K content was found in silage 100% T+ CiP. Additionally, (25%V+75%T)+W and (25%V+75%T)+CiP had low K content with values of 3.85% and 3.58%, respectively. Eğritaş and Önal Aşçı (2015) determined the average K values in their two-year study as 1.36% in pure common vetch, 0.50% in pure triticale, 1.04% in the 25%V+75%T mixture, 0.99% in the 50%V+50%T mixture, and 1.10% in the 75%V+25%T mixture. The results obtained in this study were found to be higher than those of Eğritaş and Önal Aşçı (2015).

**Table 4.** Effects of additives on silage Ca and K contents in vetch-triticale mixture silages

| Mixing Ratios | Ca(%) | | | K(%) | | |
|---|---|---|---|---|---|---|
| | Molasses | Citrus pulp | Whey | Molasses | Citrus pulp | Whey |
| **25% V+75% T** | 0.39g | 0.44fg | 0.39g | 3.95de | 3.58ef | 3.85ef |
| **50% V+50% T** | 0.86cd | 0.79d | 0.62e | 4.07cd | 4.44bc | 4.71ab |
| **75% V+25% T** | 1.21a | 1.03b | 0.87c | 4.68ab | 4.87a | 4.96a |
| **100% V** | 1.05b | 1.15a | 0.92c | 4.45bc | 4.81ab | 4.80ab |
| **100% T** | 0.40g | 0.48f | 0.42fg | 3.91de | 3.50f | 3.70df |
| **Significance** | | ** | | | * | |
| **CV** | | 5.7 | | | 5.67 | |
| **LSD** | | 0.0276 | | | 0.27 | |

As seen in Table 5, the highest Mg value was obtained from pure triticale (0.32%). On the other hand, in mixed silages, the highest value was obtained from (75%V+25%T)+M (0.32%). The lowest Mg value was 0.08% in the (25%V+75%T)+CiP mixture. The magnesium (Mg) content has been found to be higher in silages of pure vetch with the addition of molasses and in silages of pure triticale with the addition of citrus pulp. In the experiment, the highest P content was detected in (75%V+25%T)+W mixture with 0.44% (75%V+25%T)+W mixture and the lowest was 100% T+M.

**Table 5.** The effects of additives on Mg and P contents of vetch-triticale silage mixtures

| Mixing Ratios | Mg(%) | | | P(%) | | |
|---|---|---|---|---|---|---|
| | Molasses | Citrus pulp | Whey | Molasses | Citrus pulp | Whey |
| **25% V+75% T** | 0.16fg | 0.08j | 0.10ıj | 0.35fg | 0.35gh | 0.37cf |
| **50% V+50% T** | 0.21d | 0.19df | 0.14gh | 0.36dg | 0.39c | 0.38cd |
| **75% V+25% T** | 0.32b | 0.25c | 0.20de | 0.37cf | 0.38ce | 0.44a |
| **100% V** | 0.33b | 0.27c | 0.25c | 0.37cg | 0.37cf | 0.41b |
| **100% T** | 0.17ef | 0.63a | 0.11hı | 0.33h | 0.36eg | 0.38cd |
| **Significance** | | ** | | | * | |
| **CV** | | 5.59 | | | 3.63 | |
| **LSD** | | 0.0165 | | | 0.0571 | |

Eğritaş and Önal Aşçı (2015) found Mg contents as 0.48% in pure vetch, 0.15% in pure triticale, 0.30% in the 25%V+75%T mixture, 0.31% in the 50%V+50%T mixture, and 0.32% in the 75%V+25%T mixture. They determined the P content as 1.11% in pure vetch, 0.29% in pure triticale, 0.39% in the 25%V+75%T mixture, 0.40% in the 50%V+50%T mixture, and 0.45% in the 75%V+25%T mixture. Ordinary vetches, rich in minerals such as K, Ca, Mg, and P, increased the content of these substances in the silages as their proportion in the mixture increased. Regarding the addition of additives, whey showed a phosphorus-increasing effect in all mixture ratios. When compared with the results of Eğritaş and Önal Aşçı (2015), it was observed that in terms of Mg, the silages with 75V+25T additives were consistent, pure vetch and mixtures with 25%V+75%T and 50%V+50%T additives had lower content, while pure triticale silages had higher content. For phosphorus, it was noted that the pure vetch silage had lower content, silage mixtures with additives of pure triticale and 25%V+75%T had higher content, and the other silages were similar.

According to Table 6, the dry matter content of silage mixtures with additives varied between

16.66% and 42.30%. The dry matter content has been found to be higher in silages of pure vetch with the addition of whey and in silages of pure triticale with the addition of citrus pulp. Among silages with different mixing ratios, the highest dry matter content was 42.00% with (25%V+75%T)+CiP, while the lowest was in silages 26.00% with (75%V+25%T)+M. The results are in line with the findings of Balabanlı et al. (2010), who reported a dry matter content of 34% in a mixture of common vetch and triticale silage.

**Table 6.** The effects of additives on dry matter and pH values of vetch-triticale silage mixtures

| Mixing Ratios | Dry matter(%) | | | pH | | |
|---|---|---|---|---|---|---|
| | Molasses | Citrus pulp | Whey | Molasses | Citrus pulp | Whey |
| **25% V+75% T** | 33.00d | 42.00a | 39.00b | 3.87ef | 3.77ef | 3.84ef |
| **50% V+50% T** | 35.00c | 28.00fg | 33.00d | 4.09de | 4.45cd | 4.58c |
| **75% V+25% T** | 26.00h | 28.33f | 29.00f | 4.71bc | 5.10ab | 5.41a |
| **100% V** | 26.66gh | 16.66ı | 30.66e | 4.43cd | 4.81bc | 5.36a |
| **100% T** | 35.33c | 42.30a | 28.33f | 3.80ef | 3.62f | 3.93ef |
| **Significance** | | ** | | | * | |
| **CV** | | 2.04 | | | 5.43 | |
| **LSD** | | 0.24 | | | 0.0530 | |

The pH values have been found to be higher in silages of pure vetch with the addition of whey and in silages of pure triticale with the addition of molasses and whey. The highest pH values, 5.41 and 5.10, were obtained from silages with different mixture ratios containing additives, specifically (75%V+25%T)+W and (75%V+25%T)+CiP, respectively. The lowest pH, on the other hand, was obtained from all additive derivatives added to the mixture with a ratio of 25%V+75%T, with values of 3.77, 3.84, and 3.87. The increase in the proportion of common vetch in the mixture had an increasing effect on pH. Additionally, the addition of whey as an additive increased the pH in all mixing ratios. Balabanlı et al. (2010) reported a pH value of 5.22 in a mixture of common vetch and triticale silage. The results obtained are lower than those reported by Balabanlı et al. (2010) except for silage mixtures with a high proportion of common vetch.

The Flieg Scores calculated based on the formula "Flieg Score = 220 + (2 x DM%) - 40 x pH content" for silage mixtures with added additives are provided in Table 7.

The average Flieg scores determined range from 45.9 to 144.8. According to the evaluation based on Flieg scores, silage mixtures of (75%V+25%T)+CiP, (75%V+25%T)+W, (100%V)+CiP, and (100%V)+W are considered satisfactory, while the (75%V+25%T)+M silage mixture falls into the good category. All other additive mixtures have been classified as excellent. Alçiçek et al. (1999) evaluated vetch-barley mixtures collected from silos in different regions using the Flieg scoring system, and they rated them as good and moderate with scores of 84 and 37, respectively, on a scale of 100. Balabanlı et al. (2010) determined a Flieg score of 64.40 out of 100 for vetch-triticale silage mixtures and classified it as "good." The results obtained are consistent with the studies of Balabanlı et al. (2010) and Alçiçek et al. (1999) in terms of dry matter content, Flieg score, and evaluation.

**Table 7.** Flieg points for common vetch-triticale silage mixtures with added additives

| Mixing Ratios | Silages | Score | Assessment |
|---|---|---|---|
| **25% V+75%** | CiP | 138.2 | Very Good |
| **25% V+75%** | M | 116.2 | Very Good |
| **25% V+75%** | W | 129.2 | Very Good |
| **50% V+50%** | CiP | 82.8 | Very Good |
| **50% V+50%** | M | 111.4 | Very Good |
| **50% V+50%** | W | 87.6 | Very Good |
| **75% V+25%** | CiP | 57.6 | Satisfactory |
| **75% V+25%** | M | 68.4 | Good |
| **75% V+25%** | W | 46.4 | Satisfactory |
| **100% V** | CiP | 45.9 | Satisfactory |
| **100% T** | CiP | 144.8 | Very Good |
| **100% V** | M | 81.0 | Very Good |
| **100% T** | M | 123.4 | Very Good |
| **100%V** | W | 51.6 | Satisfactory |
| **100% T** | W | 104.3 | Very Good |

M: Molasses, CiP: Citrus Pulp, W: Whey

The scores and evaluations obtained from the physical analysis criteria are presented in Table 8. As seen in the table, the average scores of the physical analysis results range from 3.75 to 18.25. The silage mixture (100%V)+CiP received a score of 3.75 in the physical analysis evaluation, indicating spoilage. On the other hand, the silage mixtures (100%T)+W and (25%V+75%T)+W obtained scores of 18.25 and 17.56, respectively, indicating excellent results. It is observed that the proportion of triticale in the mixture increases, the quality of the silage improves, and the application of whey positively influences the silage. Alçiçek et al. (1999) evaluated vetch-barley mixtures collected from silos in different regions as excellent and satisfactory. Demirel et al. (2001) assessed all silage mixtures as satisfactory based on the physical analysis results when mixing Hungarian vetch and sorghum in different proportions. Balabanlı et al. (2010) rated the physical analysis results of vetch-triticale silage mixtures as excellent with a score of 17.5. The results obtained in this study are consistent with other studies.

**Table 8.** Physical analysis results of common vetch triticale silage mixtures with added additives

| Mixing Ratios+Silage | Score | Assessment |
|---|---|---|
| **(25% V+75% T)+W** | 17.56 | Very Good |
| **(50% V+50% T)+W** | 15.50 | Good |
| **(75% V+25% T)+W** | 12.18 | Medium |
| **(25% V+75% T)+CiP** | 15.62 | Good |
| **(50% V+50% T)+CiP** | 13.81 | Good |
| **(75% V+25% T)+CiP** | 13.31 | Medium |
| **(25% V+75% T)+M** | 15.06 | Good |
| **(50% V+50% T)+M** | 16.68 | Good |
| **(75% V+25% T)+M** | 9.81 | Medium |
| **(100% V)+W** | 6.52 | Low |
| **(100% V)+CiP** | 3.75 | Deteriorated |
| **(100% V)+M** | 8.42 | Low |
| **(100% T)+W** | 18.25 | Very Good |
| **(100% T)+CiP** | 16.85 | Good |
| **(100% T)+M** | 12.59 | Medium |

According to these evaluations based on physical data, silo feeds; 18-20 points = Very Good, 14-17 points = Good, 10-13 points = Medium, 5-9 points = Low, 0-4 points = Deteriorated

Ülger et al. (2015) conducted a study to determine the effect of different fruit pulps added to sugar beet pulp on silage quality. They reported that apple and orange pulps could be effective in obtaining high-quality silage. Acar and Bostan (2016) found in their study, which aimed to investigate the effect of barley bran, molasses, and whey powder additives added to clover silage, that only whey powder had a higher pH content compared to the control group. Overall, they determined that the added additives improved the forage quality. Gülümser et al. (2019) observed significant effects of molasses and barley bran additives, added in different ratios to soybean and cowpea silages, on dry matter content and pH parameters, indicating an improvement in silage quality, especially with the cowpea+10% molasses mixture.

## 4. Conclusions

An ideal silage mixture is expected to have a high crude protein content, low ADF and NDF ratios, high crude ash content, richness in nutrients, high dry matter, low pH, and a high Flieg score. In this context, the data obtained in the study are evaluated in three groups: chemical content, Flieg point, and physical analysis criteria. When evaluated in terms of chemical content, it was determined that the addition of citrus pulp and whey to vetch silage and the addition of molasses and citrus pulp to triticale enriched the silage compared to the control group, which consisted of plain silages. In mixtures, it was found that (75%V+25%T)+M and (75%V+25%T)+W were more suitable than other mixtures. When evaluated according to the Flieg score, (25%V+75%T)+CiP, (25%V+75%T)+M, (25%V+75%T)+W, (50%V+50%T)+CiP, (50%V+50%T)+M, (50%V+50%T)+W silage mixtures with the addition rated as very good. However, silage mixtures with the addition of 50% vetch and 50% triticale with molasses, citrus pulp, and triticale-protein mix rated as good. The dry matter content was lower in mixtures with 75% vetch, resulting in lower Flieg scores. Physically and sensorially analyzed criteria (odor, color, and structure) highlighted silage mixtures with the addition (25%V+75%T)+W and (100%T)+W. While chemical content showed positive results in mixtures with an increased vetch ratio, parallel increases in Flieg scores and physical analysis results were observed in a negative direction. In this study, Flieg point and physical analysis results for silage mixtures (25%V+75% T)+W were found similar.

As the vetch ratio increased in silage mixtures, crude protein, crude ash, K, P, Mg, and Ca content also increased. However, an increase in the vetch ratio led to an increase in pH. In silages with molasses as an additive, it was found that the NDF ratio was lower, and the Mg content was higher. The silage mixture with (50%V+50%T)+M had a higher ADF ratio than plain triticale silage. Silages with citrus pulp as an additive had a lower ADF ratio. In silages with whey as an additive, crude protein, P, NDF, and pH contents were higher, while Ca content was lower.

Based on these results, it can be concluded that making silage mixtures with legumes and cereals, rather than making silage from each individually, positively affects silage quality. The addition of additives to silage mixtures enhances silage quality. Also, it is suggested that evaluating physical-sensory analyses and Flieg points together with chemical content values would provide a more accurate assessment in determining silage quality.

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Research

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# Change in Monthly Mineral Content of Russian Thistle

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A B S T R A C T

This study was conducted in 2022 to determine the changes in the mineral content of Russian thistle according to its development periods on the area of Iğdır University Şehit Bülent Yurtseven Campus. In the 7-month period from April to October, the plant's N (Nitrogen), K (Potassium), P (Phosphorus), Mg (Magnesium), Na (Sodium), Ca (Calcium), Fe (Iron), Cu (Copper), Mn (Manganese) and Zn (Zinc) contents were determined. While the nitrogen content of the plant was high in April, May and June, there were decreases in nitrogen content in the following months. While the potassium content increased in May and June compared to April, there were decreases in potassium content in July and the following months. As the development of the plant advanced, there was a decrease in the phosphorus content. While magnesium content was highest in April and September, it was low in the other months. Calcium content was highest in April and May and lowest in August. While the sodium content increased until June, there were decreases in the following months. While the iron content increased until July, there were decreases in the following months. Copper content reached its highest level in July and October. Manganese content was highest in September and lowest in July. Zinc content decreased with the advancement of plant development. According to the research results, it was determined that the nitrogen, potassium, phosphorus (except April), magnesium, sodium, iron, manganese and zinc contents of Russian Thistle are among the values that should be included in feed. On the other hand, it was determined that the calcium content was high and the copper content was low.

## 1. Introduction

The most important source of animal nutrition is the forage plants grown in range-meadow areas and field areas. Misuse of grazing areas failure to comply with the principles of improvement and management have caused to decrease in the productivity of these areas and not meet the feed needs of animals (Öztürk and Güvensen, 2002; Kara and Yüksel, 2014). On the other hand, soil characteristics, excessive irrigation, annual rainfall regime, excessive fertilization cause salinization of the soil, and low annual rainfall causes drought. Xerophyte and halophyte plants grow widely in these extreme grazing areas. Russian thistle, an annual plant, grows widely in both xerophyte and halophyte areas. It has been observed that this plant begins to develop from the end of April and dries by the beginning of December. It has been observed that Russian thistle can adequately meet the daily nutritional needs of small ruminants grazing during the grazing periods from spring to autumn in arid regions and is a good alternative feed source in the winter months with its protein-rich feed supplements (Temel and Keskin 2019a).

In order to the plants to grow and develop, it must acquire sufficient nutrients from the growth environment. While the amount of some nutrients

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such as nitrogen can reach 200 kg per hectare, some nutrients such as molybdenum can only remove 20 grams (Gezgin and Hamurcu, 2006). In addition to their effects on plant development, minerals affect the healthy development and the quality of products of animals that consume these plants (Gökkuş et al., 2013). Macro minerals (N, K, P, Na, Mg, Ca) and micro minerals (Mn, Fe, Cu, Zn) are very important for living organisms, plants, animals and humans. Since these minerals are not synthesized in the metabolism of animals, the needed minerals are largely provided by plants. Deficiency and excess of these minerals affect the feed use efficiency, reproduction, growth and immunity of animals (Forstner and Witmann, 1983; Spears, 1994; Kutlu et al., 2005; Gökkuş et al., 2013).

The mineral content of plants depends significantly on the plant species and variety, the amount of rainfall, the soil in which the plant is grown, the type and amount of fertilization, and the root system of the plants. It is important to know the mineral contents of plants as well as their quality characteristics (Khan et al., 2007; Abari et al., 2011; Aksoy and Dinler, 2014; Temel and Sürmen, 2018). Macro and micro mineral contents of plants growing in areas with low soil mineral content are also low, and mineral deficiency is observed in animals grazing the plants growing in these areas (Abdullah et al., 2013). Therefore, many studies have been conducted on the determination of mineral contents of plants growing in areas with extreme climate and soil conditions and important results have been recorded (Ghazanfar et al., 2011; Abdullah et al., 2013; Gökkuş et al., 2013; Keskin, 2018; Temel, 2019).

Plants growing in the grazing areas do not always have the same amount of mineral content throughout their growth period. Plants with high mineral content at the beginning of growth experience a decrease in their mineral content as their development period progresses (Underwood and Suttle, 1999). It has been stated that the mineral content of plants obtained from degraded grazing lands with low fertility soils is insufficient than the levels needed by ruminants (Abdullah et al., 2013). Species that can grow naturally in the area in regions with arid and semi-arid climates are important feed sources for ruminants (Temel and Tan, 2011; Temel and Keskin, 2022; Keskin, 2018; Dökülgen and Temel, 2015).

This study was carried out to determine the mineral contents in different development periods of the Russian thistle plant, which grows in arid meadow areas. Additionally, it is unclear whether Russian thistle, which grown in arid meadows, will meet the mineral needs of animals and whether it is an important feed source in animal nutrition will be revealed.

## 2. Materials and Methods

This study was carried out to determine the changes in the 7 (seven) month mineral content of Russian thistle (*Salsola kali* subsp. *ruthenica* (Iljin) Soó.) (Temel et al., 2017) growing in the arid meadows area (Figure 1).

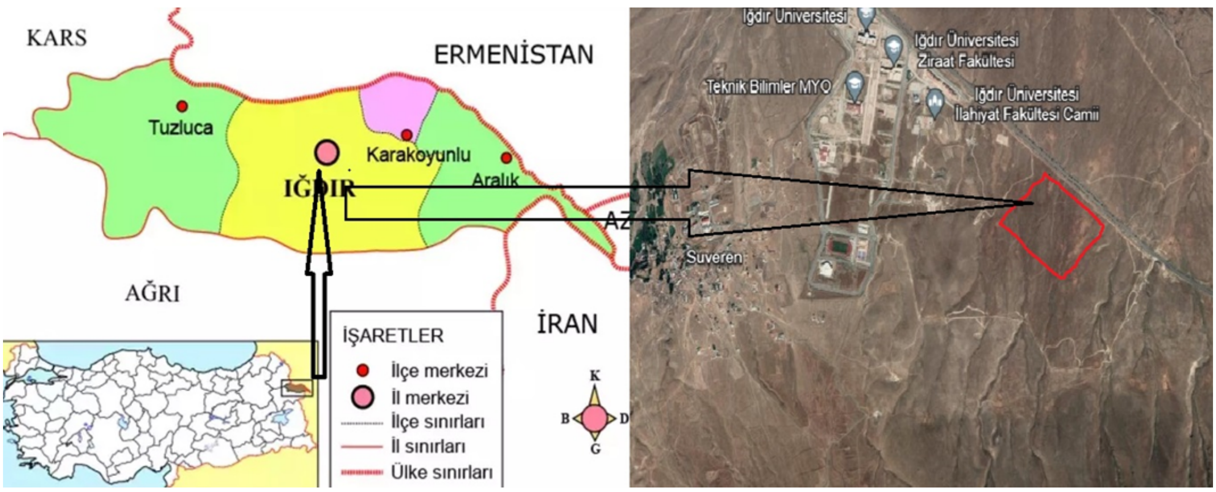


**Figure 1.** Experimental area (39° 48'' 12' N, 44° 05'' 32' E

Plant material was taken in the arid meadow with water table in the last week of each month between April and October in 2022. According to the long-term average of the region (1978-2017), the annual rainfall was 266.4 mm, the average temperature was 12.4 ºC and the relative humidity was 54.6%. In 2022, when the samples were taken, the annual rainfall was determined as 171.6 mm, the average temperature was 15.2 ºC, and the relative humidity was 51.5%. (Table 1) (Anonymous, 2022). These climate values show that the region has an arid climate.

In the area where the research was conducted, a 30 cm deep soil sample was taken and analyzed. Soil analyzes were carried out in the laboratories of Iğdır University Faculty of Agriculture. Analysis results are given in Table 2 (FAO, 1990; Lindsay and Norvell, 1969; Follet, 1969; Ülgen and Yurtsever, 1974; Richards, 1954). This study was designed according to the completely randomized trial design with 3 replications. The time of collection of plant samples was determined as a factor.

**Table 1.** Some climatic features of the research area

| Months | Temperature °C | | Precipitation mm | | Air humidity % | |
|---|---|---|---|---|---|---|
| | 2022 year | LTA* | 2022 year | LTA | 2022 year | LTA |
| January | -2.0 | -3.1 | 6.8 | 13.1 | 66.2 | 66.5 |
| February | 4.4 | 0.3 | 5.6 | 15.5 | 54.2 | 59.8 |
| March | 5.1 | 6.9 | 24.8 | 22.0 | 54.9 | 49.9 |
| April | 15.7 | 13.4 | 25.8 | 37.9 | 43.8 | 49.9 |
| May | 17.0 | 17.6 | 54.8 | 48.9 | 53.8 | 51.1 |
| June | 24.6 | 22.3 | 26.0 | 33.2 | 47.2 | 45.7 |
| July | 27.7 | 26.2 | 0.2 | 14.7 | 37.6 | 43.3 |
| August | 27.9 | 25.6 | 0.4 | 9.8 | 39.3 | 44.5 |
| September | 23.1 | 20.7 | 5.5 | 10.3 | 42.5 | 48.9 |
| October | 15.4 | 13.3 | 12.0 | 28.1 | 60.5 | 62.3 |
| November | 8.1 | 5.9 | 9.7 | 19.8 | 65.4 | 65.7 |
| December | 3.0 | -0.4 | 5.8 | 13.0 | 83.2 | 68.4 |
| Average/Total | 14.7 | 12.4 | 177.4 | 266.4 | 54.0 | 54.6 |

*LTA (Long-term Average): Average of values between 1978 and 2017.

**Table 2.** Some climatic features of the research area

| Soil properties | Value | Classification | Soil properties | Value | Classification |
|---|---|---|---|---|---|
| Organic matter | % 0.6 | very low | K | 0.40 me/100g | sufficient |
| pH | 7.5 | neutral | Mg | 3.83 me/100g | sufficient |
| EC | 0.8 dS/m | non-saline | Na | 2.48 me/100g | |
| Lime | %7.60 | medium | P | 7.30 ppm | low |
| Clay | %27.20 | | Zn | 0.98 ppm | sufficient |
| Silt | %36.60 | clay loam | Cu | 0.27 ppm | sufficient |
| Sand | %36.20 | | Fe | 2.84 ppm | low |
| N | %0.07 | low | Mn | 0.62 ppm | very low |
| Ca me/100g | 13.60 | sufficient | | | |

Plant samples were taken in an area of 1 decare. At the end of the month in which the plant samples were to be taken, 5 plants in an area of 1 decare were cut with grape shears 5 cm above the soil surface, and 1 replication was obtained. 15 plants were harvested for 3 replicates in each month of the experiment. After drying in the shade for a while, the plant samples were dried in an oven set at 70 ºC for 48 hours and then the plant samples were ground. Macro (N, K, P, Na, Mg, Ca) and micro (Mn, Fe, Cu, Zn) mineral changes were determined in the ground plant samples over a 7-month period. After weighing 0.1 g of the ground plant samples, it was placed in microwave containers. Hydrogen peroxide and nitric acid (2/3 ratio) were added into the microwave combustion containers and the lids of the container were closed after waiting for 2 minutes. The combustion process was carried out in a speedwave MWS-2 microwave incineration device. In the 1st stage of the combustion process, the combustion process was completed at 145 °C for 5 minutes at 75% microwave power, in the 2nd stage at 180 °C for 10 minutes at 90% microwave power, and in the 3rd stage at 100 °C for 10 minutes at 40% microwave power (Mertens 2005a). K, P, Na, Mg, Ca, Mn, Fe, Cu, Zn contents of plant samples were determined on the PerkinElmer Optima 2100 DV ICP/OES device (Mertens 2005b). Nitrogen contents of plant samples were determined by the micro kjeldahl method (AOAC 2005).

Data were analyzed for variance according to the completely randomized trial design using the SPSS 17.0 statistical package program, and the averages of the significant data were grouped according to the Duncan multiple comparison test (SPSS, 2008).

## 3. Results and Discussion

In the study, the differences in the N, K, P, Mg, Ca, Na, Fe, Cu, Mn and Zn contents of Russian thistle according to months were found to be significant ($p < 0.01$) (Tables 3 and 4).

**Table 3.** Macro mineral contents of Russian thistle according to different development periods

| Months | N(%) | K(%) | P(%) | Mg(%) | Ca(%) | Na(%) |
|---|---|---|---|---|---|---|
| April | 1.23 ab | 1.22 b | 1.08 a | 0.52 a | 2.88 a | 0.12 c |
| May | 1.27 ab | 1.55 a | 0.66 b | 0.44 b | 2.89 a | 0.18 b |
| June | 1.33 a | 1.49 a | 0.57 c | 0.41 b | 2.34 bc | 0.25 a |
| July | 1.14 bc | 0.89 c | 0.35 d | 0.43 b | 2.45 bc | 0.16 bc |
| August | 1.06 cd | 0.73 c | 0.24 e | 0.45 b | 2.16 c | 0.16 b |
| September | 0.96 d | 0.73 c | 0.26 e | 0.56 a | 2.38 bc | 0.15 bc |
| October | 0.93 d | 0.69 c | 0.29 de | 0.39 b | 2.57 ab | 0.14 bc |
| F value and significance | 7.86** | 25.50** | 156.16** | 9.64** | 6.38** | 15.35** |

**The statistical difference between months is significant at the 1% level; The difference between identical letters in columns is not significant.

### 3.1. Macro minerals

**Nitrogen:** The nitrogen content of Russian thistle varied between 0.93-1.33%. The protein equivalents of these nitrogen contents are between 5.81-8.31%. The nitrogen content of the plant was higher in the first months of plant development (April, May, June) than in other months. A continuous decrease in nitrogen content was observed in July and the following months. Studies conducted on herbaceous species have reported that the nitrogen content, which is high in spring, decreases in summer and autumn (Gökkuş et al., 2013).

**Potassium:** The potassium content of the plant varied between 0.69-1.55%. While the potassium content was 1.22% in April, this rate reached 1.55% and 1.49% in May and June. After June, there was a continuous decrease in the potassium content of the plant, and the lowest value was in October with 0.69%. In a study on herbaceous plants, potassium content was high in the first months when the plant started to develop, while there were decreases in potassium content towards summer and autumn (Gökkuş et al., 2013). It has been determined that the potassium content decreases as the plants mature advanced (Spears, 1994). According to NRC (2005), it is stated that 0.65% potassium in the feed of ruminants is sufficient. Potassium plays a role in the regulation of osmotic pressure, stimulation of nerves and muscles, and carbohydrate metabolism in animals. It has been reported that lack of potassium in feeds will cause a decrease in the growth and in the productivity of animals (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). In the current study, the potassium value of Russian thistle reached up to 1.55%. However, according to NRC (2005) and ANAC, (2018), it has been reported that the potassium content must be at 2% in order to have a toxic effect in animals. Therefore, the potassium content of Russian thistle is not at a level that could cause toxic effects.

**Phosphorus:** Phosphorus contents of plant samples varied between 0.29% and 1.08% depending on the months. While the highest phosphorus content was obtained in the first month (April) when the plant started to development, there were decreases in phosphorus content depending on the advanced of development. The lowest phosphorus contents were obtained in August, September and October. The amount of phosphorus contained in the plant also varies depending on growth and sampling times (Ghazanfar et al, 2011). On the other hand, the phosphorus content of the plant decreases as maturation advanced (Aygün et al., 2018; Keskin, 2018; Keskin and Temel, 2019). It has been reported that if phosphorus is not sufficient in feed, it will cause weakening of bone formation in animals, decreased appetite, milk yield and fertility rates (NRC, 2005; Kutlu et al., 2005; McDonald et al., 2011). According to NRC (2005), it has been reported that feeds for ruminants should contain 0.4-0.7% phosphorus. According to ANAC (2018), it is recommended that the phosphorus content in small ruminant feeds should not exceed 1%. According to NRC (2005), the maximum tolerable level of phosphorus has been reported as 0.7% in cattle and 0.6% in sheep. It was determined that the phosphorus content of Russian thistle exceeded the phosphorus amount determined by ANAC (2018) and NRC (2005) only in April. Animal grazing should be avoided in April in areas where Russian thistle is common.

**Magnesium:** Mg contents of plant samples varied between 0.39% and 0.56%. The Mg content of Russian thistle reached its highest values in April and September. The Mg content in other months was low and there were no significant differences between the Mg contents in these months. In a study conducted on herbaceous plants, magnesium content was high in the first months when the plant started to develop, while there were decreases in magnesium content towards summer and autumn (Gökkuç et al., 2013). Magnesium plays important roles in carbohydrate and fat metabolism, activation of some enzymes (phosphate transferase) and respiratory events. Magnesium deficiency in feed causes weakening of the nail and skeletal systems, developmental delay in nerves and muscles, and a decrease in fat and carbohydrate metabolism (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). It is recommended that feeds contain 0.07-0.10% magnesium in the nutrition of ruminants (NRC, 2005). It has also been reported that more than 0.6% magnesium must be present in sheep feed to have a toxic effect (NRC, 2005). In the current study, it was determined that the magnesium content in Russian thistle did not reach toxic levels.

**Calcium:** During the 7-month development period of Russian thistle, Ca amounts varied between 2.16% and 2.59%. The Ca content of the plant changed significantly depending on months. The first months of plant development (April and May) and the last month when plant development ceased (October) had higher Ca content compared to other months. In a study conducted on herbaceous plants, they determined that Ca accumulated the most among macro minerals in the plant (Gökkuş et al., 2013). Calcium constitutes approximately 99% of the teeth and bone structures of animals. In calcium deficiency, bone formation is weakened and bone fractures occur (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). It has been reported that the calcium content that should be included in the feed of ruminants should be 1.2% according to ANAC (2018) and 1.5% according to NRC (2005). In the current study, it was determined that Russian thistle contains calcium above the determined maximum in all development periods. In areas where Russian thistle is common, animal grazing should be avoided during all the season due to calcium toxicity.

**Sodium:** The Na content of Russian thistle varied between 0.12% and 0.25%. The Na content of the plant (0.25%) was highest in June. In the other months, the amount of Na contained in the plant was low and there was no significant difference between them. Sodium plays important roles in regulating the body's osmotic pressure, stimulating nerves, and absorbing amino acids and sugars in animals. In sodium deficiency, growth retardation, decrease in energy and protein use, and decrease in osmotic pressure are observed in animals (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). It has been reported that Na content in the range of 0.1-0.4% would be appropriate in animal feed (NRC, 2005). Although Na deficiency is most frequently observed in feed (McDowell and Arthington, 2005), in the current study it was observed that the Na content of Russian thistle was within recommended levels in all months of development.

### 3.2. Micro minerals

**Iron:** The iron content of the plant varied between 142.1 ppm and 273.4 ppm according to months. While the iron content of the plant increased until July, a continuous decrease in iron content was observed in the following months compared to July. In a study conducted on shrub plants, the iron content of the plant increased until August and started to decrease in the following months (Temel and Keskin, 2019b). It is located in the structure of hemoglobin, which plays an important role in carrying oxygen to tissues. Iron deficiency causes oxygen deficiency in animal tissues, anemia, developmental delay and loss of appetite in animals (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). According to NRC (2005), it has been reported that the amount of iron required in feed should be between 50-100 ppm. In the current study, it was determined that Russian thistle contains more iron than the amount recommended by NRC (2005) in all development stages. On the other hand, it has been reported that toxic effects may occur in animals when the iron level contained in feed is 500 ppm (NRC, 2005) and 1000 ppm (McDowell and Arthington, 2005). The amount of iron contained in Russian thistle is at a level that does not cause toxic effects on animals.

**Copper:** The copper content of plant samples varied between 1.63 pm and 2.90 ppm. The copper content in the plant reached its highest levels in July and October. The lowest copper contents were detected in May, June, August and September. It has been recommended that ruminants should contain 4-20 ppm Cu in the feed (NRC, 2005). Copper plays an important role in bone formation, hemoglobin formation, activation of some enzymes (lysyl oxidase, cytochromoxidase, triosinase), development and appetite of animals (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). In the current study, the amount of Cu contained in Russian thistle was determined below these recommended values. Due to the low copper content of Russian thistle, additional copper minerals must be given to animals when grazing in areas where the plant is common.

**Manganese:** During the 7-month development period of the plant, the manganese content was found between 25.3 ppm and 72.1 ppm. While the highest manganese content was found in September, the lowest manganese content was detected in July. While manganese was high in the months when the plant first started to develop, manganese content decreased in the following months (Gökkuş et al., 2013). Manganese is effective in the formation of many enzymes (arginase, superoxide dismutase, pyruvate carboxylase), fatty acid synthesis, amino acid metabolism, cholesterol metabolism, and the growth and fertility of animals (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). According to NRC (2001), it is recommended that the manganese content of feeds for ruminant nutrition should be up to 40 ppm. While the manganese content of Russian thistle exceeded the recommended values in August and September, it was determined that the manganese contents in the other months were among the recommended values. However, according to NRC (2005), it is stated that manganese must be 2000 ppm in order to have a toxic effect on animals. The amount of manganese contained in Russian thistle is at a level that does not cause toxicity in animals.

**Zinc:** In the research, the zinc content of plant samples varied between 22.9 ppm and 61.4 ppm. As the development period progressed, the zinc content of the plant also decreased. While zinc was high in the months when the plant first started to develop, there were decreases in zinc content in the following months (Gökkuş et al., 2013). Zinc plays a role in the activation of some enzymes (carbonic anhydrase), protein synthesis, carbohydrate metabolism, nucleic acid formation, feather and bone formation in animals (NRC, 2005; McDonald et al., 2011; Kutlu et al., 2005). It is recommended that the amount of zinc in the feed of ruminants should be between 7-100 ppm (NRC, 1985). The zinc content of Russian thistle in all development periods was within the values recommended by NRC (1985). On the other hand, it has been reported that toxic effects may occur in animals when the zinc level contained in feed is 500 ppm (NRC, 2005). It has been reported that the zinc content in plants decreases as maturation progresses (Hambidge et al., 1986).

**Table 4.** Micro mineral contents of Russian thistle according to different development periods

| Months | Fe (ppm) | Cu (ppm) | Mn (ppm) | Zn (ppm) |
|---|---|---|---|---|
| April | 142.1 e | 2.23 b | 33.1 c | 61.4 a |
| May | 166.5 de | 1.77 c | 38.9 c | 43.6 b |
| June | 188.3 cd | 1.80 c | 32.9 c | 48.8 b |
| July | 273.4 a | 2.90 a | 25.3 d | 30.6 c |
| August | 266.3 a | 1.87 c | 47.9 b | 25.6 cd |
| September | 243.3 ab | 1.63 c | 72.1 a | 22.9 d |
| October | 216.1 bc | 2.90 a | 36.4 c | 24.1 cd |

| F value and significance | 14.48** | 25.14** | 46.92** | 44.34** |
|---|---|---|---|---|

**The statistical difference between months is significant at the 1% level; The difference between identical letters in columns is not significant.

## 4. Conclusion

Changes of macro (N, K, P, Mg, Ca, Na) and micro (Fe, Cu, Mn, Zn) mineral contents during the 7-month development period of Russian thistle were examined. While the highest nitrogen content was in April, May and June, there were decreases in nitrogen content in the following months. While the potassium content was high in April, May and June, there was a decrease in the potassium content in the following months. A decrease in phosphorus content was recorded due to progress in plant development. While magnesium content was highest in April and September, it was low in other months. Calcium content was highest in April and May and lowest in August. While sodium content increased until June, there were decreases in the following months. While there was an increase in iron content until July, there were decreases in iron content in the following months. Copper content reached its highest values in July and October. The manganese contained in the plant reached its highest value in September. There has been a decrease in zinc content due to progress in plant development.

According to the results of the research, it was determined that the nitrogen, potassium, phosphorus (except April), magnesium, sodium, iron, manganese and zinc contents of Russian thistle are among the values that should be included in feed, its calcium content is high and its copper content is low. Since the sodium content of the plant is high throughout the season, grazing of animals should be avoided in areas where this plant is dense.

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Research

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# Silage Quality of Some Italian Ryegrass Varieties Grown in Sivas Ecological Conditions

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NDF

A B S T R A C T

This research was carried out to determine the silage characters of some Italian ryegrass varieties. 21 Italian ryegrass varieties (Master, Quickston, Big Boss, Koga, Venüs, Braulio, Jivet, Medoacus, Excellent, Tornado, İlkadım, Caramba, Kartetra, Efe-82, Trinova, Hellen, Devis, Vallivert, Teanna, Rambo, Zeybek-19) were used as materials. The trial was conducted in the 2022-2023 growing season on land belonging to the Agricultural Ar&Ge Center of Sivas Science and Technology University, Faculty of Agricultural Sciences and Technology. Harvesting for silage making was done when the grains on the ears reached the milking stage, silage samples were placed in 2 kg plastic vacuum bags, and the bags were opened after 60 days for analysis. As a result of the analysis, it was determined that the acid detergent fiber (ADF) rates in silage varied between 31.09-36.74%, neutral detergent fiber (NDF) rates varied between 52.56-61.75%, crude protein rates varied between 9.76-12.34%, crude ash rates varied between 8.23-12.01%, dry matter rates varied between 21.27-29.90%, pH values varied between 4.46-5.90, dry matter digestibility rates varied between 60.28-64.68%, dry matter intake rates varied between 1.95-2.28% and the relative feed value varied between 90.9-113.6, depending on the Italian ryegrass varieties. Among the Italian ryegrass varieties examined in the research, Koga and Vallivert varieties, which have low acid detergent fiber and neutral detergent fiber rates, high dry matter digestibility and dry matter intake rates, and relative feed value, stand out and it is suggested that these varieties can be grown in Sivas and similar ecologies for silage purposes.

## 1. Introduction

The fodder crop known as Italian ryegrass (*Lolium multiflorum* Lam.) holds great worldwide importance. According to Parvin et al. (2010), it is presently widely distributed over temperate regions of the world and grown in Europe, America, and Asia. One of the most important and common forages for dairy cows in temperate areas is Italian ryegrass (Lv et al., 2021).

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Its high forage production, nutritional value, digestibility, and superior ensiling properties make it a frequent fodder for grazing ruminants. Its high amounts of soluble and degradable nitrogen and carbohydrates are particularly noteworthy (Stergiadis et al., 2015). Studying these changes is essential to enhancing the quality of silage since frequent changes in the microbial population take place during the aerobic and anaerobic stages of fermentation (You et al., 2022).

Ensiling is a common procedure to preserve the forage's nutritional quality and provide a year-round supply of feed to suit the animals' production needs (Souza et al., 2022). The quality of the silage's fermentation is also influenced by the stage of plant development during harvest. Due to the fact that variables influencing ensilability, such water-soluble carbohydrates (Longland, 2012), dry matter (Xue et al., 2018), and buffering capacity (Zhao et al., 2022), vary as plants develop. It is commonly recognized that the process of natural fermentation, in which the epiphytic lactic acid bacteria transform carbohydrates into lactic acid under anaerobic circumstances, provides the basis for the preservation of fodder crops by ensiling. The pH drops as a result, preserving the silage. Because there is still air in the silage during the early stages of ensiling, plant respiration and aerobic microbial activity can occur, which results in the loss of both nutritional content and fermentation substrates. The silage is stabilized and the grass may be kept for a long time when lactic acid bacteria lower pH under anaerobic conditions. Effective silage production depends on the pace and effectiveness of acid generation during the first stage of fermentation by the epiphytic lactic acid bacteria (Weinberg et al., 1988). The quality of the silage is also significantly influenced by the early fermentation. The year-round livestock output and the seasonal imbalance in feed availability can be reconciled with the aid of Italian ryegrass silage (Wright et al., 2000).

Because of Italian ryegrass high nutritional content, it is a crucial seasonal feed for ruminants (Fluck et al., 2018). However, because growth stage is the primary element determining the nutrition and digestibility of fodder, the efficiency with which Italian ryegrass is utilized at harvest is highly dependent on it (Valente et al., 2000). However, the harvest stage of forage cannot always be carried out in accordance with the production schedules when considering the practice conditions, such as rainy or the lack of harvest equipment (Comino et al., 2014). The aim of this study was to determine silage quality of some Italian ryegrass varieties grown in Sivas ecological conditions.

## 2. Materials and Methods

Twenty-one recognized Italian ryegrass varieties (Master, Quickston, Big Boss, Koga, Venüs, Braulio, Jivet, Medoacus, Excellent, Tornado, İlkadım, Caramba, Kartetra, Efe-82, Trinova, Hellen, Devis, Vallivert, Teanna, Rambo, Zeybek-19) were employed as plant material in the study. The experiment was set up in the 2022 2023 growing season at Sivas Science and Technology University, Faculty of Agricultural Sciences and Technology, Agricultural Ar&Ge Center trial area, according to the randomized block trial design, with three replications. The experiment's parcel area was designed to have six rows and a length of 5 meters. Using a row spacing of 20 cm and 4 kg. of seeds per decare, the seeds were sown during the first week of October. The trial site was fertilized with DAP at a rate of 4 kg nitrogen (N) and 10 kg phosphorus ($P_2O_5$) per decare at the time of planting (Lale, 2020). Six kg of nitrogen per decare were used for top fertilization once the plants were about thirty cm tall.

The climate of the province of Sivas is continental, with hot, dry summers and cold, snowy winters. Key climatic variables for the study period, such as humidity, precipitation, and temperature, are shown in Table 1. The average temperature that was observed was as low as -3.6 $^0$C in February and as high as 17.3 $^0$C in June. The total amount of precipitation between October 2022 and June 2023 was 421.2 mm, above the long-term average of 326.6 mm. The average relative humidity value varied month to month from 62.8% to 95.3%, which is higher than the long-term average of 64.0% (Anonymous, 2024a).

**Table 1.** Precipitation, temperature and relative humidity values of the period of the experiment

| Months | Total Precipitation (mm) | | Average Temperature (°C) | | Average Relative humidity (%) | |
|---|---|---|---|---|---|---|
| | 2022-2023 | Long Term | 2022-2023 | Long Term | 2022-2023 | Long Term |
| **October** | 16.6 | 19.0 | 11.6 | 12.5 | 62.8 | 57.6 |
| **November** | 39.6 | 32.3 | 6.6 | 6.1 | 74.2 | 69.9 |
| **December** | 23.8 | 29.8 | 3.0 | 2.7 | 86.1 | 79.8 |
| **January** | 7.2 | 46.1 | 0.9 | -2.0 | 87.3 | 74.0 |
| **February** | 43.8 | 35.4 | -3.6 | 0.6 | 92.4 | 71.2 |
| **March** | 107.6 | 44.2 | 6.4 | 2.5 | 93.0 | 64.7 |
| **April** | 74.8 | 23.2 | 9.1 | 11.1 | 92.8 | 50.0 |
| **May** | 56.4 | 18.9 | 13.0 | 13.9 | 93.6 | 53.8 |
| **June** | 51.4 | 77.7 | 17.3 | 18.6 | 95.3 | 55.2 |
| **Total/Ave.** | **421.2** | **326.6** | **7.1** | **7.3** | **86.4** | **64.0** |

The chemical and physical properties of the testing location are listed in Table 2. The pH of the silty clay loam soil in the Sivas area was 7.28. It was also noteworthy for having low levels of organic matter (1.7%), phosphorus ($P_2O_5$) (3.40 kg/da), potassium ($K_2O$) (93.59 kg/da), lime (19.6%), and salt (0.33%)(Anonymous, 2024b). During the study, there was no groundwater problem and the land was sufficiently drained.

**Table 2.** Physical and chemical properties of the soil of the trial site

| Depth | Texture | pH | Lime (% $CaCO_3$) | Salinity (%) | $P_2O_5$ (kg/da) | $K_2O$ (kg/da) | Organic matter (%) |
|---|---|---|---|---|---|---|---|
| 0-30 cm | Silty clay loam | 7.28 | 19.6 | 0.33 | 3.40 | 93.59 | 1.7 |

The plants harvested from each parcel were chopped into pieces of 0.5-1 cm with a branch shredding machine and placed in 2 kg plastic vacuum bags. The bags were then de-aired, tightly closed and stored in a dark place (24±2 $^0$C). At the end of the 60th day, the silage bags were opened and a 30-g sample was taken from each bag. The samples were mixed with 270 mL of distilled water and pH values were measured. Additionally, 250 g of silage samples taken from each bag were dried in an oven at 70 $^0$C until they reached a constant weight and dry matter ratios were determined. pH values in silages were measured with a digital pH meter (Ergün ve ark., 2013). Dry silage samples of the Italian ryegrass varieties were ground in a mill and passed through 1 mm for chemical analysis. Crude ash ratio of Italian ryegrass silages was determined by burning at 550 $^0$C for 8 hours (Anonymous, 1990). Crude protein analyses were performed by the methods specified in Anonymous (2003). The ADF and NDF constituting the cell wall were performed by the method specified in Van Soest (1963) and Van Soest and Wine (1967). Relative feed value (RFV), dry matter digestibility (DMD) and dry matter intake (DMI) of Italian ryegrass samples were calculated according to the formulas (Morrison, 2003).

DMD % = 88.9 - (0.779 x ADF %); DMI % = 120 / NDF %; RFV = (DDM % x DMI %) /1.29.

The analysis of the data obtained silages of Italian ryegrass varieties was made in the Jump-Pro13 statistical package program and the differences between the averages were compared according to the Tukey test. Correlation analysis and color map were made in Jump-Pro13.

## 3. Results and Discussion

Acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein (CP), crude ash (CA), dry matter (DM), dry matter digestibility (DMD) and dry matter intake (DMI) ratios and relative feed value (RFV) and pH values determined in the samples of Italian ryegrass varieties grown in Sivas ecological conditions were found to be statistically significant at the 1% level (Table 3).

The ADF and NDF ratios of the silage of Italian ryegrass varieties varied between 31.09-36.74% and 52.56-61.75%, respectively. While the highest ADF and NDF ratios were obtained from Braulio variety; the lowest ADF rate was found in Koga variety, and the lowest NDF rate was found in Vallivert variety. In a study investigating the effects of the epiphytic microbiota and chemical composition of Italian ryegrass harvested at different growth stages on silage fermentation, it was reported that ADF and NDF values varied between 322-348 g/kg DM and 524-570 g/kg DM, respectively (Yin et al., 2022), while in a study investigating the effects of different nitrogen doses and varieties on the fermentation quality and nutritional value of Italian ryegrass (*Lolium multiflorum* Lam.) silages, it was reported that ADF and NDF values varied between 36.0-38.0% and 61.2-65.4% DM, respectively (Ertekin et al., 2022). In a study investigating the effects of different nitrogen doses and varieties on some nutritional values of annual grass (*Lolium multiflorum* var. *westerwoldicum*) silage, it was reported that ADF and NDF values varied between 27.7-42.47% and 45.34-65.41% DM, respectively (Orou Ouennon Assouma and Çelen, 2022). On the other hand, in a study investigating the effects of growth stage on the fermentation quality, microbial community and metabolomic properties of Italian ryegrass (*Lolium multiflorum* Lam.) silage, it was reported that ADF and NDF values varied between 28.21-28.40% DM and 50.86-54.28% DM, respectively (Fu et al., 2023).

The crude protein and crude ash rates of the silages of Italian ryegrass varieties varied between 9.76-12.34% and 8.23-12.01%, respectively. The high crude protein rate of the silages of Italian ryegrass varieties was obtained in Rambo variety, followed by Efe-82, Master, Kartetra and Excellent varieties, which are statistically in the same group. The highest crude ash rates were found in Koga variety. On the other hand, the lowest crude protein and crude ash rates in the silages of Italian ryegrass varieties were obtained in Vallivert and Trinova varieties, respectively. The crude protein and crude ash rates were obtained as 3.38-10.49% and 8.23-13.18%, respectively, in the silage of *Lolium multiflorum* var. *westerwoldicum* (Orou Ouennon Assouma and Çelen, 2022), as 8.5-14.5% and 11.7-13.1%, respectively, in the *Lolium multiflorum* Lam. (Ertekin et al., 2022). On the other hand, crude protein rates were obtained as 58.8-62.7 g/kg TN in the silage of Italian ryegrass harvested at different growth stages (Yin et al., 2022), as 19.61-23.54% of DM in the *Lolium multiflorum* Lam. (Fu et al., 2023).

**Table 3.** Average values of silage quality characteristic of Italian ryegrass varieties

| Varieties | ADF (%) | NDF (%) | CP (%) | CA (%) | DM (%) | pH | DMD (%) | DMI (%) | RFV |
|---|---|---|---|---|---|---|---|---|---|
| **Big boss** | 36.21$^{ab}$ | 60.74$^{ab}$ | 10.27$^{ef}$ | 8.44$^{g}$ | 26.73$^{d-g}$ | 5.11$^{d-f}$ | 60.69$^{gh}$ | 1.98$^{gh}$ | 93.0$^{h-i}$ |
| **Braulio** | 36.74$^{a}$ | 61.75$^{a}$ | 10.40$^{d-f}$ | 10.68$^{bc}$ | 29.90$^{a}$ | 5.90$^{a}$ | 60.28$^{h}$ | 1.95$^{h}$ | 90.9$^{i}$ |
| **Caramba** | 35.55$^{a-c}$ | 60.04$^{a-d}$ | 10.97$^{c-e}$ | 8.50$^{g}$ | 24.53$^{j}$ | 5.21$^{de}$ | 61.20$^{f-h}$ | 2.00$^{e-h}$ | 94.8$^{g-i}$ |
| **Devis** | 33.70$^{d-g}$ | 57.67$^{b-f}$ | 10.51$^{d-f}$ | 8.83$^{e-g}$ | 27.53$^{cd}$ | 5.14$^{de}$ | 62.65$^{b-e}$ | 2.09$^{c-g}$ | 101.3$^{d-g}$ |
| **Efe 82** | 33.09$^{fg}$ | 56.06$^{e-h}$ | 12.17$^{ab}$ | 9.53$^{d-f}$ | 21.27$^{l}$ | 5.13$^{de}$ | 63.12$^{bc}$ | 2.14$^{cd}$ | 104.8$^{c-e}$ |
| **Excellent** | 32.50$^{gh}$ | 54.68$^{f-i}$ | 12.04$^{ab}$ | 8.42$^{g}$ | 24.53$^{j}$ | 5.67$^{b}$ | 63.59$^{ab}$ | 2.20$^{a-c}$ | 108.2$^{a-c}$ |
| **Hellen** | 33.66$^{d-g}$ | 57.88$^{b-e}$ | 11.24$^{b-e}$ | 8.86$^{e-g}$ | 26.90$^{de}$ | 4.95$^{f-h}$ | 62.68$^{b-e}$ | 2.07$^{d-g}$ | 100.8$^{d-g}$ |
| **İlkadım** | 32.46$^{gh}$ | 55.47$^{e-i}$ | 11.17$^{b-e}$ | 8.75$^{e-g}$ | 25.63$^{f-j}$ | 4.46$^{i}$ | 63.61$^{ab}$ | 2.16$^{b-d}$ | 106.7$^{b-d}$ |
| **Jivet** | 33.07$^{fg}$ | 57.16$^{c-f}$ | 11.34$^{a-d}$ | 10.66$^{bc}$ | 25.07$^{ij}$ | 5.15$^{de}$ | 63.14$^{bc}$ | 2.10$^{c-f}$ | 102.8$^{c-f}$ |
| **Kartetra** | 34.44$^{b-f}$ | 60.15$^{a-c}$ | 12.12$^{ab}$ | 8.42$^{g}$ | 29.53$^{ab}$ | 5.27$^{d}$ | 62.07$^{c-g}$ | 2.00$^{f-h}$ | 96.0$^{g-i}$ |
| **Koga** | 31.09$^{h}$ | 53.03$^{hi}$ | 11.30$^{b-e}$ | 12.01$^{a}$ | 25.33$^{h-j}$ | 5.67$^{bc}$ | 64.68$^{a}$ | 2.26$^{ab}$ | 113.6$^{a}$ |
| **Master** | 33.52$^{d-g}$ | 57.94$^{b-e}$ | 12.14$^{ab}$ | 9.69$^{c-e}$ | 25.57$^{g-j}$ | 5.50$^{c}$ | 62.79$^{b-e}$ | 2.07$^{d-g}$ | 100.9$^{d-g}$ |
| **Medoacus** | 33.15$^{e-g}$ | 56.05$^{e-h}$ | 11.63$^{a-c}$ | 8.80$^{e-g}$ | 26.53$^{d-h}$ | 5.55$^{bc}$ | 63.07$^{b-d}$ | 2.14$^{cd}$ | 104.7$^{c-e}$ |
| **Quickstan** | 35.19$^{a-d}$ | 60.06$^{a-d}$ | 11.92$^{a-c}$ | 11.36$^{ab}$ | 27.17$^{de}$ | 5.62$^{bc}$ | 61.49$^{e-h}$ | 2.01$^{e-h}$ | 95.6$^{g-i}$ |
| **Rambo** | 34.73$^{b-f}$ | 59.82$^{a-d}$ | 12.34$^{a}$ | 8.89$^{e-g}$ | 26.03$^{e-i}$ | 5.53$^{bc}$ | 61.85$^{c-g}$ | 2.01$^{e-h}$ | 96.2$^{f-i}$ |
| **Teanna** | 32.17$^{gh}$ | 53.31$^{g-i}$ | 11.67$^{a-c}$ | 11.00$^{ab}$ | 25.17$^{ij}$ | 5.07$^{e-g}$ | 63.84$^{ab}$ | 2.25$^{ab}$ | 111.5$^{ab}$ |
| **Tornado** | 34.46$^{b-f}$ | 58.30$^{b-e}$ | 10.58$^{d-f}$ | 8.55$^{fg}$ | 23.03$^{k}$ | 5.64$^{bc}$ | 62.06$^{c-g}$ | 2.07$^{d-g}$ | 99.6$^{e-h}$ |
| **Trinova** | 33.12$^{e-g}$ | 56.37$^{e-g}$ | 11.63$^{a-c}$ | 8.23$^{g}$ | 26.83$^{d-f}$ | 5.09$^{e-g}$ | 63.10$^{b-d}$ | 2.13$^{cd}$ | 104.3$^{c-e}$ |
| **Vallivert** | 32.45$^{gh}$ | 52.56$^{i}$ | 9.76$^{f}$ | 9.62$^{de}$ | 26.87$^{de}$ | 4.85$^{h}$ | 63.62$^{ab}$ | 2.28$^{a}$ | 112.6$^{ab}$ |
| **Venüs** | 33.93$^{c-g}$ | 57.31$^{c-f}$ | 10.29$^{ef}$ | 8.80$^{e-g}$ | 27.27$^{d}$ | 4.88$^{h}$ | 62.47$^{b-f}$ | 2.09$^{c-f}$ | 101.4$^{d-g}$ |
| **Zeybek-19** | 34.90$^{b-e}$ | 56.98$^{d-f}$ | 10.37$^{d-f}$ | 10.43$^{b-d}$ | 28.57$^{bc}$ | 4.92$^{gh}$ | 61.71$^{d-g}$ | 2.11$^{c-e}$ | 100.9$^{d-g}$ |
| **Average** | 33.82 $^{**}$ | 57.30 $^{**}$ | 11.25$^{**}$ | 9.45 $^{**}$ | 26.19$^{**}$ | 5.25$^{**}$ | 62.56$^{**}$ | 2.10$^{**}$ | 101.9$^{**}$ |
| **CV** | 3.22 | 3.27 | 5.59 | 6.52 | 2.83 | 1.94 | 1.36 | 3.21 | 3.96 |

$^{**}$; significant at the P≤0.01 level. There is no statistical difference between the averages shown with the same letter.

The dry matter ratio and pH value of the silages of Italian ryegrass varieties varied between 21.27-29.90% and 4.46-5.90, respectively. While the highest dry matter rate and pH value of the silages was obtained in Braulio variety, the low dry matter rate and pH value were obtained in Braulio and İlkadım varieties, respectively. The dry matter rate and pH value were obtained as 19.3-26.2% and 5.90-4.46, respectively, in the silage of Italian ryegrass in response to nitrogen, cultivar and cutting rank (Ertekin et al., 2022), as 206-374 g/kg FW and 3.49-5.22, respectively, in the silage of Italian ryegrass harvested at different growth stages (Yin et al., 2022), as 30.86-35.23% and 4.67-6.18, respectively, in the *Lolium multiflorum* Lam. (Fu et al., 2023). On the other hand, the dry matter rate was obtained as 37.66-58.66% in silages of some annual ryegrass varieties applied with different nitrogen doses (Orou Ouennon Assouma and Çelen, 2022).

The DMD and DMI ratios and RFV values of the silages of Italian ryegrass varieties differed statistically by 1% among varieties and varied between 60.28-64.68%, 1.95-2.28% and 90.9-113.55, respectively. While the lowest DMD, DMI and RFV values of the silages was obtained in Braulio variety, the highest DMD and RFV value were obtained in Koga variety and the highest DMI rates were obtained in Vallivert variety. The DMD and DMI rates and RFV value in the silage of Italian ryegrass in response to nitrogen, cultivar and cutting rank varied between 55.9-59.0%, 1.8-.19% and 78.1-88.2, respectively (Ertekin et al., 2022). On the other hand, it has been reported that the relative feed value in silages of some annual ryegrass varieties applied with different nitrogen doses varies between 79.4-138.2 (Orou Ouennon Assouma and Çelen, 2022).

Principal Component (PC) biplot analysis was performed to strongly demonstrate the relationships between the examined traits in Italian ryegrass silage samples. According to the study results, PCA explained 69.21% of the total variation, while PC1 showed 53.45% and PC2 showed 15.76% on the biplot (Figure 1). It was determined that there was a positive relationship between CP and Ph, CA, DMD, RFV and DMI, while ADF, NDF and DM formed a separate group and had a positive relationship between each other. It was determined that there was a negative relationship between these two groups.

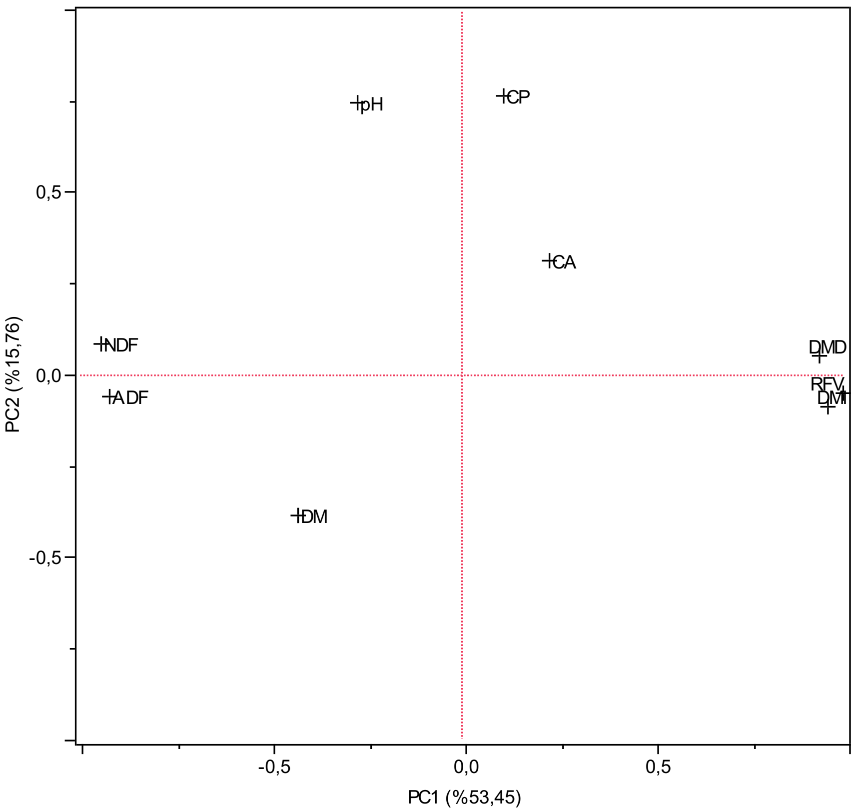


**Figure 1.** Principal component biplot analysis of the relationships between the examined features

## 4. Conclusions

This study was conducted to provide information on determining the silage quality of Italian ryegrass varieties grown in Sivas ecological conditions. Italian ryegrass varieties showed significant differences in terms of silage quality. This study depicted that (i) Koga variety was the most favorable varieties according to crude ash rate, (ii) Rambo, Efe-82, Master, Kartetra and Excellent varieties were the best for crude protein rates, (iii) İlkadım variety was the most stable varieties according to pH value (iv) Koga and Vallivert varieties showed the lowest ADF and NDF rates (v) Koga and Vallivert varieties were the best for DMD, DMI and RFV values.

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# Changes in Botanical Composition of Rangeland Sites Grazed at Different Intensities

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The study was conducted in Köşk and Büyükdere districts, which belong to Yakutiye and Pasinler districts of Erzurum province, where grazing is practised at three different intensities (light, moderate and heavy). The study was conducted in 2022 and analysed the botanical composition, soil cover, pasture condition score and pasture condition and health class. In the study, the difference between grasses and other family ratios in botanical composition, excluding the legume ratio, was statistically significant. It was found that an increase in grazing intensity led to a decrease in ground cover ratio and range condition score. In addition, differences in pasture condition and health class were observed between pasture sites grazed at different intensities.

## 1. Introduction

In addition to their value for livestock production, rangelands also provide important performance in terms of environmental and ecological functions. Rangelands host rich biological diversity, including flora, fauna, microorganisms, and various ecosystems, with environmental, economic, cultural, and scientific significance. Despite their vulnerability to droughts, many rangelands are integral parts of large basins and drainage systems, playing a crucial role in hydrological cycles. When managed sustainably, rangelands are reported to have a significant impact on reducing vegetation runoff, preventing water infiltration, increasing soil moisture, recharging groundwater resources, and reducing the risk of natural disasters such as floods and droughts (IUCN, 2015). Thus, it is stated that meadow and rangeland areas will provide very important contributions to keeping the emission of greenhouse gases that cause drought and climate change, which are the most fundamental problems of today, at a certain level (Tanrıvermiş and Erkul, 2008).

The ecology of rangelands differs significantly from that of other biomes, especially forests. The ecology of these regions is determined by various factors such as drought, temperature, seasonality, fire incidence and dependence on grazing species. In this model, rangeland vegetation and ecological communities respond in complex ways to different pressures, including natural events such as grazing, drought and fire. Plants in drylands have co-evolved with grazing species over millions of years and have become dependent on the activities of grazers to maintain plant health (Frank et al., 1998; McNaughton, 1983). Grazing stabilizes grassland ecosystems, while the absence of grazing destabilizes the system (Perevolotsky and Seligman, 1998). However, as a result of unconscious early and excessive grazing in rangeland-based livestock farming areas, the climax vegetation is physiologically damaged, the composition of the vegetation changes, good species of rangeland plants are lost, and as a result, plant species that are less preferred or not grazed at all become dominant in rangelands (Gençkan, 1992; Sürmen and Kara 2008).

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Considering the Mediterranean climate zone in which our country is located, it is observed that the livestocks are inadequately fed because the rangelands are overgrazed, 87.6% of the rangelands of our country are in moderate and poor condition (Avağ et al., 2012) and supplementary feeding is applied. As a matter of fact, many studies (Koç 1995; Bakoğlu 1999; Erkovan 2000; Sürmen 2004; Güllap 2010; Çomaklı et al. 2012; Severoğlu 2018) conducted in Erzurum province, which is located in the Eastern Anatolia Region, which has large rangeland areas in our country, have stated that excessive and untimely grazing causes serious degradation and reduction in rangeland areas.

However, although many negative effects of early and overgrazing on rangelands have been mentioned in the studies so far, no study has been conducted on the botanical composition change in rangelands depending on grazing intensity. Therefore, in this study, it was tried to reveal which grazing systems would be more suitable for the sustainability of rangelands by examining how the existing botanical composition in rangeland sites exposed to three different grazing intensities (light, moderate and heavy) responds to grazing intensities.

## 2. Materials and Methods

The study was carried out in three different (light, moderate and intensive) intensively grazed rangeland sites in Köşk and Büyükdere neighborhoods of Yakutiye and Pasinler Districts of Erzurum Province. Information about the rangeland sites where the study was conducted is briefly summarized in Table 1.

**Table 1.** Information on rangeland sites

| Rangeland sites | Characteristics |
|---|---|
| I. (Light) | This site, which is used by the Köşk neighborhood itself, was determined as the study area. This site has a total of 8977.76 ha of rangeland and a total of 3305 livestocks, including 1388 cattle and 1917 sheep, graze in this area. Its value in Livestock Unit (LSU) is 1579.7. However, considering the livestock population of the village, 144.62 ha was rented and the total rangeland area of the village became 8833.14 ha. In other words, 1597.7 LSU graze on an area of 8833.14 ha in this rangeland site. The altitude of this rangeland site is around 2246 m. |
| II. (Moderate) | The rangeland site rented from Köşk village pasture was determined as the study area. This site is 144.62 ha, and if it is taken into consideration that the person leasing here also has his own 150 ha area, 1070 sheep graze on a total area of 294.62 ha. The number of sheeps grazed in this site is 107 in LSU. The altitude of this rangeland site is around 2610 m. |
| III. (Intensive) | Büyükdere Neighborhood, which borders Köşk Neighborhood, has a total of 3749.62 ha of rangeland and 1340.10 ha of this area is rented for 2870 sheep and this area was determined as the study area. However, considering that approximately 15,000 thousand small cattle enter this area, approximately 17,870 small cattle grazes in this area. The total number of small cattle grazed in this area is 1787 in LSU. The altitude of this rangeland site is around 2780 m. |

When the capacities of the rangeland areas given in Table 1 for one grazing season are calculated; it is calculated that the first rangeland site has an area of 55.89 da for one grazing season with 1579.7 LSU. In the study, it was determined that the second rangeland site had an area of 27.53 da for one grazing season with 107.0 LSU. And, in the study, it was calculated that the third rangeland site had an area of 7.5 da for one grazing season with 1787 LSU. Considering that an area of 40 ha in LSU (Altın et al., 2011; Çomaklı et al., 2012) is needed for one grazing season, rangeland sites were classified as lightly, moderately and heavily grazed.

Erzurum Province, which has very cold and snowy winters and very hot and dry summers, is covered with snow for almost 2-3 months of the year. Although the year of the study was 2022, since the current botanical composition is likely to be affected by the fall precipitation in the previous year (Koç, 2001), precipitation, temperature and humidity rates for 2021 were also given (Table 2). The average temperature value recorded in 2022 was 7.9°C, which was higher than the previous year (7.1°C) and the long-term average (6.7°C). In 2022, the lowest temperature value was -7.1°C (January) and the highest temperature value was 23.1°C (August). Relative humidity, which was 65.2% on average for many years, was 62.8% in 2021 and 62.1% in 2022. The highest relative humidity was determined in December (79.3%) and the lowest relative humidity was determined in August (37.39%). The total annual precipitation in 2022 was 496.3 mm, the highest precipitation was 104.5 mm in May and the lowest precipitation was 2.3 mm in July (Table 2).

**Table 2.** Some climatic values of Erzurum province for 2021 and 2022 and long-term average

| Months | Monthly Average Temperature ($^0$C) | | | Monthly Average Relative Humidity (%) | | | Monthly Total Precipitation (mm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2021 | 2022 | Long term Average | 2021 | 2022 | Long term Average | 2021 | 2022 | Long term Average |
| January | -7.4 | -7.1 | -8.1 | 78.8 | 74.3 | 78.6 | 14.3 | 35.3 | 24.8 |
| February | -5 | -3.0 | -6.2 | 78.5 | 75.2 | 78.4 | 27.6 | 16.0 | 25.1 |
| March | -2 | -3.5 | -0.2 | 75.1 | 74.2 | 72.6 | 66.8 | 103.4 | 44.6 |
| April | 8.9 | 7.7 | 6.3 | 56.3 | 59.0 | 64.5 | 13.4 | 65.9 | 62.3 |
| May | 13.4 | 9.6 | 11.1 | 49.8 | 66.3 | 64.3 | 32.8 | 104.5 | 78.3 |
| June | 17.5 | 16.7 | 15.9 | 44.0 | 60.8 | 58.2 | 16.0 | 75.0 | 42.2 |
| July | 20.6 | 20.5 | 19.9 | 47.4 | 48.6 | 51.9 | 15.4 | 2.3 | 24.0 |
| August | 20 | 23.1 | 20.6 | 48.5 | 37.39 | 47.9 | 25.8 | 5.0 | 21.2 |
| September | 14.2 | 16.9 | 15.4 | 53.3 | 43.3 | 51.1 | 31.6 | 16.0 | 21.5 |
| October | 7.1 | 10.3 | 9.0 | 64.5 | 58.49 | 64.0 | 60.6 | 43.6 | 51.3 |
| November | 2.5 | 4.1 | 1.6 | 76.7 | 68.4 | 71.5 | 29.8 | 18.3 | 28.0 |
| December | -5.2 | -0.8 | -5.2 | 81.1 | 79.3 | 79.6 | 12.2 | 11.0 | 22.7 |
| Total/Avg | 7.1 | 7.9 | 6.7 | 62.8 | 62.1 | 65.2 | 346.3 | 496.3 | 446.1 |

In the three rangeland sites where the study was conducted, it was determined that the soil texture class varied between clay loam and sandy loam (Ergene, 1993). Aggregate stability was found to be 66.00%, 45.23% and 24.92% in light, moderate and heavy grazed areas, respectively (Demiralay, 1993). It was determined that the pH values determined in the sites in the study area varied between 6.10 and 6.48 and in general the sites were slightly acidic (Sağlam, 1994). In the study, it was recorded that there was no problem in terms of salinity in all three sites (Richards, 1954). In the rangeland sites, the lightly grazed site had the highest organic matter ratio with 5.42%, while the heavily grazed site had the lowest organic matter ratio with 1.33% (Aydın and Sezen 1995). According to the method determined by Olsen and Summer (1982), the amount of phosphorus available to the plant varied between sites by 3.19-8.18 kg/da. Based on the method determined by Sağlam (1994), it was determined that K contents in lightly, moderately and heavily grazed sites varied between 1.65 me/100 g, 1.36 me/100 g and 1.20 me/100 g, respectively, while Na contents varied between 0.16 me/100 g, 0.12 me/100 g and 0.9 me/100 g in lightly, moderately and heavily grazed sites, respectively. Also, based on the method determined by Sağlam (1994), it was determined that the Ca contents between the sites varied between 3.38 and 4, me/100 g and it was noted that these ratios would not cause Ca deficiency (Aydın and Sezen 1995) between the sites. The values obtained from 3 different rangeland sites were subjected to analysis of variance in SPSS package program and Duncan multiple comparison test was applied (Yıldız and Bircan, 1994).

## 3. Results and Discussion

### Botanical composition

Grasses had an average of 26.34%, 34.77%, 29.84% and 14.40% of the vegetation cover in the lightly grazed, moderately grazed and heavily grazed areas, respectively. It was noted that the lightly grazed rangeland sites had a higher proportion of grasses compared to the other grazed sites. It was determined that the legume ratios, which was 18.75% on average, varied between 13.07% and 23.20% between rangeland sites. The proportions of species belonging to other families were 42.04% in the lightly grazed site, 50.16% in the moderate grazed site and 72.54% in the heavily grazed site (Table 3).

The difference in botanical composition among rangeland sites grazed at different intensities may be influenced not only by the number of grazing livestock but also by the grazing preferences of the livestock. The fact that rangelands are richer and more homogeneous in terms of nutrients causes an increase in grazing pressure in these areas (Koç, 1995; Goss et al., 1998; Güllap, 2010; Çomaklı et al., 2012) and that the species diversity in these areas has changed as a result (Bobbink, 1991; Willems et al., 1993; Gough et al., 2000; Smith et al., 2000) is in parallel with our study. Similarly, many studies (Kruess and Tscharntke, 2002; Scimone et al., 2007; Wallis De Vries et al., 2007; Severoğlu, 2018) reported that grazing intensity significantly affects species components. In addition, since both sheep and cattle were grazed in the study, their feed preferences may have affected the change in botanical composition. As a matter of fact, Koç and Gökkuş, 1993 and Erkovan et al., 2016 stated that the differences in both the anatomical and physiological structure of the grazing livestock species significantly affect the species ratio in the botanical composition. Grazing habits and grazing intensities of grazing livestocks affect the continuous change of species composition in rangelands (Yunusbaev et al. 2003; Altın et al., 2011; Koç and İleri, 2016). This was also found in this study and it was determined that the heavily grazed area, especially the sheep grazed area, had a lower proportion of grasses compared to the lightly grazed area. Similarly, in many studies (Fırıncıoğlu et al., 2007; Chartier et al., 2009; Çelik, 2019), it was determined that intensive grazing caused significant reductions in the proportion of grasses.

**Table 3.** Species ratios in botanical composition of rangeland sites grazed at different intensities and analysis of variance results

| Plant Species | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | lightly grazed | moderately grazed | heavily grazed | Avg. | F values |
| **Grasses (%)** | 34,77 a | 29,84 ab | 14,40 b | 26,34 | 4,687* |
| **Legumes (%)** | 23,20 | 20,00 | 13,07 | 18,75 | 2,706 ns |
| **Other families (%)** | 42,04 B | 50,16 B | 72,54 A | 54,91 | 7,786** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

In the lightly, moderately and heavily grazed sites where the research was conducted, the proportion of legumes was 23.20%, 20.00% and 13.07%, respectively, which were higher in the lightly grazed site, but this difference between the sites was not statistically significant (Table 3). Grazing systems that are not in accordance with range management principles generally lead to the predominance of other families with low forage value and not preferred by livestocks (Erkovan 2000; Gökkuş and Koç 2001; Daşcı 2002; Öztaş et al. 2003; Güllap 2010; Severoğlu 2018). For this reason, it is expected that the rates of other families detected in the heavily grazed site of the study would be higher than the other sites. In addition to the fact that the area per livestock for a grazing season is less in the heavily grazed site as shown in Table 1, the fact that this site is at a higher altitude may have been effective in the high rate of undesirable species among the identified species. As a matter of fact, in many studies (Erkovan, 2000; Erkovan et al., 2003; Koç et al., 2008; Wassie et al., 2018), it was stated that the increase in altitude has a significant effect on the decrease in the proportion of quality species in the botanical composition, which is in line with the results obtained in our study.

**Soil coverage rate (SCR)**

In rangeland sites grazed at different intensities, the SCR ratios ranging between 65.40% and 24.60% was 65.40% in the lightly grazed site, 48.00% in the moderately grazed site and 24.60% in the heavily grazed site (Table 4).

As can be seen from the examination of Table 4 in the study, it is seen that the SCR rate decreases with increasing grazing pressure, in other words, there is an inverse relationship between grazing pressure and SCR. As a result of heavy grazing, especially in arid areas (Gökkuş, 2014), plants that cannot regenerate themselves weaken physiologically and this causes the places to remain empty (Çaçan et al., 2014). As a result of heavy grazing, both plant roots will be weakened and the organic matter and nitrogen content of soils will decrease, which will exacerbate vegetation and soil degradation (Han et al., 2008). In many studies (Koç 1995; Güllap 2010; Deng et al., 2014; Severoğlu, 2018; Mathewos et al., 2023), it was stated that the increase in grazing intensity negatively affected the SCR rate. In addition, in the study, intensive grazing of sheep above its capacity in the heavily grazed rangeland site may be an important factor in the decrease in the SCR rate compared to other sites. Because although sheep are small in size and exert less rangeland on the soil than cattle (Golodets and Boeken 2006; Li et al. 2008), they move around the rangeland more and cause more bare soil surface ((Milton et al. 1997; Erkovan et al. 2016).

**Table 4.** Soil coverage ratios of rangeland sites grazed at different intensities and analysis of variance results

| | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | **the lightly grazed** | **moderately grazed** | **heavily grazed** | **Avg.** | **F values** |
| **SCR (%)** | 65,40 A | 48,00 B | 24,60 C | 46,00 | 15,851** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

**Rangeland condition score (RCS)**

In this study, the RCS in the heavily grazed site (21.65) was lower than the RCS in the lightly grazed site (47.37), and in general, RCS decreased with increasing grazing intensity (Table 5).

We can say that such a difference in terms of RCS between the sites is due to the fact that the area allocated to livestock for a grazing season is lower, especially in the heavily grazed site, and sheep are grazed intensively. Because as a result of heavy grazing, the desirable species that are most preferred by livestock in botanical composition are lost and these species are replaced by species that are not preferred by livestock (Tsiouvaras et al., 1996; Allen-Diaz and Jackson, 2000; Tamartash et al., 2007; Güllap, 2010; Çomaklı et al., 2012). As a matter of fact, in many studies (Gür, 2014; Sürmen et al., 2015; Severoğlu, 2018; Nasiyev et al., 2022), it was stated that the difference in range quality grade was caused by grazing intensity and different utilization. In addition, the fact that sheep graze more selectively than cattle and prefer legumes and other high-quality family species (Rose et al. 2012; Erkovan et al. 2016) may be effective in the low RCS in the sheep grazed site in the study.

**Table 5.** Rangeland condition scores and analysis of variance results of rangeland sites grazed at different intensities

| | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | **the lightly grazed** | **moderately grazed** | **heavily grazed** | **Avg.** | **F values** |
| **RCS** | 47,37 A | 34,22 B | 21,65 C | 34,41 | 23,349** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

**Rangeland condition and health class**

This situation, detected in the heavily grazed pasture section in the study, almost reflects the current situation of our country's rangeland. Because the rangelands of our country have lost almost 90% of their climax vegetation cover (Gençkan et al., 1990).

The grazing factor is one of the most important factors in the change of range vegetation cover and the increase in grazing intensity, especially in arid and semi-arid climates, causes the vegetation cover to deteriorate more quickly (Holechek and Pieper 1992). Therefore, this situation in the heavily grazed rangeland site may have been caused by excessive and irregular grazing. As a matter of fact, studies (Koç et al., 2013; Severoğlu 2018; Çelik 2019; Bilgili and Koç 2020) reported that intensive grazing in rangelands weakens the rangeland condition as the desirable plant species ratios present in the botanical composition decrease.

**Table 6.** Rangeland condition and health classes of rangeland sites grazed at different intensities

| **Rangeland condition and health class** | **the lightly grazed** | **moderately grazed** | **heavily grazed** |
|---|---|---|---|
| | moderate-healthy | moderate-healthy | weak-risky |

## 4. Conclusion

In the light of the data we obtained as a result of the study, it is noteworthy that the effect of both ecological and grazing intensities in the areas allocated between the sites is important for these differences in terms of the factors examined among the sites studied. In the study, it was recorded that the heavily grazed and sheep grazed site was in a very poor condition in terms of botanical composition and rangeland condition and health compared to the other sites. For this reason, it is very important for the sustainability of rangelands to make a good grazing planning in order to reduce the effect of grazing intensity on the rangeland site, especially in the heavily grazed site.

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# Factors Effective on Farmer Satisfaction for the Forage Crops Supports and the Tendency to Continue Forage Crop Production (TRA-1)

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A B S T R A C T

In this study, it was aimed to determine the support satisfaction of forage crops producers who benefit from forage crops supports and the factors that are effective in continuing forage crops agriculture. A face-to-face survey was conducted with 196 farmers identified by simple random sampling method in TRA-1. Descriptive statistical methods and binary logistic regression model were used to analyse the data.

According to the results obtained in the study; It was determined that the farmers benefiting from forage crop support were on average 46 years old and 30.6% were high school graduates, 35.2% had non-agricultural income and 17.3% had social security. It was determined that 55.1% of the farms engaged in livestock and plant production together, the average land size owned was 9.2 hectares. Alfalfa (21.295 hectares) is mostly grown as a forage crop on farms. There are an average of 14 cattle and 10 sheep per farms. It was found that 60% of the farmers were not satisfied with the support, 22.4% of them grew forage crop to benefit from the support, and approximately 59% of them tended to continue forage crop farming despite being dissatisfied. In the study, the satisfaction state of forage crop producers forage crops supports and the factors affecting their continuation of forage crop agriculture were analysed separately using the logit model has been analysed. As a result of the logit model, producers' satisfaction with the supports is increasing by the insufficient pasture areas and low costs state. In addition, the high productivity of forage crops, the presence of livestock on the farm and the sufficient support amount also increase satisfaction state. Factors affecting the tendency to continue forage crop farming are determined as high level of education, lack of migration tendency, lack of alternative products, insufficient pasture areas, experience and lack of non-agricultural income.

In this context, studies should be carried out to increase the ratio of forage crop cultivation areas in the total field area in forage crop agriculture, whose sustainability will be ensured with supports, and it is recommended to provide gradual supports in parallel with the increasing cultivation area, production amount or number of animals.

## 1. Introduction

The TRA-1 sub-region, located in the Eastern Anatolia Region, whose economy is based on animal husbandry, suitable for animal husbandry due to its topographic and ecological features. Livestock farming is based on forage crop cultivation and pasture feeding. In the region covering 38% of our country's pastures, water erosion and stony problems restrict pasture use,

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especially in the provinces of Ağrı, Artvin, Erzincan, Erzurum and Kars. Existing pasture areas in the region have decreased due to many reasons, falling from 9 million hectares to 4 million hectares. In particular, there is excessive and misuse of pastures as well as mismanagement. For these reasons, the productivity and quality of existing pastures have decreased significantly. Although the difficulties in grazing meadows and pastures according to management rules and the lack of pasture maintenance cause their productivity to decrease (Yolcu & Tan, 2008), the changing animal profile with both support and breeding studies necessitates the necessity of feeding the animals in a closed environment (barn/pen). Considering that animals should be fed 2.5% of dry grass or 10% of green grass of their live weight daily (Çeri & Acar, 2019), it seems that the production of forage crops is inevitable and will be the most effective way to provide feed to animals (Yavuz et al., 2020). In addition, it is predicted that the deficit of quality roughage will change especially with global climate change, pasture improvement studies, and changes in animal breeds and numbers (TAGEM, 2022). Although it is envisaged to increase the forage crop cultivation areas in the five-year development plans made in our country, efforts to achieve this goal are still continuing. According to Turkish Statistical Institution data for 2024; At TRA-1 NUTS II Region (Erzurum, Erzincan, Bayburt) level alfalfa, oats, sainfoin, silage corn and vetch are the forage crops that are preferred to be cultivated. Alfalfa is the most cultivated forage crop with an area of 68.340 hectares (Figure 1).

There has been a decrease in the area cultivated in forage crops and a major change in the types of forage crops cultivated. Especially annual plants have started to be cultivated as forage crops. Among the forage crops preferred to be cultivated in all three provinces, alfalfa has the priority (Figure 2).

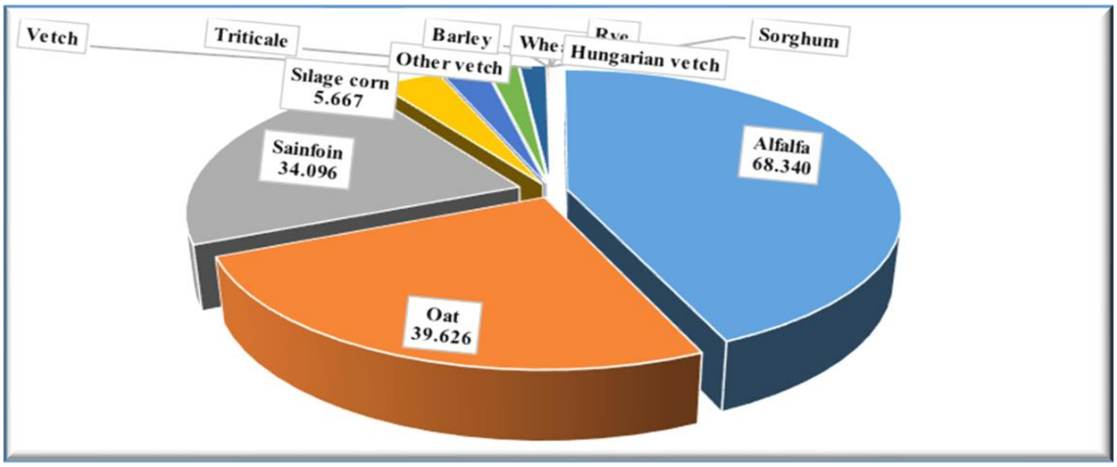


**Figure 1.** Forage crops cultivated areas (hectares) in TRA-1 subregion in 2023 (TUIK, 2024)

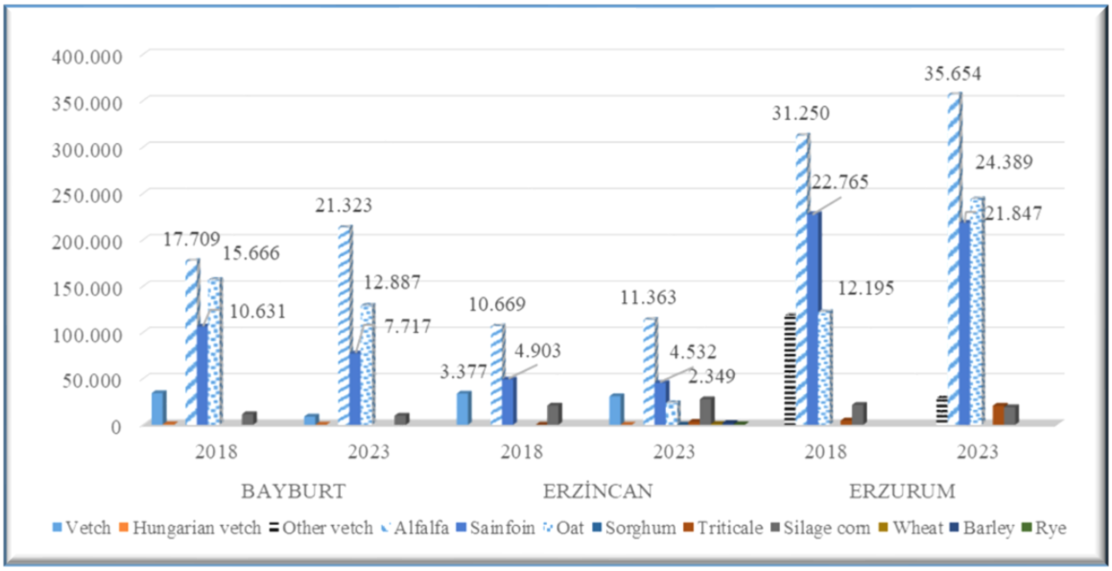


**Figure 2.** Changes in the amount of cultivated area (hectares) of forage crops producing green grass between 2018 and 2023 (TUIK, 2024)

In this context, studies to support forage crop production started in 2000 (Şahin & Yılmaz, 2008). According to the data of the General Directorate of Plant Production (BUGEM); In 2000, the forage crops cultivation area was approximately 54 thousand ha and the support amount was 2.4 million TL. In 2022, the area cultivated with forage crops was 950.285 ha, the amount of support given was 733.6 m TL, and the number of farmers benefiting from the support was 238.093 (Table 1). The total area where forage crops are cultivated in our country is 2.752.838 hectares. Farmers benefit from support with forage crops cultivated in approximately 35 hectares of the total area. When examined in five-year periods, it is seen that the number of farmers and the amount of cultivated area do not increase regularly. It is seen that there are increases and decreases in the number of farmers and the amount of cultivated area, especially with the effect of the studies on including different forage crops within the scope of support and regulating the conditions of support (Table 1). Within these reasons; adequate improvements in meadows and pastures ıf this cannot be achieved, it is very important to consider and organize support policies to continue the production of forage crops or to start forage crop farming and to increase the production of forage crops.

**Table 1.** Changes in forage crop cultivation area, number of farmers receiving support and support amount over the years (BUGEM, 2024)

| | | | Forage crops cultivated area (ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Years | No. of farmers | Support amount million (TL) | Alfalfa | Sainfoin | Vetch | Other annual forage crops | Artificial grass pasture | Silage corn | Other silage forage crops | Other perennial forage crops | Total |
| 2000 | 10.741 | 2.4 | 4.325 | 1.723 | 6.320 | 4.556 | 9 | 36.923 | | | 53.855 |
| 2005 | 209.288 | 280.9 | 59.845 | 21.197 | 194.811 | 42.430 | 45 | 135.745 | | | 454.073 |
| 2010 | 189.277 | 252.9 | 51.084 | 28.377 | 291.596 | 32.075 | 124 | 156.706 | 4313 | | 564.278 |
| 2015 | 157.204 | 343.0 | 36.658 | 22.794 | 223.647 | 20.874 | 1265 | 216.609 | 3885 | | 527.732 |
| 2020 | 259.561 | 820.8 | 223.216 | 62.259 | 140.290 | 32.5313 | 1442 | 305.424 | 1812 | 16.3 | 1.059.772 |
| 2022 | 238.093 | 733.6 | 217.491 | 52.281 | 110.594 | 310.023 | 1411 | 256.980 | 1489 | 16 | 950.285 |

For this reason, within the scope of forage crop agriculture and the supports provided, the factors affecting the approach of forage crop producers should be addressed, the cultivation of forage crops should be encouraged, and the factors affecting forage crop supports should be revealed. In order for the studies to be carried out to increase the production of forage crops to be successful and to take precautions, it is necessary to determine why and how the supports should be given. For this reason, this study aims to discuss the factors affecting the approach of forage crop producers within the scope of forage crop cultivation and the supports provided, and to reveal the factors that are effective in promoting or sustaining forage crop cultivation.

## 2. Materials and Methods

Primary study data were collected from the farms benefitting forage crop support as the previous studies and the relevant records of the institutes in the study area constituted the secondary data. The following formula of the simple random sampling method, developed for finite populations, was used to determine the sample size (Çiçek & Erkan, 1996). The records provided by the Provincial Directorates of Agriculture and Forestry were used to determine the farms examined in the study. Farmers who benefit from forage crop support constitute the sampling frame.

$$n = \frac{N.\sigma^2.z^2}{(N-1).d^2 + \sigma^2.z^2} \qquad (1)$$

In the formula;
n: Sample size
$\sigma^2$: Population variance
N: Population size (14.750)
z: Critical z-score at the 90% confidence interval (1.65)
d: Shows the acceptable error as a percentage of the average

When calculating the sample size, a 90% confidence limit and a margin of error of 10% of the population average were used, and the sample size (n) was determined as 196. Study data was obtained through face-to-face surveys with forage crop producers benefiting from forage crop support in purposively selected districts and villages (8 districts, 24 villages) in Erzincan, Erzurum and Bayburt provinces in 2019 years. The data obtained from surveys were transferred to Excel

2013 computer program. The percentage values were obtained by using frequency analysis in descriptive statistical method. The statistical package SPSS 26.0 (IBM Corp, released 2019) was used in the analysis of the data.

Factors affecting forage crop producers' satisfaction with the support and their ability to continue forage crop farming were determined using Binary Logistic Regression. Binary Logistic Regression Analysis is a logistic regression method applied when the dependent variable has two categories. While coding the data, the code 0 is used for no and 1 is used for yes. It is an analysis method that allows the statistical significance of each explanatory variable as a risk factor to be evaluated and the estimated risk factor (odds ratio) to be calculated (Kılıç, 2015). Logistic regression function; returns only values between 0 and 1 for the dependent variable, regardless of the values of the independent variable. Logistic regression predicts the value of the dependent variable with this formula.

$$f(x) = \frac{1}{1+e^{-x}} \quad (2)$$

The first step in logistic regression is the "initial model" created to compare the development or improvement in model fit. The second step in logistic regression is the estimation of the intended model. This model is a regression model that includes explanatory variables. Here, it is expected that there will be an improvement in fit with the introduction of explanatory variables into the analysis after the initial model. The explanatory nature of the model is evaluated with Cox&Snell or Nagelkerke $R^2$ values. It is interpreted that the closer these values are to 1, the better the model. The Hosmer and Lemeshow test also gives information about whether this model is a good model or not. In order to express that the fit of the model is sufficient, it is desired that the "p" value be greater than 0.05. The variables, definitions and codes included in the logit regression models are given in the Table 2. The logit models established in the study are specified in the formulas below:

$$Y1 = \beta0 + \beta1X1 + \beta2X5 + \beta3X13 + \beta4X14 + \beta5X15 + \beta6X6 + \beta3X8 + \beta4X11 + \beta5X12 + \beta6X16 + \epsilon$$

$$Y2 = \beta0 + \beta1X1 + \beta2X2 + \beta3X3 + \beta4X4 + \beta5X5 + \beta6X6 + \beta7X7 + \beta8X8 + \beta9X9 + \beta9X10 + \beta9X11 + \beta9X12 + \epsilon$$

**Table 2.** Variables, codes and other terms used in the logistic regression formula

| **In the first model** | **In the second model** |
|---|---|
| Y1: Satisfaction with forage crops support or not | Y2: whether they want to continue forage crops farming |
| β's: regression parameters<br>ϵ indicates the error term | β's: regression parameters<br>ϵ indicates the error term |
| **Independent variables** | **Codes** |
| X1: Age of the producer<br>1- 18-35 2- 36-55 3- 56-65 4- 66+ | AGE |
| X2: Education status of the farmers<br>1- Literate 2- Primary school 3- Secondery school 4-High school 5- University | EDUCATION |
| X3: Whether there is a tendency to migrate<br>0- doesn't want 1- want | MIGRATION |
| X4: Whether there are alternative products<br>0- no 1-yes | ALTERNATIVE CROP |
| X5: Whether the pasture is sufficient<br>0- sufficient 1- insufficient | SUFFICIENT PASTURE |
| X6: Whether the cost of producing forage crops is high | COST |
| X7: Whether the land is suitable for the cultivation of forage crops or not<br>0- not suitable 1- suitable | SUITABLE LAND |
| X8: Whether there is animal husbandry in the farm<br>0-no 1- yes | FARM TYPE |
| X9: Whether the climate is suitable for forage crops cultivation<br>0- not suitable 1- suitable | SUITABLE CLIMATE |
| X10: Whether the workforce is sufficient<br>0- sufficient 1- insufficient | SUFFICIENT LABOR |
| X11: Whether the producer is experienced or not<br>0- sufficient 1- insufficient | EXPERIENCE |
| X12: Whether there is non-agricultural income<br>0- sufficient 1- insufficient | NON-AGRICULTURAL INCOME |
| X13: Whether the yield of forage crops is high<br>0- low 1- high | YIELD OF FORAGE CROPS |
| X14: Whether there is membership in agricultural organizations<br>0- not member 1- member | MEMBERSHIP IN AGRICULTURAL ORGANIZATIONS |
| X15: indicates whether there is a marketing problem<br>0- no 1- yes | MARKETING PROBLEM |
| X16: indicates whether the forage crops support amount given is sufficient<br>0- sufficient 1- insufficient | SUFFICIENT SUPPORT AMOUNT |

## 3. Results and Discussion

When the demographic characteristics of the producers benefiting from forage crop support are examined; It is seen that the average age of the producers is 46 years old and 57% of them are between the ages of 36-55. 33.7% of the farmers benefiting from forage crop support are primary school graduates and 30.6% are high school graduates (Figure 3).

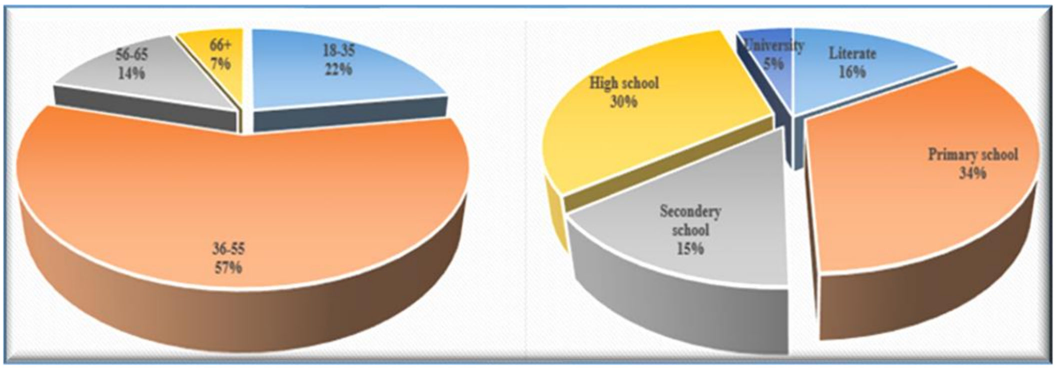


**Figure 3.** Age and educational status of forage crop producers

The average household size is four people, with a minimum of 1 and a maximum of 8 people. 55.1% of the farms carry out livestock and plant production together. It was determined that 35.2% had non-agricultural income and 17.3% had social assurance (security) (Table 3).

The average of the cultivated areas where producers produce forage crops is 9.2 hectares. The largest land is 75 hectares in size and the smallest land is one hectares. 35.4% of the farmers in Bayburt, 29.5% in Erzincan and 20.2% in Erzurum grow forage crops in the range of 1-2 hectares. 47% of producers grow forage crops on 80% or even all of their property lands. Producers cultivate alfalfa, sainfoin, oats, vetch and silage corn plants respectively and receive support from those crops. (Figure 4).

The farms dealing with both livestock and plant production constitute 55.1 of all respondent farms as the rest engages with only forage crop production. The rate of farms producing only forage crops is 44.9%. In livestock farming farms, mostly cattle are raised (Table 4). 64% of the farmers engage in both cattle and sheep farming. There are an average of 14 cattle and 10 sheep per farm.

In general, farmers who want to benefit from forage crop support apply with the Forage Crops Support Agricultural Land Declaration Form before harvesting the forage crop, and the total forage acreage to be evaluated within the scope of support must be at least one hectare. In addition, as a result of the harvest control, the part of the applicant's relevant parcels of vegetation should not be less than one hectare. In this context, although all producers in the study area benefit from supports, benefiting from supports is ranked first as the primary reason for the production of forage crops.

**Table 3.** Some demographic characteristics of forage crop producers

| **Membership to agricultural organizations** | **Choices** | **Percentage** |
|---|---|---|
| Yes | 120 | 61.2 |
| No | 76 | 38.8 |
| **Production type in farm** | | |
| Livestock and crop production | 108 | 55.1 |
| Crop production | 88 | 44.9 |
| **Non-farmıng ıncome** | | |
| Yes | 69 | 35.2 |
| No | 127 | 64.8 |
| **Social assurance** | | |
| Yes | 34 | 17.3 |
| No | 162 | 82.7 |
| **Number of households** | | |
| Less than 4 | 103 | 52.6 |
| 4 | 47 | 24.0 |
| More than 4 | 46 | 23.5 |

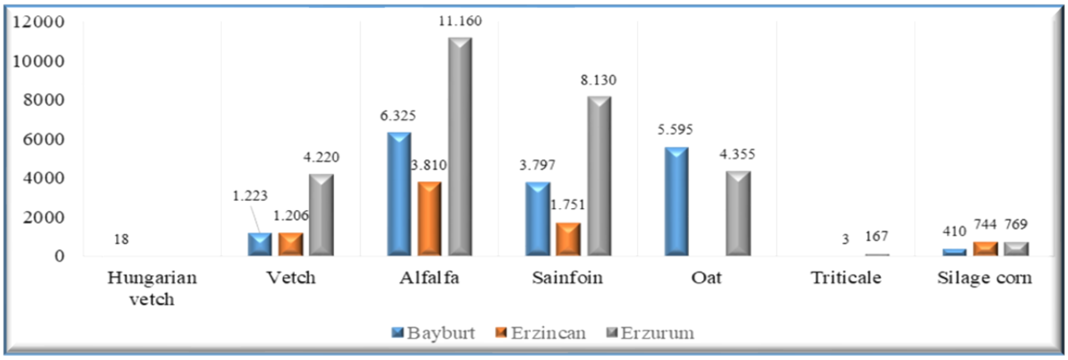


**Figure 4.** Forage crops cultivated in the study area (hectares)

**Table 4.** Some statistical data of farm and farmers

| | Age of farmers | No. of house houlds | Forage crops area sown | Sheep in farm | Cattle in farm |
|---|---|---|---|---|---|
| N/ Total | 196 | 196 | 196 | 142 | 179 |
| Mean | 45.9 | 3.47 | 91.5 | 9.95 | 14.25 |
| Mod | 40 | 2 | 10.0 | 20 | 2 |
| Std. Sapma | 12.9 | 1.49 | 113.6 | 43.7 | 17.3 |
| Minimum | 18 | 1 | 10,0 | 20 | 2 |
| Maximum | 80 | 8 | 750.0 | 300 | 122 |

The purpose of forage crops supports is to increase production, and it has been determined in this and similar studies that the aim has been achieved (Cevher et al., 2012; Ağırbaş et al., 2017). In our study; When asked about the reason for growing forage crops, 22.4% stated that they produced forage crops to benefit from supports, 21.4% stated that they produced forage crops to meet the needs of their own animals, and 18% stated that they produced forage crops because there was no market problem in forage crops (Figure 5a). Özsaglıcak & Yanar (2021) determined that 74.8% of the cattle breeding farms in Erzincan province produce forage crops, and Aşkan & Dağdemir (2016) determined in their study in the provinces of Erzurum, Erzincan and Bayburt in the TRA1 region that 82.42% of the farms produce forage crops. The absence of a market problem means that livestock is raised and used to meet the needs of one's own animals or sold to neighbours. The reason for the production of forage crops based on need is due to the fact that businesses have to carry out small-scale production (Yıldırım et al., 2001).

Although the majority of farmers stated that they were not satisfied with the support; 40% of farmers are satisfied with the support; 29.4% stated that forage plant cultivation areas increased, 19.6% stated that grass production increased and 5.2% stated that they started growing different forage crops (Figure 5b). As a result, it seems that the purpose of providing forage crops support has been achieved. The supports have led to an increase in the area planted with forage crops and forage production, and have also led to changes in farmers' cropping patterns. Similar studies have also shown that forage crop support causes the structuring of supports and the regulation of policies to be shaped according to producer requests (Balabanlı et al., 2016; Ağırbaş et al., 2017). For these reasons, the prominent factors in revealing satisfaction with supports help support policies and contribute to the literature.

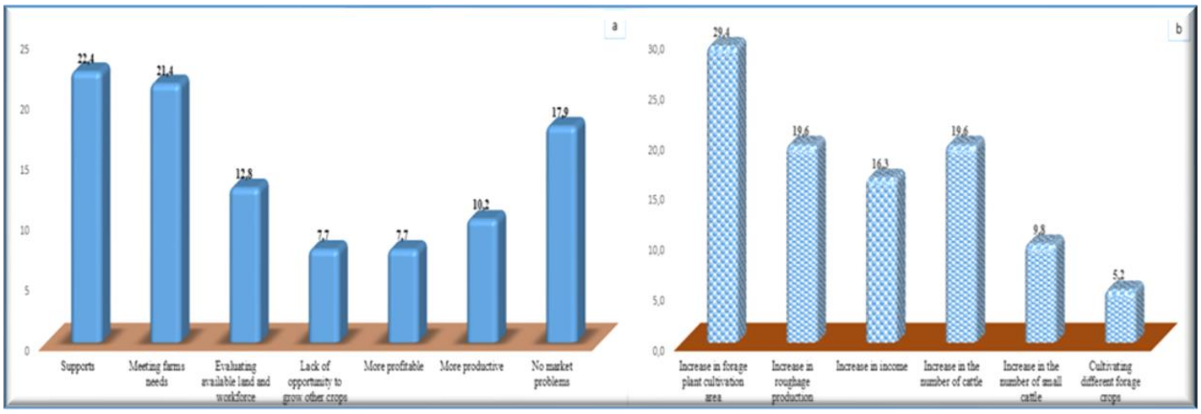


**Figure 5.** Reasons why forage crop producers prefer forage crops

Farmers stated that they encountered many problems in forage crop farming and that they had expectations to solve these problems. Forage crop producers in the study area; reducing the costs of seeds, fertilizers, pesticides and irrigation, especially diesel fuel, continuing the support for forage crops and certified seeds, and increasing the amount of support, increasing education and publishing activities, expanding the use of certified seeds, and states that forage crop species suitable for the region should have been produced. The problems faced by farmers in the study area similar with some studies conducted in Van and Ankara (Yavuz & Ceylan, 2005; Şahin & Yılmaz, 2008). Farmers; It has been stated that there are problems in irrigation, certified seeds, marketing, family labor shortage and equipment inadequacy in the cultivation of forage crops.

**Analysis results for binary logit regression model (factors affecting the satisfaction levels of forage crop supports in forage crop agriculture)**

When the satisfaction levels of supports in forage crop agriculture are examined with the logistic regression model; The model has been found to fit the data (Chi-square=124.455 p≤0,01). When $R^2$ values, which mean the percentage of explanation of the dependent variable by the independent variables, are examined; Cox&Snell $R^2$ value was calculated as 0.470 and Nagelkerke $R^2$ value was calculated as 0.636. Accordingly, it is determined that 47% and 63.6% of the variability on the dependent variable is explained by the independent variables considered within the scope of the study, respectively. The fact that this value is above 50% indicates that it is considered very important (Çokluk et al., 2021). Since the significance level in the Hosmer and Lemeshow test is 0.823≥0.05, it can be seen that the predictions of the model do not differ from the observations and the model fit is very good (Hosmer et al., 2013).

Approximately 40% of producers stated that they were satisfied with the supports. There is a negative and significant relationship between producers' finding the pasture areas inadequate, their low input costs for forage crops, and their satisfaction with the support. In other words, decreases in these factors increase their satisfaction. Among the factors that positively affect satisfaction, high yields from forage crops and livestock farming in the business indicate a significant relationship at 1% significance level, while the support amount being sufficient indicates a significant relationship at 5% significance level (Table 5).

**Table 5.** Logistic regression analysis results of factors affecting satisfaction with forage crop support

| VARIABLES | B | S.E. | Wald | P value | Exp(B) |
|---|---|---|---|---|---|
| AGE | 0.032 | 0.282 | 0,013 | 0.909 | 1.033 |
| SUFFICIENT PASTURE | -1.125 | 0.572 | 3.861 | 0.049** | 0.325 |
| YIELD OF FORAGE CROPS | 2.928 | 0.631 | 21.546 | 0.000*** | 18.691 |
| MEMBERSHIP IN AGRICULTURAL ORGANIZATIONS | -0.217 | 0.594 | 0.134 | 0.714 | 0.805 |
| MARKETING PROBLEM | -0.125 | 0.592 | 0.044 | 0.833 | 0.883 |
| COST | -1.132 | 0.672 | 2.836 | 0.092* | 0.322 |
| FARM TYPE | 1.626 | 0.542 | 9.013 | 0.003*** | 5.084 |
| EXPERIENCE | -0.476 | 0.771 | 0.382 | 0.537 | 0.621 |
| NON-AGRICULTURAL INCOME | 0.61 | 0.655 | 0.866 | 0.352 | 1.84 |
| SUFFICIENT SUPPORT AMOUNT | 1.549 | 0.678 | 5.216 | 0.022** | 4.709 |
| CONSTANT | 0.661 | 2.007 | 0.109 | 0.742 | 1.937 |

P value is significant at *0.10,**0.05,***0.01 level.

When the odd ratios of the coefficients of the model are interpreted (the odds ratio for negatively significant variables was calculated by correcting according to Tüzüntürk, 2007; Karabaş & Gürler, 2012); support from producers; It can be said that it will increase 3.08 times as long as the pastures are insufficient, it will increase 3.10 times with a unit decrease in cost, 18.6 times with a one unit increase in the yield of forage crops, 5.08 times with livestock on the farm, and 4.70 times with sufficient support amount.

The most important factors that determine producers' satisfaction with the support are the high yield from forage crops and the low cost. This is linked to the fact that producers prefer high-yield varieties, especially in recent years. They reduce the cost by using inputs more efficiently and in more appropriate amounts, and as a result, they find the amount of support received sufficient. On the other hand, due to insufficient or weak pasture areas, the need for roughage in livestock farms is high, especially in the months when the animals need to be fed indoors, and they turn to forage crop agriculture. While similar results were obtained in other studies conducted with forage plant supports (Balabanlı et al., 2016; Aksu & Dellal, 2016), in another study, the amount of forage plant support was found to be insufficient (Erdal et al., 2013).

**Analysis results for binary logit regression model (factors affecting the sustainability of forage crops cultivation)**

The rate of farmers stating that they will continue cultivating forage crops was found to be 59%. In the binary logistic regression model designed to determine the factors affecting farmers' desire to continue producing forage crops; The significance value of the model is 0.000, and since this value is less than 0.05, the model was found to be suitable for the data. Cox&Snell $R^2$ value is 0.661, Nagelkerke $R^2$ value is 0.890. Since the Nagelkerke $R^2$ value is greater than the Cox&Snell $R^2$ value, it was seen that 89% of the variance in the dependent variable of the Nagelkerke $R^2$ value was due to explanatory variables. Therefore, the representative power of the $R^2$ criteria used in logistic regression models can be described as good. The fact that these values are above 50% indicates that it is very important. In the Hosmer and Lemeshow test, it was concluded that the model fit was good since 0.529≥0.05 (Hosmer et al., 2013). When the statistical significance levels of the variables related to the most appropriate logit regression model were examined, migration and pasture adequacy were found to be significant at the 1% level, while education, alternative products, experience were found to be significant at the 5% level and non-agricultural income was found to be significant at the 10% level. When the odds ratios of the coefficients of the model given in Table 6 are interpreted; As producers become less likely to migrate, the probability of continuing forage crop production will increase by 28.57 times, the possibility of continuing forage crop production will increase 1.000 times due to insufficient pastures, one unit increase in education level will increase the probability of continuing forage crop production by 2.186 times, as the alternative crop decreases, the probability of producing forage crops will be 12.66 (adjusted odds ratio) times higher than the probability of not producing forage crops, one unit increase in the experience variable in forage crops will increase sustainability in forage crops by 19.36 times, it was determined that as non-agricultural income decreases, the probability of sustaining forage crop production will increase by 8.62 times.

**Table 6.** Logistic regression analysis results for factors affecting the tendency to continue cultivated forage crops

| VARIABLES | B | S.E. | Wald | P value | Exp(B) |
|---|---|---|---|---|---|
| AGE | -0.206 | 0.546 | 0.142 | 0.706 | 0.814 |
| EDUCATION | 0.782 | 0.404 | 3.745 | 0.053** | 2.186 |
| MIGRATION | -3.339 | 1.197 | 7.78 | 0.005*** | 0.035 |
| ALTERNATIVE CROP | -2.542 | 1.337 | 3.613 | 0.057** | 0.079 |
| SUFFICIENT PASTURE | -7.187 | 1.403 | 26.228 | 0.000*** | 0.001 |
| COST | 0.243 | 0.856 | 0.081 | 0.777 | 1.275 |
| SUITABLE LAND | 0.776 | 0.981 | 0.626 | 0.429 | 2.172 |
| FARM TYPE | 1.873 | 1.222 | 2.35 | 0.125 | 6.509 |
| SUITABLE CLIMATE | -0.742 | 1.723 | 0.185 | 0.667 | 0.476 |
| SUFFICIENT LABOR | 0.782 | 2.272 | 0.119 | 0.731 | 2.187 |
| EXPERIENCE | 2.964 | 1.454 | 4.157 | 0.041** | 19.383 |
| NON-AGRICULTURAL INCOME | -2.152 | 1.176 | 3.352 | 0.067* | 0.116 |
| CONSTANT | 2,832 | 2.797 | 1.026 | 0.311 | 16.985 |

P value is significant at *0.10,**0.05,***0.01 level.

The main factors that affect them in continuing to cultivate forage crops are the lack of desire to migrate and therefore the need to continue living in the village and the insufficient pasture areas ($p \leq 0.01$). Other factors include the farmer's good education level and experience in forage crop farming, not having a non-agricultural income, and not having an alternative product to grow (Table 6). Farmers choosing their villages as their living space and accepting agriculture as their primary source of income in the area where they will continue their lives makes their agricultural activities more efficient and sustainable. As a matter of fact, the lack of non-agricultural income was found to be another factor. It is seen that the farmers' high education levels (most farmers are high school graduates) and their experience in forage crop agriculture are also effective in their continued forage crop farming. In a study conducted in Konya; They determined that forage crop farming will be more successful in farms where producers are young, have good education levels and experience, and also where animal husbandry and crop production are carried out together (Karadavut et al., 2011). Additionally, farmers' livestock farming and pasture lands being scarce and insufficient for animal feeding have also been identified as important factors. For many producers, the lack of pasture areas or poor pastures is an important criterion for them to turn to or continue planting forage crops. Again, although the factors of land being suitable for forage crop cultivation due to topographic, ecological and meteorological factors are not considered important in the model, it emerges as an important criterion with the factor of lack of alternative products. In similar studies, it is seen that the factors that are effective in the sustainability of forage crop agriculture are almost similar (Karadavut et al., 2011; Yavuz et al., 2016).

## 4. Conclusions and Recommendations

Promotion and dissemination of forage crop production in Turkey and especially in the research region is of great importance in the region with an economy based on animal husbandry. Revealing the opinions and tendencies of producers will contribute to other studies and policies.

In the study, whether forage crop producers in the TRA-1 region are satisfied with the support, the factors affecting their satisfaction levels and the factors affecting their tendency to continue forage crop farming were examined. Research data; It was obtained by conducting a survey with 196 producers who benefit from forage crop support, determined by simple random sampling method. According to the data obtained, approximately 57% of the participants were in the 36-55 age group. 35% had high school education or above, 35.2% have non-agricultural income and 17.3% have social security, farms cultivate forage crops on an average area of 9.2 hectares; it was determined that these were alfalfa, sainfoin, oats, vetch and silage corn, respectively. In the research, it was noted that approximately 40% of the farmers were satisfied with the support they received and 60% were inclined and willing to continue the production of forage crops.

According to regression analysis results; Factors that positively affect satisfaction with the support given to forage crops: High productivity in forage crops, Livestock farming is carried out in the farms, and the amount of support provided is deemed sufficient. In farms; Producers have high levels of education and experience, Farmers have no tendency to migrate, Lack of alternative crop options to grow, and lack of non-agricultural income affect their willingness to continue cultivating forage crops. It is thought that through research on forage crop supports, as in this research, guiding results can be obtained regarding the production, marketing and policies of forage crops.

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# Changes in Feed Quality among Rangeland Sites Grazed by Different Livestock Species

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Rangelands provide valuable feed for livestock industry but the quality of feed changes among both season and plant composition. Grazing is the most important factor shaping plant composition. This study was conducted in the Umudum district of Erzurum province in 2023. In the study, three different rangeland sites, which grazed different livestock herds (only cattle, cattle + sheep, and only sheep), were examined. The study investigated available forage amounts and its some feed quality properties on the rangelands sites. The investigated parameters are amount of available forage, crude protein, NDF, ADF ratios, and RFV values. It was observed that the rangeland site grazed by only sheep herds had lowest available forage and feed quantity properties such as crude protein ratio, and RFV compared to the sites grazed by only cattle and cattle + sheep herds, whereas it had higher NDF and ADF in the sites grazed by sheep herd. The results showed that single sheep herds, which grazed uncontrolled, have the detrimental effect on forage quality by cause decreasing valuable plant species in botanical composition.

## 1. Introduction

Grazing is an important environmental factor that shapes the rangeland plant cover and structure in a particular area, however, grazing effect changes depending on size, breed and genus of the grazing animal. In general, cattle prefer grasses and leave 3-4 cm stubble while sheep utilize forbs efficiently and leave less than 1 cm stubble (Altın et al., 2011). Therefore, detrimental effect of sheep herds is more pronounced under heavy grazing pressure. Grazing pressure can be understand easily estimating available forage on the grazing area. As grazing pressure increase, available forage get decrease (Güllap, 2010; Yu et al., 2024).

Additionally, while moderate grazing is a necessary factor for sustainable production, over grazing practices have had adverse effects on production, the condition and health of rangelands (Koç and Gökkuş, 1994; Çomaklı et al., 2012; Aydoğdu et al., 2020; Gökkuş, 2020). Grazing has been reported to both reduce plant species diversity in dry forest areas (Schulz et al., 2019) and enhance plant species diversity in grazed rangeland sites (Gonzalez-Hernandez et al., 2020). The positive and negative effects of heavy, moderate, and light grazing on plant species diversity and production have been identified in many studies (McNaughton, 1983; Cardinale et al., 2012).

Heavy grazing has been reported to decrease the plant and shrub diversity in rangeland areas (Zhao et al., 2006), with some species disappearing while others persist based on morphological or physiological characteristics (Wang et al., 2002). If herd sizes remain constant and grazing areas continuously decrease, the plant species diversity decreases with grazing levels dropping (Haynes et al., 2013). In contrast, light and moderate grazing have been shown to increase plant diversity by reducing the dominance of any particular plant species and suppressing others (SRM, 2003). The

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potential impact of grazing intensity varies significantly depending on animal size and grazing habits (Yunusbaev et al., 2003; Altın et al., 2011; Erkovan, 2016). Cattle prefer to graze on taller plants, using their tongues to pull in to mouth and cut plants with a minimum height of 5-6 cm. Additionally, cattle, having a higher capacity for consuming grass and seeds compared to small ruminants, contribute significantly to the change in plant composition by allowing the spread of seeds through their dung (Bakker and Olff, 2003). Sheep, on the other hand, have slender, mobile lips and selectively bite plants and shoots, grazing on single leaves with a height of 3 cm when conditions permit. Compared to cattle, sheep are observed to be more selective in their grazing habits, showing a preference for forbs which are untasted for cattle (Rose et al., 2012).

Livestock grazing has a significant impact on the soil, and this effect is largely associated with the reduction of vegetation cover in rangelands (Oztas et al., 2003; Monaghan et al., 2017; Abdalla et al., 2018). Intensive grazing in rangelands leads to a considerable deterioration of soil physical properties such as permeability, infiltration, pore volume and function, bulk density, and structural aggregation (Monaghan et al., 2017; Laurenson et al., 2018). The degree of soil disturbance during grazing in rangelands varies significantly depending on factors such as hoof pressure (Greenwood and McKenzie, 2001; Hu et al., 2018), grazing duration (Drewry et al., 2003), and the history of previous grazing events (Cournane et al., 2011). Additionally, as a result of grazing, significant increases can occur not only in the volume weight of the soil but also in the pH value (Evans et al., 2012). This effect may vary based on the intensity of grazing and the moisture content of the soil (Çetiner et al., 2012; Lenssen et al., 2013). Grazing different types of livestock on rangelands can also impact soil properties to varying degrees. Cattle, despite being heavier than sheep and exerting more pressure on the soil, may contribute to better soil conditions in the grazed areas due to their less intensive trampling (Erkovan et al., 2016).

In various district across Turkey and particularly in the Eastern Anatolia Region, which constitutes 34.8% of our country's rangeland areas, numerous studies have been conducted on rangelands (Yavuz et al., 2012; Çınar et al., 2014; Ünal et al., 2014; Çomaklı et al., 2015; Uzun et al., 2015; Alay et al., 2016; Erkovan et al., 2016; Koç and İleri, 2016; Reis and Şen, 2017; Seydoşoğlu et al., 2018). However, upto date, no study has been conducted on grazing sites involving single herd or mixed grazing. Therefore, this study aims to determine the effects of grazing practiced different livestock species on the forage quality of rangelands. Additionally, based on the data obtained, efforts will be made to develop rangeland management plans suitable for each type of livestock.

In various provinces across Turkey and particularly in the Eastern Anatolia Region, which constitutes 34.8% of our country's rangeland areas, numerous studies have been conducted on rangelands (Yavuz et al., 2012; Çınar et al., 2014; Ünal et al., 2014; Çomaklı et al., 2015; Uzun et al., 2015; Alay et al., 2016; Erkovan et al., 2016; Koç and İleri, 2016; Reis and Şen, 2017; Seydoşoğlu et al., 2018). However, to date, no study has been conducted on grazing sites involving both sheep and cattle or a combination of both. Therefore, this study aims to determine the effects of grazing different livestock species on the forage quality of rangelands. Additionally, based on the data obtained, efforts will be made to develop rangeland management plans suitable for each type of livestock.

## 2. Materials and Methods

The study was conducted in the Umudum district of Yakutiye town of Erzurum Province, in the year of 2023. Three rangelands site where was similar to each other grazed with different herds was selected the total rangeland area in Umudum district 3. 281 ha, with a livestock population of 2.797 cattle and 100 sheep LSU. Vegetation survey were carried out during the flowering stage of common plants in the second week of July (Gökkuş et al., 2000). The rangeland sites and their using practices are given in the Table 1.

Erzurum has a continental climate and long-term average temperature is 5.6 $^{o}$C and precipitation is 429 mm. Winters are generally cold and snowy, while summers are hot and dry. Although the research was conducted in 2023, presented the years of 2022 climate data because autumn precipitation of previous year had significant impact on rangeland vegetation (Koç, 2001). The humidity, temperature, and relative humidity values for that years are shown in Figure 1. In the year 2023 when the study was conducted, it was determined that the recorded temperature value (7,89 °C) were higher than the long-term average temperature value (5,75 °C). The highest temperature recorded in the year of the study occurred in August. The lowest temperature recorded in the year 2023 was -7,9 °C in February, while the lowest temperature recorded in the long-term average was -9,1 °C in January (Figure 1).

**Table 1.** Grazing practices and size of the rangeland sites

| | |
|---|---|
| Rangeland site I | In this rangeland site are grazed by only cattle herd, and the allocated area is approximately 1.881 ha. The Herd size is average 2.797 Livestock unit (LU). Allocated area per LU is 0,67 ha. |
| Rangeland site II | In this rangeland site are grazed by mixed herd of cattle and sheep and the allocated area is approximately 1.300 ha. The herd size is average 2.897 LU. Allocated area per LU is 0,45 ha |
| Rangeland site III | In this rangeland site grazed by only sheep herd, and the allocated area is approximately 100 ha. The herd size is about 100 LU. Allocated area per LU is 1 ha |

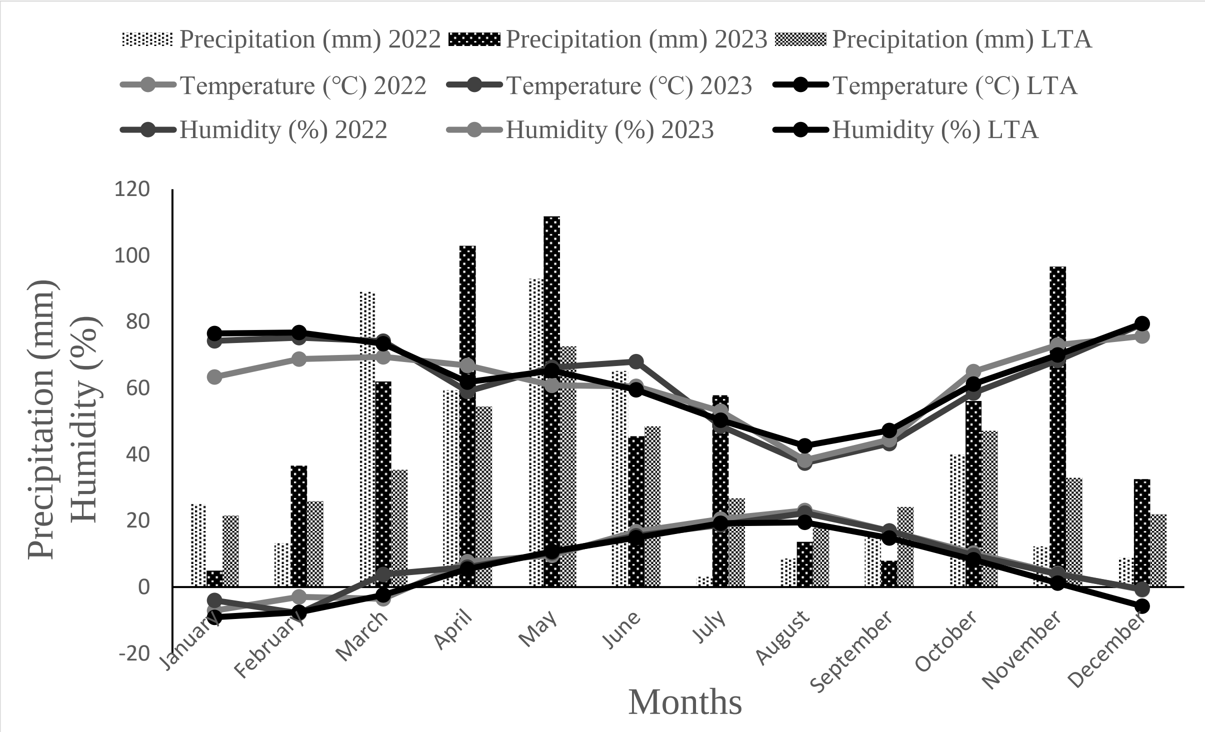


**Figure 1.** Some climate data of Yakutiye District of Erzurum Province in 2022, 2023, and long-term average (LTA).

The recorded relative humidity values for long term average and observed years were 62,7%, 61,60%, and 63,70%, respectively. While relative humidity was higher during cold moths; it was lower during hot summer months. In the experimental year, the total annual precipitation was higher (mm) than long term average (429 mm) (Figure 1).

According to the soil samples taken from the study area, the texture classes of the three-rangeland site I, II and III were recorded as clay-loam, clay-loam, and sandy-loam, respectively (Ergene, 1993). Among the rangeland sites, site I had the highest aggregate stability at 66,28%, while site III had the lowest aggregate stability at 24,23% (Demiralay, 1993). Soil pH of the all sites indicated a slightly acidic character (Sağlam, 1994). The electrical conductivity (EC) values determined in the rangeland sites ranged between 0,171 and 0,224, suggesting that there is no issue with salinity (Richards, 1954). The organic matter content in the soils taken from rangeland sites showed variations between 1,39% and 5,36%, with the rangeland site grazed by cattle having a higher organic matter content (Aydın and Sezen, 1995). The content of plant available phosphorus was determined based on the method stated by Olsen and Summer (1982), it was found to be 82,5 kg $ha^{-1}$ in the rangeland site I, 63.2 kg $ha^{-1}$ in the site II, and 32,5 kg $ha^{-1}$ in the site III. The potassium (K), sodium (Na), and calcium (Ca) contents of the three different rangeland sites, determined based on the method established by Sağlam (1994), showed variations in the ranges of 1,24-1,63 me $100^{-1}$, 0,08-0,15 me $100^{-}$

$^{1}$, and 3,43-4,20 me $100^{-1}$, respectively. Variance was first applied to the values obtained from the pasture sections in the SPSS package programme and then Duncan multiple comparison test was used to compare the values (Yıldız and Bircan, 1994).

## 3. Results and Discussion

### The amount of available forage

The amounts of available forage amount are recorded as 982,7 kg $ha^{-1}$, 641,8 kg $ha^{-1}$, and 312,0 kg $ha^{-1}$ for the rangeland site I, II and III, respectively.

Grazing livestock generally rely on their senses of touch, sight, and smell when selecting their food. Livestock feeding in this manner prioritizes young leaves, older leaves, green stems, and finally, older stems in terms of preference. However, significant differences exist in grazing behavior among different livestock species. For instance, sheep tend to be more selective, generally preferring legumes and other plant species with high palatability (Harper, 1977; Hodgson, 1990; Rose et al., 2012; Erkovan et al., 2016). Despite not being able to grasp and wrap around plants effectively due to their split upper lips, sheep engage in grazing close to the soil surface (Çavuşoğlu and Akyürek, 2017). In conclusion, sheep are likely to leave less residue compared to cattle in areas grazed by sheep, as they are more selective in their foraging habits (Sanon et al., 2007; Rose et al., 2012; Erkovan et al., 2016). Additionally, in areas where small ruminants graze, they may have smaller spatial coverage compared to other types of grazed areas (Table 1). Despite smaller body sizes and lower pressure applied per unit area compared to large ruminants, small ruminants, especially sheep, may move more extensively in the rangeland (Golodets and Boeken 2006; Sydes and Miller 1988; Vickery et al., 2001; Li et al., 2008). In addition to all these factors, it is thought that the heavy grazing of the area from the past to the present also has an effect, and especially the bottom grazing of sheep (Erkovan et al., 2016) is also thought to be effective in the formation of such a difference between rangeland sections.

**Table 2.** The amount of available forage and variance analysis results of rangeland sites grazed by different livestock species

| The amount of available forage (kg $ha^{-1}$) | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | Site I | Site II | Site III | Average | F Value |
| | 982,7 A | 641,8 B | 312,0 C | 645,5 | 58,940** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

### Crude protein ratio

The crude protein ratios determined in site I, II and III are 14,26, 11,9%, and 9,00%, respectively. The difference among them has shown significance at the 1% significance level (Table 3).

The observed difference in crude protein ratios among rangeland sites may be attributed to the presence of different livestock species in each site. Specifically, sheep, due to their unique mouth structure (Koyuncu and Tuncel, 2010), tend to be more selective grazers compared to cattle and they preferentially graze leaves and forbs especially legumes which have higher crude protein content (Bakır, 1987; Grace et al., 2002; Altın et al., 2011; Rose et al., 2012; Koç and İleri, 2016). Consequently, ungrazed residues which presented as available forage had lover as sheep density increase in the sites.

### NDF ratio

The Neutral Detergent Fiber (NDF) ratio, consisting of cellulose, lignin, and hemicellulose (Rayburn, 2004), was determined to be an average of 51,34% and it changed between 44,79 and 56,52 % among the rangeland sites (Table 4). The observed difference in NDF ratios among rangeland sites may be attributed to the general preference of sheep for plants with high energy value and nitrogen content and low cellulose content in the botanical composition (Ünal and Akçapınar, 1994).

**Table 3.** Crude protein ratios and variance analysis results of rangeland sites grazed by different livestock species

| Crude protein ratio (%) | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | Site I | Site II | Site III | Average | F Value |
| | 14,26 A | 11,97 B | 9,00 C | 11,74 | 74,442 ** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

**Table 4.** NDF ratios and variance analysis results of rangeland sites grazed by different livestock species

| NDF (%) | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | Site I | Site II | Site III | Average | F Value |
| | 44,79 C | 52,71 B | 56,52 A | 51,34 | 97,682** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

Indeed, the findings of our study are in line with similar research (Bilgen and Özyiğit, 2005; Erkovan et al., 2016; Çavuşoğlu and Akyürek, 2017; Çelik, 2019) that indicates a decrease in legumes sensitive to grazing (Çomaklı et al., 2021) with sheep grazing. Additionally, the results obtained in our study regarding the NDF ratios parallel the findings of Aydın et al., 2014 (46,59-47,69%), Çaçan et al., 2014 (43,31-50,86%), Özaslan Parlak et al., 2015 (43,18-51,57%), and Taşdemir, 2015 (49,00-56,00%).

### ADF ratio

The Acid Detergent Fiber (ADF) ratio, consisting of structural carbohydrates and including cellulose-lignin (Anonymous, 2011), has varied between 36,33% and 42,07% in areas grazed by different types of animals. The ADF ratio determined in the study, with a value of 36,33%, is noted to be lower in areas grazed by cattle compared to areas grazed by sheep with a ratio of 42,07% (Table 5).

The observed variation in ADF ratio in the study, as evident from the examination of Table 5, may be due to the different intensities and livestock species grazing among the rangeland sites. Because intensive grazing can lead to a reduction in rangeland cover and height, it consequently results in a decrease in rangeland site productivity and a significant decline in particularly palatable livestock species that contribute to the botanical composition (Zhang et al., 2006). Intensive grazing by sheep can lead to a decrease in the amount of forage consumed by livestock, increasing the need for nutrients that provide high levels of energy for livestock to be adequately nourished. Because sheep tend to be more selective grazers compared to cattle (Spedding, 1965; Karslı and Küçük, 2000; Glindemann et al., 2009; Erkovan et al., 2016; Koç and İleri, 2016) and they choose more palatable legumes and other family species (Traczyk and Kotowska, 1976; Losvik, 1993; Bakoğlu, 1999; Rose et al., 2012; Erkovan et al., 2016), it seems likely that in the studied rangeland site, where high-quality vegetation cover is lacking due to intensive sheep grazing, the ADF ratio is higher in areas grazed by sheep.

### Relative feed value (RFV)

The Relative feed value (RFV), determined based on the digestion and consumption of dry matter, has been found to vary between 93,10 and 125,84 among the rangeland sites.

This value, which varies according to plant composition and plant parts, it decreases with the increase in ADF and NDF ratios (Canbolat and Karaman, 2009; Temel et al., 2015; Gürsoy and Macit, 2017; Tan et al., 2019). The results consisted with the NDF and ADF content of the hay obtained from the sites.

**Table 5.** ADF ratios and variance analysis results of rangeland sites grazed by different livestock species

| ADF (%) | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | Site I | Site II | Site III | Average | F Value |
| | 36,33 B | 39,68 A | 42,07 A | 39,36 | 7,013** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

**Table 6.** Relative feed value (RFV) and variance analysis results of rangeland sites grazed by different livestock species

| RFV | Rangeland Sites | | | | |
|---|---|---|---|---|---|
| | Site I | Site II | Site III | Site I | F Value |
| | 125,84 A | 102,48 B | 93,10 C | 107,14 | 71,759** |

** significant F value at 1%, * significant F value at 5%. ns: non-significant

## 4. Conclusions

When the results obtained from the rangeland sections grazed by different breeds of animals were evaluated as a whole, it was noted that especially the rangeland section grazed by sheep exhibited a very bad trend in terms of both the amount of available forage obtained and forage quality compared to the other sections. In addition, significant decreases in feed quality were determined in the pasture section where cattle and sheep were grazed together, and it is thought that the preference of sheep for broad-leaved plant species in general has an important effect. When an evaluation is made in terms of erosion in the pasture sections where the study was carried out, we can say that the section grazed by cattle has a very low erosion risk compared to the other sections. To summaries the study, it should never be ignored that sheep and cattle should be grazed in a controlled manner in mixed grazing in order to ensure that the rangeland are not grazed above their capacity and that the species components show a proper distribution in terms of a sustainable pasture. In addition, it is very important in terms of rangeland management to graze with the animal species suitable for the type of rangeland in the grazing season in order not to spoil the structure of the pasture and to get the maximum yield from the rangeland.

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Research

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# Determination of Seasonal Changes of Feed Value of Common Grazable Species in Aşağı Gökdere Macquis Shrublands

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A B S T R A C T

This study was conducted in the years of 2018-2020 to determine the feed value of common shrub species that can be grazed in the maquis area around Aşağı Gökdere village of Isparta. Ten species (*Quercus coccifera, Quercus infectoria, Quercus cerris, Phillyrea latifolia, Spartium junceum, Crataegus monogyna, Paliurus spina-christi, Juniperus oxycedrus, Cistus creticus* and *Arbutus andrachne*) were used in the study. Leaf samples were collected from these species in each season. Dry matter content, crude protein content, NDF, ADF, total digestible nutrients, relative feed value and tannin content were determined. According to the analysis of variance, the differences between seasons and shrub species were found to be statistically significant in all traits analyzed.

According to the two-year averages, when the seasons were compared, the highest crude protein content, total digestible nutrients and relative feed value were obtained in spring, decreased as the seasons progressed, and the lowest values were obtained in winter. The lowest dry matter ratios, ADF and NDF values were obtained in spring and they increased in parallel with the progression of the seasons. The lowest condensed tannin ratios were obtained in spring and summer, while the highest values were determined in autumn.

When the species were compared, the lowest dry matter and condensed tannins contents were found in *Spartium junceum*, while NDF and ADF ratios were found in *P. spina-christi*. The highest crude protein content was determined in *Quercus infectoria*, while total digestible nutrients and relative feed value were determined in *P. spina-christi* species. As a result, it was observed that shrubs, shrub-formed trees and shrubs in the maquis have an important potential as high quality feed for ruminants during the critical period in semi-arid and arid regions.

## 1. Introduction

The areas under the influence of the Mediterranean climate type in the world are around 100 million ha (Le Houerou, 1981). 32 million hectares of these areas are located in countries bordering the Mediterranean Sea. There are approximately 7.5 million hectares of maquis in Turkey and almost all of them are under the influence of the Mediterranean climate. (Baytekin et al., 2005). Maquis vegetation can spread in all kinds of soil conditions from acidic soils to basic soils. Due to their wide adaptability, maquis species have spread from sea level to the mid-alpine zone of high mountains and from arid to semi-arid regions (Tsiouvaras, 1987). In places where the summer dry period is severe, after the herbaceous layer dries up, the grasses lose their fodder quality and are not sufficient to meet the basic needs of animals. Shrubs can retain their greenery during this period and can provide much better-quality nutrients than dried grasses. Changes in plants depending on climate factors also affect

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the grazing habits of animals (Papachristou and Papanastasis, 1994; Temel and Tan, 2013; Gökkuş et al., 2009; Bakoğlu et al., 1999; Koç, 2000). Gutman et al. (1999) stated that herbaceous species are densely present in the vegetation during the early growth periods, they withdraw from the vegetation with maturity, but shrub and tree species are continuous throughout the year. Evergreen and deciduous shrubs and woody species are important sources of food for animals when herbaceous species are not available or are too few to meet the needs of animals (Silva-Pando et al., 1999; Temel and Kır, 2015).

Shrub communities with high fibre content (maquis and garig) are important feed resources for animals. Young shoots and leaves of these species contain more nutrients than herbaceous species in their young stages. Especially in the summer period, their feeding properties are very important (Dzowela et al., 1995; Tolera et al., 1997; Kamalak, 2006; Narvaez et al., 2010; Kökten et al. 2012; Dökülgen and Temel 2015; 2019; 2020). Because shrubs can largely meet the protein needs of grazing animals. In addition, they are important roughage sources at the end of winter and in summer, and especially their seeds are indispensable feed sources for wildlife in winter (Koç, 2000). Due to these characteristics, shrubs contribute to sustainable agriculture and have the potential to do much more. This great potential has found a serious place in the studies of scientists in our country only in the last 20 years, and many more issues related to shrubs are waiting to be studied.

In this study, it was aimed to determine the seasonal changes in the feed values of grazable common shrub species around Aşağı Gökdere village of Isparta.

## 2. Materials and Methods

This study was conducted in 2018-2020 in the shrubland area around the village of Aşağı Gökdere in Isparta (37° 32' 53.55" N, 30° 46' 18.65" E, 351 m). According to the climate data, annual total precipitation values in Aşağı Gökdere were 770.20 mm in 2018 and 848.80 mm in 2019, lower than the long-term average (856.0 mm). The average temperature was 14.58 ºC in 2018 and 14.05 ºC in 2019, higher than the long-term average (14.03 ºC). Average relative humidity values were 60.78% in 2018 and 60.15% in 2019, higher than the long-term average (58.21%).

The soils in Aşağı Gökdere are sandy-clay texture, salt-free (0.12 dS/m), lime content is below 2.5% and classified as non-lime, pH value is 7.40, slightly alkaline and organic matter content is below 2%.

Preliminary studies on the species included in the study and their locations were carried out in April 2018 and 10 common species with forage potential in the region were identified and their locations were marked with a GPS device (Table 1).

Leaf samples of the identified species were collected from the parts of the plants where animals can graze in each season (spring, summer, autumn and winter) in 2018 and 2019 (Alatürk et al., 2014). During sampling, 5 plants were selected from each species in each season. The locations of all sampled plants were determined with a GPS device, the plants were labelled and the same plants were sampled in each season. Spring samples were collected in April, summer samples in July, autumn samples in October and winter samples in February. Winter samples could not be taken from all plants due to defoliation of some species.

During the sampling periods, sufficient samples were taken for chemical analysis from each plant were dried in a drying oven at 65°C for 48 hours and kept at room humidity for 24 hours, then weighed on a 0.1 g sensitive balance and dry grass weights were determined. Dry matter was calculated as percentage by using the values obtained (Cevheri and Avcioglu, 1998).

**Table 1.** Species identified in the study

| | Turkish Name | Latin Name | Family |
|---|---|---|---|
| 1 | Kermes Meşesi | *Quercus coccifera* L. | *Fagaceae* |
| 2 | Mazı Meşesi | *Quercus infectoria* Olivier | *Fagaceae* |
| 3 | Saçlı Meşe | *Quercus cerris* L. | *Fagaceae* |
| 4 | Akçakesme | *Phillyrea latifolia* L. | *Oleaceae* |
| 5 | Katırtırnağı | *Spartium junceum* L. | *Fabaceae* |
| 6 | Adi Alıç | *Crataegus monogyna*. Lindm. | *Rosaceae* |
| 7 | Karaçalı | *Paliurus spina-christi* Mill. | *Rhamnaceae* |
| 8 | Katran Ardıcı | *Juniperus oxycedrus* L. | *Cupressaceae* |
| 9 | Tüylü Laden | *Cistus creticus* L. | *Cistaceae* |
| 10 | Sandal | *Arbutus andrachne* L. | *Ericaceae* |

After the shrub samples obtained were dried and ground, the amount of nitrogen was determined by Kjeldahl method, the value found was multiplied by 6.25 and crude protein ratios were determined (Helrich, 1990). NDF and ADF analyses were performed with the help of ANKOM 220 Fibre Analyser device according to the principles reported by ANKOM technology (Ankom, 2017). Condensed tannin content was determined according to the butanol-HCl method described by Makkar (2003). Total digestible nutritive value and relative feed value were calculated according to Horrocks and Vallentine (1999) (1, 2, 3, 4).

TDN = (-1.291 x ADF%) + 101.35 (1)
DMI = 120 / NDF% dry matter basis (2)
DDM = 88.9 – (0.779 x ADF dry matter basis) (3)
RFV = DDM% x DMI% x 0.775 (4)

NDF: Neutral Detergent Fiber
ADF: Acid Detergent Fiber
TDN: Total digestible nutrients
DMI: Dry matter intake
DDM: Digestible dry matter
RFV: Relative feed value

The results obtained in the study were subjected to statistical analysis by using SAS computer package programme according to factorial trial design in random blocks. Duncan multiple comparison test was used to compare the differences between means (Düzgüneş et al., 1987).

## 3. Results and Discussion

According to the variance analysis results of the data obtained from the study, season, species and season x species interaction had a statistically significant effect at the 1% level on all examined traits (Table 2).

In terms of seasonal averages, the highest dry matter ratio was obtained in autumn (60.55%) and the lowest value was obtained in spring (42.42%). The highest dry matter content among shrub species was obtained from *C. monogyna* with 62.06% and the lowest value was obtained from *S. junceum* with 46.20%. When the seasons are evaluated separately, *P. latifolia*, *C. monogyna*, *J. oxycedrus*, *Q. infectoria* and *Q. cerris* (47.43%, 49.85%, 47.33%, 44.23% and 43.95%) in spring, *C. monogyna* (70.90%) in summer, *P. latifolia*, *C. monogyna*, *Q. coccifera*, *J. oxycedrus* and *Q. cerris* (63.22%, 65.43%, 63.04%, 58.14% and 65.88%) in autumn, *Q. coccifera* (67.21%) in winter has a higher dry matter ratio than other species. The lowest values were obtained in *S. junceum* in spring, *S. junceum* and *A. andrachne* in summer, *P. spina-christi*, *S. junceum*, *C. creticus* and *A. andrachne* in autumn, *S. junceum* and *C. creticus* in winter. In seasonal averages, dry matter ratios increased until autumn and decreased in winter. However, in some species (*C. monogyna*, *P. spina-christi*) the highest values were determined in summer and in some species (*Q. coccifera*) in winter, and the differences in the rates of increase and decrease caused the species x season interactions to be significant (Table 3). The dry matter ratios were lowest in spring when the plants were green and juicy and increased to their highest level in the following seasons due to the decrease in air relative humidity and the drying of the plants. Similar results were found in other studies that analysed the seasonal variation of dry matter content in shrub leaves (Lyons et al., 1996; Muruz et al., 2000; Khorchani et al., 2000; Pollock et al., 2007; Gökkuş et al., 2009; Tölü, 2009; Tolunay et al., 2009).

**Table 2.** Results of variance analysis (Mean Squares)

| Sources of Variation | Df | | DM Ratio | CP Ratio | ADF Ratio | NDF Ratio | TDN Ratio | RFV | Tannin Content |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | | | | | | | |
| **Block** | 2 | 2 | 1.73 | 1.31 | 3.60* | 16.98** | 6.01* | 708.97** | 0.07 |
| **Year (Y)** | - | 1 | 257.28** | 8.51** | 1.29 | 1.11 | 2.15 | 65.72 | 1.37 |
| **Season (S)** | 3 | 3 | 3676.18** | 236.77** | 248.62** | 759.98** | 414.46** | 25839.92** | 16.63** |
| **Species (Sp)** | 9 | 9 | 519.93** | 60.58** | 1686.83** | 2014.28** | 2811.31** | 101012.61** | 109.90** |
| **S*Y Interaction** | - | 3 | 193.03** | 2.92* | 2.07 | 2.02 | 3.47 | 77.40 | 0.39 |
| **Sp*Y Interaction** | - | 9 | 34.64** | 0.65 | 0.50 | 1.13 | 0.84 | 41.96 | 0.81 |
| **S*Sp Interaction** | 27 | 27 | 72.68** | 17.09** | 16.52** | 36.47** | 27.52** | 1247.41** | 2.66** |
| **S*Sp*Y Interaction** | - | 27 | 18.88** | 1.73** | 0.55 | 0.88 | 0.91 | 48.68 | 0.26 |
| **Error** | 66 | 158 | 2.77 | 0.74 | 1.02 | 0.86 | 1.70 | 63.08 | 0.60 |

*P<0.05,**P<0.01, Df: Degrees of freedom, DM:Dry matter, CP:Crude protein, ADF: Acid detergent fiber, NDF: Neutral detergent fiber, TDN: Total digestible nutrient, RFV: Relative feed value.

**Table 3.** Two-year average dry matter rates determined in the study (%)

| Shrub Species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 47.43 k-m | 58.56 f-j | 63.22 b-d | 58.99 e-h | **57.05 c** |
| *Spartium junceum* | 31.03 p | 49.14 k | 54.41 ij | 50.23 k | **46.20 g** |
| *Juniperus oxycedrus* | 47.33 k-m | 58.14 g-j | 64.58 b-d | 62.53 c-f | **58.15 c** |
| *Cistus creticus* | 41.75 no | 58.69 f-i | 55.22 h-j | 48.24 kl | **50.97 e** |
| *Arbutus andrachne* | 40.30 no | 47.31 k-m | 56.14 h-j | 54.17 j | **49.48 f** |
| *Quercus coccifera* | 40.17 no | 65.58 b-d | 63.04 b-e | 67.21 ab | **59.00 b** |
| *Quercus infectoria* | 44.23 l-n | 55.04 h-j | 61.46 d-g | - | **53.57 d** |
| *Quercus cerris* | 43.95 mn | 66.87 bc | 65.88 bc | - | **58.90 b** |
| *Paliurus spina-christi* | 38.20 o | 57.12 h-j | 56.16 h-j | - | **50.49 ef** |
| *Crataegus monogyna* | 49.85 k-m | 70.90 a | 65.43 b-d | - | **62.06 a** |
| **Mean** | **42.42 d** | **58.74 b** | **60.55 a** | **56.90 c** | |

There is no statistical difference between the averages shown with the same letter.

When the average crude protein ratios are examined, it is seen that there is a significant difference between the seasons and crude protein ratios decreased with the progression of the seasons. The highest value was obtained in spring with 12.68% and the lowest value was obtained in winter with 7.20%. The highest crude protein ratios were obtained from *Q. infectoria* and *Q. cerris* with 12.09% and 11.94%. The lowest value was obtained from *J. oxycedrus* with 6.49%. Especially in the measurements in spring, it is seen that evergreen plant species have lower values in terms of crude protein ratio compared to other species. When the crude protein ratios of the species in Aşağı Gökdere are examined in terms of seasons, it is seen that *Q. infectoria* in spring, *P. spina-christi*, *Q. coccifera*, *Q. coccifera*, *C. creticus*, *Q. infectoria* and *Q. cerris* in summer, *C. monogyna*, *Q. coccifera* and *S. junceum* in autumn, *C. monogyna*, *Q. coccifera* and *S. junceum* in autumn and *S. junceum* in winter have the highest crude protein ratio. The lowest crude protein ratios were obtained from *J. oxycedrus* in spring, *J. oxycedrus* and *A. andrachne* in summer, autumn and winter. When comparing species in spring, it should not be overlooked that all the leaves of plant species that shed their leaves in winter are young in this season, while mature and young leaves are found together in evergreen plant species. When evergreen species were evaluated within themselves, the highest crude protein content was found in *A. andrachne* in spring, *Q. coccifera* and *C. creticus* in summer, *S. junceum* and *Q. coccifera* in autumn, and *S. junceum* in winter. The irregular seasonal variation in crude protein ratios of some species examined caused the species x season interaction to be significant in two-year averages (Table 4).

**Table 4.** Two-year average crude protein ratios determined in the study (%)

| Shrub species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 11.25 d-f | 7.89 k-m | 7.11 m-o | 6.82 m-p | **8.26 d** |
| *Spartium junceum* | 10.21 e-i | 9.06 h-k | 9.84 g-j | 9.71 g-j | **9.71 c** |
| *Juniperus oxycedrus* | 7.01 m-o | 6.46 n-p | 6.88 m-p | 5.60 p | **6.49 e** |
| *Cistus creticus* | 11.43 de | 10.09 f-j | 7.89 k-m | 7.92 k-m | **9.33 c** |
| *Arbutus andrachne* | 14.24 c | 6.75 m-p | 6.04 op | 5.59 p | **8.15 d** |
| *Quercus coccifera* | 12.18 d | 10.03 f-j | 9.04 h-k | 7.57 l-n | **9.70 c** |
| *Quercus infectoria* | 18.31 a | 10.34 e-h | 7.61 m-l | - | **12.09 a** |
| *Quercus cerris* | 16.14 b | 10.73 e-g | 8.94 i-k | - | **11.94 ab** |
| *Paliurus spina-christi* | 16.18 b | 10.82 e-g | 7.23 m-o | - | **11.41 b** |
| *Crataegus monogyna* | 9.81 g-j | 8.81 j-l | 9.00 i-k | - | **9.21 c** |
| **Mean** | **12.68 a** | **9.09 b** | **7.96 c** | **7.20 d** | |

While the highest crude protein ratios in leaves of all species were obtained in spring, crude protein ratios decreased in parallel with the progression of the seasons. As the growth rate slows down with the advancement of maturation in plants, the synthesized assimilates are stored in the form of carbohydrates and the crude protein ratio decreases accordingly (Koç et al., 2000). Similar results were obtained in many studies where changes in crude protein ratios of shrubs were monitored (Pollock et al., 2007; Gökkuş et al., 2009; Muruz et al., 2000; Lyons et al., 1996; Khorchani et al., 2000; Tölü, 2009; Ayhan et al., 2009; Tolunay et al., 2009; Aygün et al., 2018; Dökülgen and Temel, 2020). Considering that the crude protein ratio of forages used in feeding ruminants should be at least

10.60% (NRC, 2001), *P. latifolia*, *P. spina-christi*, *Q. coccifera*, *C. creticus*, *Q. infectoria*, *A. andrachne* and *Q. cerris* in spring and *P. spina-christi* and *Q. cerris* in summer produced forage with sufficient crude protein ratio for animals. In terms of crude protein ratios, *P. spina-christi*, *Q. infectoria* and *Q. cerris* were the prominent species.

The lowest NDF rates were obtained in spring with 33.12%, the NDF rate increased depending on the progression of the seasons and the highest values were obtained in winter with 46.31%. While the lowest NDF rate among the species was obtained from *P. spina-christi* with 22.00%, the highest NDF rate was obtained from *S. junceum* with 63.27%. When the seasons are evaluated separately, it is seen that *S. junceum* has a higher NDF rate compared to other species in all seasons. The lowest NDF rates were detected in *P. spina-christi* in spring, summer and autumn, and in *A. andrachne* in winter. When evergreen species are evaluated among themselves, the lowest NDF rate in all seasons was obtained from *A. andrachne*. The irregular seasonal variation in NDF ratios of some species examined caused the species x season interaction to be significant (Table 5). While the lowest NDF rates were obtained in spring, NDF rates increased as the seasons progressed. Similar findings have been revealed by many researchers (Castle, 1982; Holechek et al., 1989; Huston and Pinchak, 1991; Steen, 1992; Gonzalez–Andres and Ceresuela, 1998; Ventura et al., 1999; Ventura et al., 2004; Pecetti et al., 2007; Frost et al., 2008; Özarslan Parlak et al., 2011a; Özarslan Parlak et al., 2011b, Özarslan Parlak et al., 2011c, Bouazza et al., 2012; Aygün et al., 2018; Yüksel and Arslan Duru, 2019). Kökten et al. (2012) in their study examining the changes in nutritional value of different species, they found that the NDF ratio increased as the ripening period progressed in all species. It is known that at the beginning of growth, the majority of the cell protoplasm content of plants consists of water and cell wall substances are at low levels. Cell wall substances are associated with the presence of mature cells rather than young cells (Lyons et al., 1996). The amount of stem and cell wall substances responsible for the fibrous structure increases as the plant matures (Akyıldız, 1966; Griffin and Jung, 1983; Nelson and Mooser, 1994; Papachristou and Papanastasis, 1994; Koç et al., 2000; Açıkgöz, 2001; Frost et al., 2008). This increase leads to a significant reduction in the digestibility of the plant (Jung and Allen, 1995).

**Table 5.** Two-year average NDF ratios determined in the study (%)

| Shrub species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 33.57 l | 34.85 k | 36.44 ij | 37.87 h | **35.68 f** |
| *Spartium junceum* | 54.17 c | 64.30 b | 67.01 a | 67.58 a | **63.27 a** |
| *Juniperus oxycedrus* | 35.98 jk | 41.77 g | 46.74 f | 52.22 d | **44.18 c** |
| *Cistus creticus* | 27.95 q | 32.37 mn | 36.03 jk | 38.50 h | **33.71 g** |
| *Arbutus andrachne* | 26.80 q | 27.34 q | 27.64 q | 29.72 p | **27.87 h** |
| *Quercus coccifera* | 38.07 h | 47.57 f | 49.59 e | 51.95 d | **46.80 b** |
| *Quercus infectoria* | 31.83 no | 40.84 g | 46.72 f | - | **39.80 d** |
| *Quercus cerris* | 30.96 o | 37.86 h | 41.35 g | - | **36.73 e** |
| *Paliurus spina-christi* | 18.76 t | 22.42 s | 24.81 r | - | **22.00 i** |
| *Crataegus monogyna* | 33.09 lm | 35.92 jk | 37.33 hi | - | **35.44 f** |
| **Mean** | **33.12 d** | **38.52 c** | **41.37 b** | **46.31 a** | |

When the average ADF ratios were analysed, it was observed that there was a significant difference between the seasons and ADF ratio increased as the seasons progressed. The lowest ADF ratio was obtained in spring with 23.70%, the ADF ratio increased with the progression of the seasons and the highest values were obtained in winter with 34.10%. The lowest ADF rate was obtained from *P. spina-christi* with 11.81% and the highest ADF rate was obtained from *S. junceum* with 52.55%. When the seasons are evaluated individually, *P. spina-christi* in spring, summer and autumn, and *C. creticus* and *A. andrachne* in winter had lower ADF rates than other species. The highest ADF rates were detected in *S. junceum* in all four seasons. When evergreen species are evaluated within themselves, the lowest ADF rate in all seasons was obtained from *C. creticus* and *A. andrachne*. ADF rates of the examined species generally increased depending on the progression of the seasons. The lack of this statistical increase in some species (*P. latifolia* and *A. andrachne*) during the transition from spring to summer caused the species x season interaction to be significant. Considering that the NDF content of the grass consumed daily by ruminant animals should be at most 45.80% and the

ADF content should be at most 25% (NRC, 2001); *P. latifolia*, *C. monogyna*, *P. spina-christi*, *C. creticus*, *Q. infectoria*, *A. andrachne* and *Q. cerris* in spring, *C. monogyna*, *P. spina-christi*, *C. creticus*, *A. andrachne* and *Q. cerris* in summer, *C. monogyna*, *P. spina-christi*, *C. creticus* and *A. andrachne* in autumn contained fiber below the specified values. While the lowest ADF rates were obtained in spring, they increased as the seasons progressed (Table 6). Similar findings have been revealed by many researchers (Castle, 1982; Holechek et al., 1989; Huston and Pinchak, 1991; Steen, 1992; Gonzalez–Andres and Ceresuela, 1998; Ventura et al., 1999; Ventura et al., 2004; Pecetti et al., 2007; Frost et al., 2008; Özarslan Parlak et al., 2011b; Bouazza et al., 2012; Yüksel and Arslan Duru, 2019).

**Table 6.** Two-year average ADF ratios determined in the study (%)

| Shrub species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 24.80 k-n | 25.52 j-m | 26.54 ij | 27.63 hi | **26.12 d** |
| *Spartium junceum* | 43.93 d | 51.58 c | 55.31 b | 59.37 a | **52.55 a** |
| *Juniperus oxycedrus* | 28.28 h | 33.72 f | 32.92 fg | 33.60 f | **32.13 c** |
| *Cistus creticus* | 18.63 t | 22.06 pq | 22.73 p | 24.31 m-o | **21.93 fg** |
| *Arbutus andrachne* | 19.46 st | 20.20 rs | 21.30 qr | 24.48 l-n | **21.36 g** |
| *Quercus coccifera* | 28.06 h | 33.40 f | 32.06 g | 35.20 e | **32.18 b** |
| *Quercus infectoria* | 25.01 k-n | 26.43 j | 25.73 j-l | - | **25.72 d** |
| *Quercus cerris* | 18.91 t | 23.13 op | 25.79 jk | - | **22.61 e** |
| *Paliurus spina-christi* | 9.67 v | 12.55 u | 13.21 u | - | **11.81 h** |
| *Crataegus monogyna* | 20.27 rs | 22.30 pq | 23.93 no | - | **22.17 ef** |
| **Mean** | **23.70 d** | **27.09 c** | **27.95 b** | **34.10 a** | |

When the seasons were compared in terms of TDN ratios obtained in the study, it was observed that the highest value was obtained in spring with 70.75% and the lowest value was obtained in winter with 57.33%. In terms of total digestible nutrient ratio, the highest value was obtained from *P. spina-christi* with 86.11% and the lowest value was obtained from *S. junceum* with 33.51%. When we compare the species separately in each season, it is seen that *P. spina-christi* in spring, summer and autumn, *C. creticus* and *A. andrachne* in winter have the highest TDN ratio. The lowest rates were found in *S. junceum* in all seasons. When the species x season interactions were examined, there was no significant difference between summer and autumn averages in most of the species, while there was an increase in some species (*Q. coccifera*) and a decrease in some species (*C. monogyna*, *S. junceum* and *Q. cerris*), which caused the species x season interactions to be significant. While the highest TSBM rates were obtained in spring, TDN ratios decreased in parallel with the progression of the seasons. From spring to winter, TDN ratios decreased from 70.75% to 57.33% (Table 7). Türk et al. (2018) found the highest TDN ratios in the spring months in their study on *Q. coccifera* in Isparta and found that this ratio decreased until autumn.

**Table 7.** Two-year average TDN ratios determined in the study (%)

| Shrub species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 69.34 i-l | 68.40 j-m | 67.09 mn | 65.68 no | **67.63 e** |
| *Spartium junceum* | 44.63 s | 34.76 t | 29.95 u | 24.70 v | **33.51 h** |
| *Juniperus oxycedrus* | 64.84 o | 57.82 q | 58.85 pq | 57.97 q | **59.87 f** |
| *Cistus creticus* | 77.30 c | 72.88 fg | 72.00 g | 69.97 h-j | **73.04 bc** |
| *Arbutus andrachne* | 76.22 cd | 75.27 de | 73.85 ef | 69.75 i-k | **73.77 b** |
| *Quercus coccifera* | 65.12 o | 58.23 q | 59.96 p | 55.91 r | **59.81 g** |
| *Quercus infectoria* | 69.07 i-l | 67.23 m | 68.13 k-m | - | **68.14 e** |
| *Quercus cerris* | 76.94 c | 71.49 gh | 68.06 lm | - | **72.16 d** |
| *Crataegus monogyna* | 75.18 de | 72.56 fg | 70.45 hi | - | **72.73 cd** |
| *Paliurus spina-christi* | 88.87 a | 85.15 b | 84.30 b | - | **86.11 a** |
| **Mean** | **70.75 a** | **66.38 b** | **65.26 b** | **57.33 c** | |

When the relative feed values determined in the study are considered on a seasonal basis, it is seen that the highest value is obtained in spring with 216.1, relative feed values decrease as the seasons progress and the lowest values are obtained in winter with 138.9. While the highest value among the species was obtained from *P. spina-christi* with 342.1, the lowest value was obtained from *S.*

*junceum* with 71.7. When the relative feed values of the species are considered in terms of seasons, it is seen that *P. spina-christi* in spring, summer and autumn and *A. andrachne* in winter have the highest relative feed values. The lowest values were found in *S. junceum* in all seasons. While the relative feed values decreased in most of the species from spring to summer, there was no statistically significant decrease in *P. latifolia* and *A. andrachne*, which caused the species x season interaction to be significant (Table 8).

**Table 8.** Two-year average relative feed values determined in the study

| Shrub species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 192.8 h | 184.2 h | 174.2 ij | 165.5 jk | **179.1 e** |
| *Spartium junceum* | 93.9 r | 70.5 s | 63.6 st | 58.7 t | **71.7 i** |
| *Juniperus oxycedrus* | 172.9 ij | 139.5 n | 125.9 o | 111.7 pq | **137.5 g** |
| *Cistus creticus* | 247.5 de | 206.1 g | 183.7 h | 169.0 i-k | **201.6 c** |
| *Arbutus andrachne* | 255.9 d | 248.9 de | 243.3 e | 218.5 f | **241.7 b** |
| *Quercus coccifera* | 163.8 kl | 122.9 o | 119.9 op | 110.1 q | **129.2 h** |
| *Quercus infectoria* | 202.8 g | 155.6 lm | 137.1 n | - | **165.2 f** |
| *Quercus cerris* | 222.8 f | 174.1 ij | 154.8 m | - | **183.9 de** |
| *Paliurus spina-christi* | 403.3 a | 328.3 b | 294.7 c | - | **342.1 a** |
| *Crataegus monogyna* | 205.5 g | 185.2 h | 175.1 i | - | **188.6 d** |
| **Mean** | **216.1 a** | **181.5 b** | **167.2 c** | **138.9 d** | |

Relative feed value is a parameter calculated by using ADF and NDF values and used to compare the quality of feeds (Moore and Undersander, 2002). Therefore, the fibre ratio in the plant affects the relative feed value of the feed. Türk et al. (2018) determined the highest relative feed value in the spring months in their study *on Q. coccifera* in Isparta and stated that this ratio decreased until autumn. In this study, a similar decrease was found in terms of relative feed value in *Q. coccifera*. Kökten et al. (2012) from pre-flowering to fruit setting period relative feed values decreased from 328.0 to 107.7 in *Q. coccifera*, from 186.6 to 160.1 in *P. latifolia*, from 384.4 to 234.6 in *P. spina-christi*, from 769.3 to 402.8 in *P. terebinthus*. Temel (2015) stated that the highest relative feed values were obtained in the early vegetative development period in his study conducted in Igdir. These results were in parallel with the results we obtained.

**Table 9.** Two-year average tannin ratios determined in the study (%)

| Shrub species | Spring | Summer | Autumn | Winter | Mean |
|---|---|---|---|---|---|
| *Phillyrea latifolia* | 0.61 lm | 0.25 m | 0.41 lm | 0.57 lm | **0.46 f** |
| *Spartium junceum* | 0.42 lm | 0.25 m | 0.23 m | 0.38 lm | **0.32 f** |
| *Juniperus oxycedrus* | 6.57 b-d | 7.24 b | 8.39 a | 8.18 a | **7.60 a** |
| *Cistus creticus* | 4.49 fg | 3.76 g-i | 6.84 bc | 6.07 c-e | **5.29 b** |
| *Arbutus andrachne* | 3.48 hi | 3.17 ij | 5.45 e | 5.64 de | **4.43 c** |
| *Quercus coccifera* | 3.54 g-i | 2.26 jk | 3.13 i-j | 2.76 i-j | **2.92 d** |
| *Quercus infectoria* | 1.05 lm | 2.13 j-k | 3.12 ij | - | **1.99 e** |
| *Quercus cerris* | 2.40 j | 4.36 f-h | 5.22 ef | - | **3.99 c** |
| *Paliurus spina-christi* | 2.23 jk | 1.31 kl | 2.33 j | - | **1.96 e** |
| *Crataegus monogyna* | 6.75 bc | 6.04 c-e | 8.33 a | - | **7.04 a** |
| **Mean** | **3.15 c** | **3.19 c** | **4.23 a** | **3.93b** | |

When the seasons were compared in terms of tannin ratios, it was observed that the highest tannin ratio was obtained in autumn with 4.23% and the lowest values were obtained with 3.15% in spring and 3.19% in summer. In terms of tannin content, among the species, the highest values were obtained from *J. oxycedrus* and *C. monogyna* with 7.60% and 7.04%, while the lowest values were obtained from *S. junceum* and *P. latifolia*. When the seasons were evaluated separately, it was determined that *C. monogyna* and *J. oxycedrus* had the highest tannin ratio in spring, summer and autumn seasons, *J. oxycedrus* had the highest tannin ratio in winter season, while the species with the lowest ratios were *P. latifolia* and *S. junceum* in all seasons. When the species x season interactions were examined, it was observed that the tannin ratio increased significantly in *C. monogyna*, *P. spina-christi*, *J. oxycedrus*, *C. creticus* and *A. andrachne* from summer to autumn, while it did not change in *P. latifolia*, *Q. coccifera*, *S. junceum*, *Q. infectoria* and *Q. cerris*. The irregular variation of the tannin ratios of the studied species according to the seasons caused the species x season interactions to be significant (Table 9).

In the study, tannin ratios increased from spring to autumn and decreased in winter. Alatürk et al. (2014) examined 9 shrub species in Çanakkale and reported that the lowest tannin rate was determined in spring with 1.19% and the highest rate was determined in winter with 1.62%. Although the tannin rates we detected are higher, this result is similar to our study in terms of change according to seasons.

It is stated that in addition to ripening, genetic differences and environmental factors also affect the tannin content of plants (Barry and Forss, 1983; Mueller Harvey and Dhanoa, 1991). Tannin content is one of the factors that limit the grazing and digestion in shrub and tree species (Altın et al., 2021). Proanthocyanidins, also known as condensed tannins due to their chemical structure, are the most commonly found tannin group in trees and shrubs used as forage plants (Hagerman, 1987; Gutteridge and Shelton, 1994). Tannin ratios vary in terms of plant species, tissues and vegetation periods, and cattle, which have the lowest tolerance, can tolerate 1-4% tannin in the ration, while sheep can tolerate 6% and goats can tolerate 8-10% tannin in the ration. Although the effect varies according to the structure of the tannin and various factors, the generally acceptable tannin ratefor ruminants is 5% (Piluzza et al., 2014). A tannin content above 5% in the feed consumed by animals can cause toxic effects (Brooker et al., 1994). In the study *P. latifolia, P. spina-christi, Q. coccifera, S. junceum, C. creticus, Q. infectoria, A. andrachne* and *Q. cerris* in spring, *P. latifolia, P. spina-christi, Q. coccifera, S. Junceum* and *Q. infectoria* in autumn, *P. latifolia, Q. coccifera* ve *S. junceum* in winter were found to have tannin content below 5%, which is the threshold value to show a harmful effect for animals.

## 4. Conclusion

When the species, which are common in the around of Aşağı Gökdere and have feed potential, were evaluated in terms of the quality characteristics that should be present in the feeds of ruminants, it was determined that most of them had sufficient nutritional value. It was determined that these species produce sufficient quality grass for grazing, especially in the spring, and that additional feeding was not required in spring and summer. The maquis species have the highest feeding value in spring, but since this season is the period when meadows and pastures are at maximum value in terms of yield and quality, the need for quality roughage can be met at a much better level in this period compared to other seasons. Therefore, maquis species are of great importance in summer, autumn and winter seasons when it is difficult to provide quality roughage due to the herbaceous species drying up and withdrawing from vegetation, being consumed by grazing or becoming dormant. Because maquis species can maintain their greenness and quality feed value better than herbaceous species during these periods. Evergreen species are a source of feed even in winter. Considering the ratio of evergreen species in vegetation and the quality of forage they produce in autumn and winter, it is thought that additional feeding in this period will be beneficial for the health and productivity of grazing animals.

When the data obtained from the study are analysed in terms of quality parameters, it is seen that most of the maquis species, especially *P. spina-christi*, *Q. infectoria* and *Q. cerris*, produce quality forage for sheep and goats even in the summer period when the pastures are dormant, so it is concluded that it is a necessity to include maquis areas in grazing systems. In this way, the grazing period in pastures can be extended, feed costs which is the biggest input of animal husbandry can be reduced and profitability can be increased.

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Research

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# Water Use of Guinea Grass as Affected by Different Planting Density and Urea Rates Under Rainfed Conditions in Sub-Saharan Africa

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A B S T R A C T

Ongoing efforts are currently being made to rehabilitate drought-affected pastures in Sub-Saharan Africa. One approach being explored is the introduction of non-native grass species, such as *Megathyrsus maximus* (Guinea grass). This study aims to investigate the water use of Guinea grass in semi-arid environments under rainfed conditions. Additionally, it aims to a better understanding of the variability of water use in Guinea grass through the utilization of the Bagging machine learning algorithm. Split-plot field experiments were carried out over two consecutive rainy seasons (2020 and 2021). The treatments included two in-situ rainwater harvesting practices, RWH (ridging plus terracing and terracing alone), three seeding rates, SR (1.5, 2.5, and 3.5 kg ha$^{-1}$), and two soil nitrogen fertilization rates, SF (95 kg N ha$^{-1}$ and 0 kg N ha$^{-1}$). These treatments were compared to a control plot that involved zero-tillage, no fertilization, and no rainwater harvesting. The collected datasets were analyzed using R, SPSS 15, and spreadsheets. The results showed significant differences in plant indices and soil moisture content among the treatments. However, the treatments had insignificant effects on seasonal actual crop evapotranspiration ($ET_a$), which ranged from 1.93 to 3.29 mm day$^{-1}$. The interactions between SR and RWH were found to have significant impacts on water use. The Bagging algorithm revealed that the variability in $ET_a$ could be attributed to SR (42%), RWH (31%), and SF (26%), respectively. The implementation of rainwater harvesting practices resulted in a significant reduction in water usage, saving 86% of the green water used with a water footprint of 0.25 m$^3$ kg$^{-1}$, compared to 1.7 m$^3$ kg$^{-1}$ for no adoption of RWH conditions. The water use of rainfed Guinea grass was also found highly sensitive to dry spells. Further detailed studies using multiple-layer models are recommended to gain a better understanding of the non-linear interactions in semi-arid environments.

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## 1. Introduction

The importance of green water (rainwater that is infiltrated into the soil) in achieving sustainable development goals (SDGs), particularly SDG 2 (food security), is widely acknowledged. Nevertheless, efficient use of green water remains a challenging goal that requires significant effort. In arid and semi-arid environments, accurate estimates of crop evapotranspiration ($ET_c$) are essential for efficient use of green water. $ET_c$ is a term that combines non-productive water use, such as evaporation from the soil surface (E), and productive water use, such as transpiration from plants (T). Equation (1) links $ET_c$ linearly with the climatic water demand (i.e. reference evapotranspiration, $ET_o$, which is standardized using a hypothetical grass) through a crop

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coefficient ($K_c$) that varies depending on many factors such as crop type, growth stage, and local conditions, including on-farm water management practices (Allen et al., 1998). Various methods, such as soil water balance, lysimeters, remote sensing algorithms, and sap flows, have been used to estimate $ET_c$, each with its advantages and disadvantages (Calera et al., 2017; Singh et al., 2019).

Crop evapotranspiration ($ET_c$) is a measure of the maximum crop evapotranspiration that would occur under ideal conditions, such as no water stress and healthy plants. However, in reality, the actual evapotranspiration ($ET_a$) is typically lower than $ET_c$. Although Equation (1) has primarily been used for irrigation management, it can also provide science-based operational guidance for enhancing water use efficiency (WUE) under rainfed conditions. WUE is defined as "*the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop*" (Hatfield and Dold, 2019). It has been suggested that sustainable on-farm practices that increase transpiration (T) while reducing non-productive evaporation (E) can significantly improve crop WUE at the canopy level (Hatfield and Dold, 2019). One promising practice that has shown positive results is rainwater harvesting (RWH). However, the design of RWH systems is critical for maximizing the benefits while minimizing any negative environmental and agricultural impacts (Rahman, 2017).

Rainfed grazing lands play a crucial role in ensuring food security and financial stability. In fact, these lands account for 91% of the livestock production area worldwide (di Virgilio et al., 2019). However, due to frequent droughts, the sustainability of these grazing lands has been severely impacted (Catunda et al., 2021; Chandregowda et al., 2022; Churchill et al., 2022). To combat land degradation, sustainable land management practices have been suggested by the Intergovernmental Panel on Climate Change, IPCC, (2019). In Africa, rainwater harvesting (RWH) systems have been identified as the most suitable method to combat the disappearance of perennial grasses in semi-arid pastures (Mganga et al., 2021). Additionally, to counter the alarming disappearance of some nutritional native pasture species, several countries have introduced exotic nutritious pasture species, such as Guinea grass (Ainsworth and Long. 2021; Benabderrahim and Walid, 2021). Guinea grass is known for its deep root system, high genetic variability C4 plant, and native to tropical conditions (Benabderrahim and Walid, 2021; Soti and Thomas, 2021; Isabel et al., 2021; Deo et al., 2020). Although Guinea grass is tolerant to moderate drought events, it requires a good amount of rainfall (900 - 1500 mm) and is sensitive to waterlogging than deficit conditions (de Oliveira et al., 2022). However, there is a lack of information on the crop coefficients and water use of Guinea grass, especially under rainfed semi-arid conditions. Most of the available estimates are based on irrigation practices (Oliveira et al., 2018; Sanches et al., 2019)

Variability plays a crucial role in various domains, and understanding it is essential for advancing knowledge and making informed decisions. Recent studies have claimed the outperformance of the machine learning algorithms in understanding variability compared to classical methods (Leng and Hall, 2020). Machine learning algorithms build an ensemble decision tree to classify concerned variables via sub-grouping and best-fitting processes (Mupangwa et al. 2020). Ultimately, it reduces the variance and ranks the importance of each variable. To overcome over-fitted model complications associated with machine learning algorithms, variance reduction algorithms like Bagging were developed.

This study was aimed to determine the water use and crop coefficients (Kc) of rainfed Guinea grass as affected by rainwater harvesting (RWH), plant density, and soil fertilization as local conditions in the semi-arid environment in Sudan. The study also employed the Bagging machine learning algorithm to better understand the variability of water use in Guinea grass. These objectives will provide valuable insights into improving water management strategies and sustaining pasture productions in semi-arid regions using non-native species like Guinea grass.

## 2. Materials and Methods

### 2.1. Study area

Sudan, an African country located in Sub-Saharan Africa, possesses a vast natural pasture spanning 96 million hectares. The majority of this land, approximately 80%, is situated in arid and semi-arid climates. This extensive pasture plays a crucial role in supporting over 50% of the agricultural sector's contribution to the national gross product (Hussein et al., 2021; Sudan's country report 2015). Primarily consisting of traditional pasture, Sudan heavily relies on livestock breeding, particularly ruminant animals, as a dominant means of livelihood and a vital source of food in the form of meat and milk. However, due to drought conditions, the pastures are currently dominated by low-nutritional quality species with crude protein levels below 8% (Ezzat et al., 2016). This situation is further exacerbated by overgrazing and soil erosion issues. Despite efforts to control grazing (Boke-Olén et al., 2018), pastoralism remains widespread, often leading to the complete destruction of vegetation cover. To mitigate conflicts between grazing and crop farming, the availability of pasture land is limited. Therefore, implementing improved green water management techniques through Rainwater Harvesting (RWH) systems, along with the introduction of scientifically selected moderately drought-tolerant and nutritious fodder grasses like Guinea grass, could have a positive impact on the sustainability of rangelands in Sudan's semi-arid environments. This approach would help conserve water, soil, and plants without causing detrimental effects on the environment (Motta-Delgado et al., 2019).

## 2.2 Experiment

The experimental site (33.08 $^{0}$E and 14.13 $^{0}$N) is located in the semi-arid environment, Gezira state, Sudan. Rainfall is seasonal (June – October) of 290 mm (coefficient of variation = 25%), surface air temperature ranges from 21 $^{o}$C, to 37 $^{o}$C, 21 – 65% for relative humidity (RH), 1.6 – 2.8 m s$^{-1}$ for wind speed at 2 m height, 21.1 – 25.1 MJ m$^{-2}$ day$^{-1}$ for radiation, and 6.4 – 9.8 mm day$^{-1}$ for $ET_o$. The soil is vertisols where deep cracks develop due to changes in soil moisture contents; topographically, the land is endowed with a gentle slope of 10 cm km$^{-1}$.

The treatments included two in-situ rainwater harvesting (RWH) practices: ridges plus terracing (RD) and terracing (TR), three seeding rates, SR: 1.5 kg ha$^{-1}$ (SR1.5), 2.5 kg ha$^{-1}$ (SR2.5), and 3.5 kg ha$^{-1}$ (SR3.5), and two nitrogen (urea) soil fertilization rates, SF: 0 kg ha (ZSF) and 95 kg ha (FSF); which were applied as a single dose 21 days after the sowing date in both seasons. These treatments were compared to a control (CT) which consisted of flat, zero-tillage, unfertilized plots without any RWH practices (the common practices in the studied pasture). The selection of RD and TR was based on their popularity and cost-effectiveness in the study area.

A Split-plot Complete Randomized Block design was implemented with three replications (10 m x 10 m per plot) in this study. The main plots consisted of RD, TR, and CT, while the subplots were SR and SF as shown in Figure 1. The experiments were conducted over two rainy seasons, specifically from June to December in the years 2020 and 2021. The experimental sites were prepared in mid-June, with the RD plots undergoing primary plowing using a wide disk plow (20 cm depth), leveling, furrowing using the moldboard (0.8 m apart), and terracing using a disk (30 cm in height). The TR plots were prepared in a similar manner, except for the furrowing practice. Subsequently, Guinea grass seeds were manually spread on July 28$^{th}$ for the first season (June – December 2020) and August 1$^{st}$ for the second season (June – December 2021). At the end of the experiment, Guinea grass was not subjected to any harvesting cycles and grazing was allowed in January.

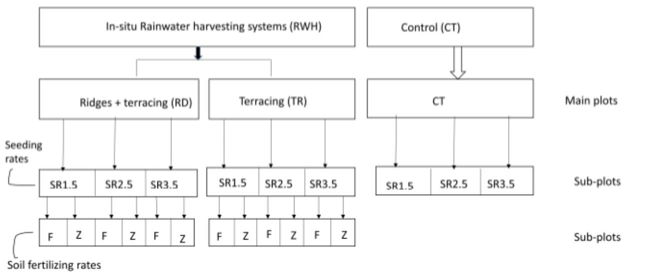


**Figure 1.** The split-plot experimental design, for studying the impacts of rainwater harvesting, seeding rates and soil fertilization on rainfed Guinea grass, a semi-arid environment, Sudan (2020-2021)

## 2.3 Data collection

### 2.3.1 Climatic

A rain gauge was installed at the experimental site to measure daily rainfall. Minimum and maximum surface air temperature, relative humidity, wind speed, and sunshine duration (at 2 m height) were collected from the nearby agrometeorological station, Agricultural Research Corporation, Wadmedani (14.2 $^{o}$N and 33.48 $^{o}$E),

### 2.3.2 Agronomic and Soil Moisture Datasets

Field plant and soil samples were collected every ten days over the two seasons. Collected plant indices included height, number of leaves, leaf area index, and fresh and dry biomass; the plant height (cm) was estimated using a tape meter; the leaf area index (m$^{2}$ m$^{-2}$) was directly estimated by multiplying the manually measured area of a single leaf by the number of leaves per square meter; the fresh and dry biomasses were estimated by taking random plant samples from 1 × 1 $m^2$ per each plot, immediately weighed for estimating the fresh biomass (g $plant^{-1}$); then samples were dried in an oven (70 °C for 24 hrs) and weighed for estimating the dry biomass (g $plant^{-1}$). Estimated biomass was converted to kg $ha^{-1}$ by multiplying the average weight per plant by the average number of plants per unit area (Alebele et al., 2020). these measurements were replicated three times per plot (Yang et al., 2022). The growth stages were determined according to the methodology described by Allen et al. (1998).

Soil moisture contents (0 – 20 cm, 20 – 40 cm, and 40 -100 cm depth) and soil bulk density were measured gravimetrically, i.e. Auger technique, samples were analyzed at the Soil Laboratory of the Faculty of Agricultural Sciences, University of Gezira, Wadmedani, Sudan

### 2.4 Data analysis

#### 2.4.1 Water use and crop coefficients

The crop evapotranspiration (mm $day^{-1}$) was estimated using Eq. (1). The reference evapotranspiration ($ET_o$, mm $day^{-1}$) was estimated based on the Penman-Monteith model (a short grass approach) (Allen et al., 1998). The actual crop evapotranspiration ($ET_a$, mm $day^{-1}$) was estimated using the soil water balance as follows (Eqs. 2 – 10). The water footprint (WFP) was estimated using Eq. (11), as follows:

$$ET_c = ET_o * K_c \quad (1)$$

$$ET_a = P - \Delta\theta - R_o - D_p \quad (2)$$

$$\Delta\theta_v = \theta_{vi} - \theta_{vi+1} \quad (3)$$

$$\theta_g = \frac{w_w - w_d}{w_d} \quad (4)$$

$$\theta_v = \theta_g * \rho_b \quad (5)$$

$$\rho_b = \frac{m_s}{V_t} \quad (6)$$

$$WC = \sum_{i=1}^{j} \theta_{vi} z_i \quad (7)$$

$$\mathrm{DP}_i = \begin{bmatrix} 0 & \theta_i \leq \theta_{FC} \\ 1000\,(\theta_i - \theta_{FC}) & \end{bmatrix} \quad (8)$$

$$R_o = 2.336e^{0.504P}, \quad R^2 = 0.90 \quad (9)$$

$$K_c = \frac{ET_c}{ET_o} \quad (10)$$

$$\mathrm{WFP} = \frac{ET_c}{\mathrm{DBM}} \quad (11)$$

Where, $K_c$ is the crop coefficient (dimension less), and $ET_o$ is the reference evapotranspiration (mm $day^{-1}$). WFP is the water footprint ($m^3$ $kg^{-1}$), and DBM is the dry biomass (kg $ha^{-1}$); $\theta_g$ and $\theta_v$ are gravimetric (g $g^{-1}$) and volumetric ($m^3$ $m^{-3}$) soil moisture contents, $w_w$ and $w_d$ are wet and dry weights, respectively, $\rho_b$ is the soil bulk density (g $cm^{-3}$) , $m_s$ is the soil sample dry weight (g), $V_t$ is the soil sample total volume ($cm^3$), z is the soil depth (cm), WC is the moisture content at z (cm), P is the rainfall (mm), $D_P$ (mm) is the deep percolation (the groundwater contribution was rendered to zero as the groundwater table is deep of > 15 m); $R_o$ is the runoff volume ($10^{-6}$ $m^3$), and P is the rainfall event in $m^3$ (rainfall depth (m) * catchment area ($m^2$)), which was applied only for estimating runoff amounts under the CT treatments, developed by Shamseddin et al. (2014) for the studied area, i.e. $R_o$ was rendered to zero under RWH practices as terraces were mainly constructed to prevent runoff running outside the boundaries. Equation (12) is a commonly used RWH design model for agricultural purposes (Critchley et al., 1991).

$$\frac{Ca}{Cu} = \frac{CWR - R}{R * Ro * Ef} \quad (12)$$

Where, Ca is the catchment area, Cu is the cultivated area, CWR is the crop water requirements, R is the design rainfall, Ro is the runoff coefficient, and Ef is the efficiency factor of the system. Eq. (1) provides good estimates of CWR.

#### 2.4.2 Statistical analysis

The statistical analysis was conducted using SPSS 15.0. The null hypothesis stated that none of the treatments and their interactions would improve the water use of rainfed Guinea grass in a semi-arid environment. Descriptive statistics were used to summarize the measured datasets. The analysis was based on the general linear model (GLM) with the full factorial model, and the Bonferroni test was used for post hoc multiple comparisons of observed means (P = 0.05). The dependent variables included a set of measured plant and soil indices, while the independent variables were RWH, SR, SF, and season. A one-factor analysis of variance was used to assess the comparisons for observed means of soil fertilization and season, as the groups were less than three, which is a requirement for the Bonferroni test.

In order to better understand the variability in ETa, the Bagging machine learning algorithm was applied. The decision tree was built using the "ANOVA" method from the "rpart" package in R software (version 4.2.2). The dataset was divided into 70% for model training and 30% for testing. The Bagging algorithm generated the ensemble mean from 10 cross-validated regression models. The performance metric used to evaluate the models was the root mean square error (RMSE).

## 3. Results and Discussion

### 3.1. Water use of rainfed Guinea grass

#### 3.1.1 impacts of rainwater harvesting

Table (1) presents a summary of the estimated $ET_a$ (actual crop evapotranspiration) of rainfed Guinea grass in the semi-arid environment of Sudan, considering the impact of RWH practices (RD and TR treatments). The seasonal $ET_a$ values for RD, TR, and CT were 2.7 mm day$^{-1}$, 2.9 mm day$^{-1}$, and 2.5 mm day$^{-1}$, respectively. These values are 27-37% lower than the estimate of 3.99 mm day$^{-1}$ for subtropical conditions by Sanches et al. (2019). While the applied RWH techniques significantly increased the seasonal soil moisture content by 37-97% for RD and 42-84% for TR compared to the control (CT), there was no significant difference in the seasonal $ET_a$ between RWH practices and CT. However, the seasonal $ET_a$ of CT was generally 8%-18% lower than that of RWH treatments (RD and TR).

The concept of water use efficiency (WUE) establishes a linear relationship between biomass production and water use, indicating that the higher ET, the higher biomass production. This explains the higher biomass production observed with RWH treatments compared to CT (Table 1). Consequently, the implementation of RWH practices maximized consumptive water use (T) at the expense of non-consumptive water use (E). This finding aligns with the reported increase in maize biomass without a change in water use by Hatfield and Dold (2019). RWH practices achieved this by increasing soil moisture content, which in turn promoted plant canopy development, reducing the exposed surface area for evaporation and improving plant-soil water interactions. Additionally, RWH practices allowed for more infiltration time for harvested runoff; in heavy clayey soils, decreased soil bulk density due to increased soil moisture, creating favorable conditions for root system growth and interaction. Furthermore, the improved leaf area index (LAI) resulting from RWH practices will have a substantial impact, as evaporation losses were exponentially related to LAI (Eq.13).

$$E = ET_o * e^{-0.39LAI} \quad (13)$$

According to eq. (13), the presented LAI values in Table (1) estimated the seasonal evaporation losses (E) at 0.01 – 0.7 mm day$^{-1}$, 0.03 – 1.01 mm day$^{-1}$ for the TR, and 2.35 – 3.61 mm day$^{-1}$ for the CT.

**Table 1.** Growth and water use of rainfed Guinea grass as affected by two in-situ rainwater harvesting systems (Ridges plus terracing, RD, and Terracing, TR) over two experimental seasons, compared to a control CT (flat, zero tillage, unfertilized without rainwater harvesting plots), the semi-arid environment, Sudan

| Index | RD | TR | CT |
|---|---|---|---|
| | | Season 1 | |
| Plant height (cm) | 41$^a$ | 41$^a$ | 13$^b$ |
| Leaf number (number) | 17$^a$ | 16$^a$ | 10$^a$ |
| Fresh biomass (t ha$^{-1}$) | 8.7$^a$ | 8.5$^a$ | 1.2$^b$ |
| Dry biomass ( t ha$^{-1}$) | 2.2$^a$ | 2.1$^a$ | 0.3$^b$ |
| Leaf area index (m$^2$ m$^{-2}$) | 1.7$^a$ | 1.3$^a$ | 0.09$^a$ |
| Soil moisture (mm) | 207$^a$ | 193$^a$ | 144$^b$ |
| Soil bulk density (g cm$^{-3}$) | 0.9$^a$ | 1.03$^a$ | 1.11$^b$ |
| Crop evapotranspiration (mm day$^{-1}$) | 2.96$^a$ | 3.29$^a$ | 3.02$^a$ |
| | | Season 2 | |
| Plant height (cm) | 43$^a$ | 42$^a$ | 18$^b$ |
| Leaf number (number) | 16$^a$ | 16$^a$ | 10$^a$ |
| Fresh biomass (t ha$^{-1}$) | 9.2$^a$ | 9.2$^a$ | 2.7$^b$ |
| Dry biomass (t ha$^{-1}$) | 2.3$^a$ | 2.3$^a$ | 2.0$^a$ |
| Leaf area index (m$^2$ m$^{-2}$) | 0.5$^a$ | 0.4$^a$ | 0.2$^a$ |
| Soil moisture (mm) | 144$^a$ | 149$^a$ | 105$^b$ |
| Soil bulk density (g cm$^{-3}$) | 0.84$^a$ | 0.86$^a$ | 0.96$^b$ |
| Actual crop evapotranspiration (mm day$^{-1}$) | 2.37$^a$ | 2.54$^a$ | 1.93$^a$ |

Different letters mean the difference is significant (P = 0.05)

During the two experimental seasons, the rainfall amounts were 262 mm and 252 mm for the first and second seasons, respectively. These amounts accounted for 92% and 90% of the normal rainfall. However, the results presented in Table (1) indicated significant differences in $ET_a$ between the two seasons, with the first season had the higher $ET_a$ values, with increases of 25%, 30%, and 56% for RD, TR, and CT, respectively. This was also accompanied by better soil moisture content and leaf area index (LAI) compared to the second season, as shown in Table 1. The variation in water use between the seasons can be mainly attributed to the distribution of rainfall rather than the actual amounts received. The second season experienced longer dry spells, with an average of 7.2 days with rainfall less than 1.0 mm, compared to 3.4 days in the first season.

### 3.1.2 Planting density

Table (2) presents a comparison of the estimated $ET_a$ influenced by plant density, specifically three seeding rates (SR1.5, SR2.5, and SR3.5). In terms of statistical significance, the applied seeding rates had minimal effects on all measured properties, except for the soil moisture content and soil bulk density during the first season. Ding et al. (2015) suggested a multi-layer model as a replacement for the single-layer model (such as Penman-Monteith) to gain a better understanding of the non-linear interactions between microclimate and crop physiology. Consequently, more detailed studies based on a multi-layer model are necessary to comprehend the non-linear interactions between seeding rates and water usage of Guinea grass in semi-arid environments. In general, a lower seeding rate results in higher water use ($ET_a$) for Guinea grass, while a higher seeding rate leads to increased biomass production. The lowest applied seeding rate (SR1.5) is associated with the lowest LAI, indicating relatively its higher evaporation losses compared to SR2.5 and SR3.5 treatments.

**Table 2.** Growth and water use of rainfed Guinea grass as affected by three seeding rates, SR (1.5, 2.5, and 3.5 kg ha$^{-1}$) over two experimental seasons in a semi-arid environment, Sudan

| index | SR1.5 | SR2.5 | SR3.5 |
|---|---|---|---|
| | | Season 1 | |
| Plant height (cm) | 51 $^a$ | 52 $^a$ | 47 $^a$ |
| Leaf number (number) | 29 $^a$ | 30 $^a$ | 28 $^a$ |
| Fresh biomass (t ha$^{-1}$) | 10.4 $^a$ | 11.8 $^a$ | 12.2 $^a$ |
| Dry biomass (t ha$^{-1}$) | 3.3 $^a$ | 3.4 $^a$ | 3.8 $^a$ |
| Leaf area index (m$^2$ m$^{-2}$) | 3.5 $^a$ | 4.3 $^a$ | 3.8 $^a$ |
| Soil moisture (mm) | 193 $^a$ | 190 $^a$ | 141 $^b$ |
| Soil bulk density (g cm$^{-3}$) | 0.98 $^a$ | 1.01 $^b$ | 1.02 $^b$ |
| Crop evapotranspiration (mm day$^{-1}$) | 2.84 $^a$ | 2.75 $^a$ | 2.66 $^a$ |
| | | Season 2 | |
| Plant height (cm) | 18 $^a$ | 17 $^a$ | 16 $^a$ |
| Leaf number (number) | 7 $^a$ | 7 $^a$ | 7 $^a$ |
| Fresh biomass (t ha$^{-1}$) | 2.8 $^a$ | 2.9 $^a$ | 3.1$^a$ |
| Dry biomass (t ha$^{-1}$) | 2.5 $^a$ | 2.6 $^a$ | 2.9 $^a$ |
| Leaf area index (m$^2$ m$^{-2}$) | 0.05 $^a$ | 0.05 $^a$ | 0.05 $^a$ |
| Soil moisture (mm) | 147 $^a$ | 138 $^a$ | 103 $^b$ |
| Soil bulk density (g cm$^{-3}$) | 0.87 $^a$ | 0.87 $^a$ | 0.87 $^a$ |
| Actual crop evapotranspiration (mm day$^{-1}$) | 2.59$^a$ | 2.64 $^a$ | 2.51 $^a$ |

### 3.1.3 Soil fertilization

Table 3 presents the findings of a study conducted in Sudan, which examined the effects of soil fertilization on Guinea grass in semi-arid environments. The study compared two different soil fertilization rates, 95 kg N ha$^{-1}$ and 0 kg N ha$^{-1}$, and found that there were no significant differences between the two rates, except for the soil moisture during the second season. Therefore, the impact of soil fertilization on the seasonal water use of Guinea grass was found to be insignificant (Table 3). These findings contradict the results of a study conducted in Brazil by Maués Macedo et al. (2022), who indicated a positive correlation between fertilization (160 - 200 kg N ha-1) and $ET_c$ of Guinea grass based on a principal component analysis of data collected from various rainfed and irrigation trials.

The optimal seeding rate for Guinea grass under rainfed conditions is not well-documented, with only one experimental seeding rate of 40-45 pure seeds m$^{-2}$ reported by Maués Macedo et al. (2022). In Sudan, it is common to practice zero soil fertilization for both pasture and crop farming. However, due to increasing soil degradation rates, a minimum amount of nitrogen might be necessary.

Santos et al. (2012) suggested that the growth and productivity of Guinea grass in pastures were dependent on nitrogen supply, while Paciullo et al. (2016) highlighted the uncertainty surrounding the relationship between production and fertilization of Guinea grass. Maués Macedo et al. (2022) recommended a nitrogen dose of 200 kg N $ha^{-1}$ for Guinea grass grown under fully rainfed conditions in Brazil.

**Table 3.** The effects of soil fertilization on rainfed Guinea grass over two experimental seasons, semi-arid environments, Sudan

| index | Fertilized | Unfertilized |
|---|---|---|
| | Season 1 | |
| Plant height (cm) | 58 [a] | 44 [a] |
| Leaf number (number) | 32 [a] | 26 [a] |
| Fresh biomass (t $ha^{-1}$) | 133 [a] | 92 [a] |
| Dry biomass (t $ha^{-1}$) | 33 [a] | 36 [a] |
| Leaf area index ($m^2$ $m^{-2}$) | 4.7 [a] | 3.1 [a] |
| Soil moisture (mm) | 194[a] | 189 [a] |
| Soil bulk density (g $cm^{-3}$) | 1.0 [a] | 1.0 [a] |
| Crop evapotranspiration (mm $day^{-1}$) | 2.7 [a] | 2.6 [a] |
| | Season 2 | |
| Plant height (cm) | 18 [a] | 16 [a] |
| Leaf number (number) | 7 [a] | 6 [a] |
| Fresh biomass (t $ha^{-1}$) | 32 [a] | 26 [a] |
| Dry biomass (t $ha^{-1}$) | 32 [a] | 23 [a] |
| Leaf area index ($m^2$ $m^{-2}$) | 0.06 [a] | 0.04 [a] |
| Soil moisture (mm) | 148 [a] | 127[b] |
| Soil bulk density (g $cm^{-3}$) | 0.86 [a] | 0.87 [a] |
| Actual crop evapotranspiration (mm $day^{-1}$) | 2.6 [a] | 2.5[a] |

Same letters mean the difference is insignificant (P = 0.05)

### 3.1.4 Seasonal effects

Table (4) presents a summary of the effects of different seasons on the growth of Guinea grass in a rainfed semi-arid environment. The findings indicate that the season has a significant influence on rainfed Guinea grass, with the exception of dry biomass production and water use. The first season stands out as it demonstrates favorable indices due to well-distributed rainfall, although the soil bulk density decreases by 13% in the second season. This decrease suggests that the continuous growth of Guinea grass positively affects the soil's hydrological conditions, leading to an increase in infiltration rate as the soil bulk density decreases. On the other hand, the impact of the season on the growth of Guinea grass under wet conditions is insignificant, as stated by Pezzopane et al. (2017).

**Table 4.** seasonal impacts on selected plant, soil and water use of Guinea grass grown under a semi-arid environment Sudan (2020 – 2021)

| Index | Season 1 | Season 2 |
|---|---|---|
| Plant height (cm) | 53[a] | 18[b] |
| Leaf number (number) | 30 [a] | 7 [b] |
| Fresh biomass (t $ha^{-1}$) | 11.6 [a] | 2.9 [b] |
| Dry biomass (t $ha^{-1}$) | 3.4 [a] | 2.9 [a] |
| Leaf area index ($m^2$ $m^{-2}$) | 4.2 [a] | 0.05 [b] |
| Soil moisture (mm) | 194 [a] | 135 [b] |
| Soil bulk density (g $cm^{-3}$) | 0.99 [a] | 0.86 [b] |
| Actual crop evapotranspiration (mm $day^{-1}$) | 2.73 [a] | 2.48 [a] |

### 3.1.5 Interactions

The effects of interactions between treatments on various parameters were studied using linear multivariate models. Results were presented in Table (5). The results state that: firstly, the intercepts of the models are significant and of high values, suggesting that either the interactions are non-linearly controlled or there is a need to consider more explanatory variables. Secondly, the RWH*SR interaction has no significant effects, except for the soil moisture contents during the first season (S1SM). Thirdly, the RWH*SF interaction only affects significantly the soil bulk density of the first season (S1BD). Fourthly, the SR*SF interaction showed insignificant effects. Finally, the RWH*SR*SF interactions have significant impacts on all indices, except for the LAI during the second season (S2LAI), actual crop evapotranspiration during the first season ($S1ET_a$), the seasonal soil moisture content (S1SM and S2SM), and the soil bulk density of the second season (S2BD). Also, the trend of the significant effects of the RWH*SR*SF interactions are seasonally consistent on leaf height, leaf number, and the production of fresh and dry biomass (Table 5). Consequently, the treatments as local conditions presented statistically varied results. Relative to the soil fertilization, planting density (SR) and water supply (RWH) as local conditions play a crucial role in sustaining Guinea grass under rainfed conditions of semi-arid environments. Generally, the treatments RDSR1.5Z, TRSR1.5Z, TRSR1.5Z, TRSR2.5F, TRSR1.5Z, RDSR1.5Z, CTSR1.5Z, and TRSR1.5Z were associated with the highest recorded values for plant height, leaf number, fresh biomass, dry biomass, leaf area index, soil moisture content, soil bulk density, and $ET_a$ of rainfed Guinea grass, respectively.

**Table 5.** Effects of treatments' interactions on Guinea grass under rainfed conditions of semi-arid environments, based on multivariate models. The treatments were rainwater harvesting (RWH), Seeding rate (SR), and soil fertilization (SF). The dependent variables were season (S), selected plant indices (leaf height, H, leaf number, LN, fresh biomass, FBM, dry biomass DBM, and leaf area index LAI), soil indices (moisture content, SM, and bulk density, BD), and actual crop evapotranspiration ($ET_a$)

| index | intercept | SR*RWH | SR*SF | RWH*SF | RWH*SR*SF |
|---|---|---|---|---|---|
| S1H | 78,037* | 501.278 | 156.874 | 5.567 | 5.037* |
| S2H | 89,854* | 648.178 | 168.206 | 0.254 | 0.330* |
| S1LN | 15,797* | 411.704 | 103.998 | 7.211 | 22.354* |
| S2LN | 14,719* | 118.155 | 44.758 | 1.523 | 3.536* |
| S1FBM | 290,486* | 1,774.62 | 1,199.26 | 5.85 | 28.261* |
| S2FBM | 384,401* | 2,872.18 | 1,779.05 | 77.898 | 143.889* |
| S1DBM | 18,486* | 112.221 | 64.984 | 0.821 | 2.193* |
| S2DBM | 38,551* | 220.948 | 135.074 | 3.86 | 8.444* |
| S1LAI | 92* | 1.499 | 1.464 | 0.201 | 0.424* |
| S2LAI | 10* | 0.098 | 0.054 | 0.003 | 0.055 |
| S1ETc | 646* | 9.668 | 3.852 | 0.013 | 5.74 |
| S2ETc | 351* | 2.438 | 1.615 | 0.014 | 0.158* |
| S1SM | 1,223,845* | 8,059* | 325.545 | 214.437 | 876.058 |
| S2SM | 2,242,302* | 258.654 | 4.251 | 46.962 | 713.909 |
| S1BD | 67* | 0.017 | 0.002 | 0.014* | 0.0003* |

* indicates significant at P = 0.05

### 3.1.6 A stepwise regression modeling and Bagging algorithm

The collected indices, including plant height, leaf number, biomass, leaf area index, soil moisture, and bulk density, were used to stepwise regress the $ET_a$ (dependent variable). The resulting model indicated that the soil moisture content (SM) was the only significant variable (Eq. 14), highlighting the crucial role of implementing RWH for sustaining Guinea grass under rainfed conditions. To evaluate the performance of the model in predicting $ET_a$, Fig. (2) was utilized. The model generally underestimated $ET_a$, with a root mean square error (RMSE) of 1.69 mm day$^{-1}$, and could only explain 20% of the variability in $ET_a$ (Fig. 2).

$$ET_a = -2.034 + 0.025 * SM \quad R^2 = 0.20 \quad (14)$$

Fig. (3) displays the decision tree that was built using the Bagging algorithm. The decision tree exhibited RMSE values of 1.49 mm day$^{-1}$ for the training dataset and 1.46 mm day$^{-1}$ for the validation dataset, with an overall average $ET_a$ (for all treatments) of 2.4 mm day$^{-1}$. The variable importance analysis revealed that the SR treatment is responsible for 42% of the variability in Guinea grass water use, followed by RWH at 31%, and SF at 26%. Consequently, SR had the most significant impact on $ET_a$, followed by RWH and SF. The RWH practices (RD and TR) resulted in relatively higher water use (2.5 mm day$^{-1}$) compared to the CT (2.2 mm day$^{-1}$). The highest and lowest $ET_a$ values were observed in the RDSR3.5F and RDSR1.5Z treatments, with values of 3.0 mm day$^{-1}$ and 1.7 mm day$^{-1}$, respectively. These findings partially contradicted the results obtained from the classical statistical analysis presented in Table (5), where the highest $ET_a$ (3.8 mm day$^{-1}$) was achieved by the TRSR1.5Z treatment, and the lowest one (2.2 mm day$^{-1}$) by the RDSR1.5F treatment.

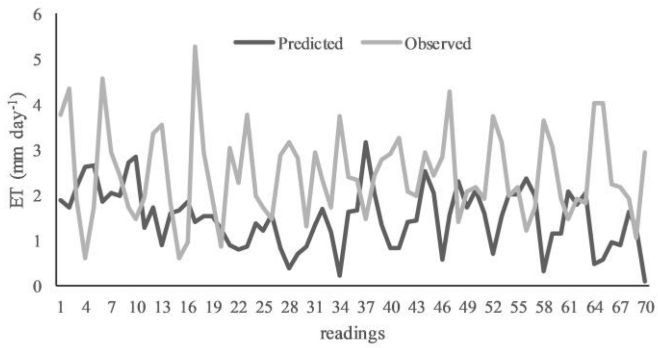


**Figure 2.** The performance of a stepwise regression model for predicting crop evapotranspiration ($ET_a$) of Guinea grass, under rainfed conditions enhanced by in-situ rainwater harvesting practices, the semi-arid environment in Sudan. The estimated root mean square error is 1.69 mm a day

### 3.2 Crop coefficients ($K_c$) of rainfed Guinea grass

Table (6) presents the average Kc values for rainfed Guinea grass cv. Mombasa during the experimental seasons. The Kc values for the RWH treatments (RD and TR) were significantly different from the CT values. For the initial, development, midseason, and late stages, the Kc values were 0.19, 0.26, 0.98, and 0.49 for the RWH treatments, compared to 0.66, 0.43, 0.60, and 0.36 for the CT, respectively.

Table (6) Estimated crop coefficients of rainfed-based *Guinea grass* cultivated under two in-situ rainwater harvesting practices (ridging plus terracing, RD, and terracing, TR), and three seeding rates, SR (SR15 for 1.5 kg $ha^{-1}$, SR25 for 2.5 kg $ha^{-1}$, and SR35 for 3.5 kg $ha^{-1}$), compared to the control, CT (flat, zero-tillage plots), the semi-arid environment, Sudan. Averages of two experimental seasons were presented (2020 – 2022)

| Growth Stage | RD | TR | CT |
|---|---|---|---|
| | | SR1.5 | |
| initial | 0.14 | 0.31 | 0.60 |
| development | 0.24 | 0.30 | 0.42 |
| mid | 0.93 | 0.93 | 0.69 |
| late | 0.37 | 0.62 | 0.32 |
| | | SR2.5 | |
| initial | 0.33 | 0.23 | 0.61 |
| development | 0.35 | 0.24 | 0.40 |
| mid | 1.04 | 0.75 | 0.56 |
| late | 0.45 | 0.42 | 0.33 |
| | | SR3.5 | |
| initial | 0.17 | 0.32 | 0.77 |
| development | 0.21 | 0.29 | 0.46 |
| mid | 0.82 | 0.77 | 0.55 |
| late | 0.54 | 0.38 | 0.44 |

The Kc values for the CT during the initial and development stages were higher than those of the RWH treatments due to higher evaporation rates during these early growth stages. However, when the plants reached the midseason and late growth stages, the transpiration part became dominant following the increased soil moisture content resulting from the RWH practices. During the early stages, the $K_c$ values were influenced by the wetted exposed area to evaporation, which decreased as the canopy increased. Despite similarities in the wetted exposed areas to evaporation for RD, TR, and CT, the RWH practices significantly improved the hydrological conditions of the soil, as evidenced by the reduction in soil bulk density. The RWH treatments showed reductions of 11.7% - 15.5% in soil bulk density compared to the CT. This reduction allowed for more infiltrated rainwater under the RWH treatments. However, Fig. (4) indicates that $ET_a$ tends to increase as the soil bulk density increases. This is because rainwater takes longer to infiltrate in poor surface soil hydrological conditions caused by increased soil bulk density, especially during the initial and development stages. This explains the 59% difference in $K_c$ values between the RWH practices ($K_c$ = 0.22) and the CT ($K_c$ = 0.54) for the initial and development growth stages, on average.

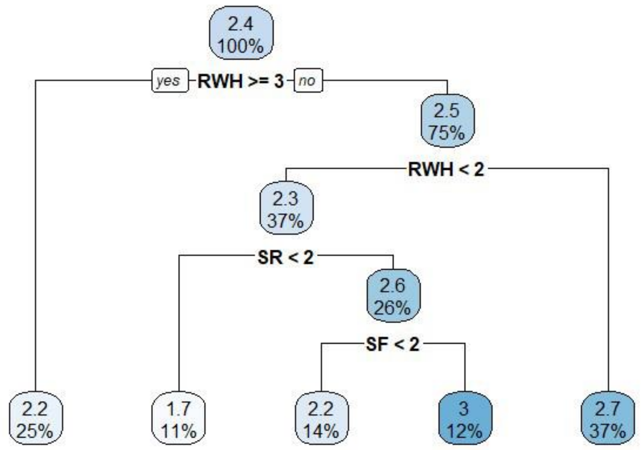


**Figure 3.** A developed decision tree showing how the variability of the seasonal crop evapotranspiration of rainfed Guinea grass (mm $day^{-1}$) as affected by rainwater harvesting (RWH), seeding rate (SR), and soil fertilization (SF). The RWH consisted of three levels: ridging plus terracing (1), terracing (2), and control (3); three levels for SR: 1.5, 2.5, and 3.5 kg $ha^{-1}$; two levels for SF; 95 kg N $ha^{-1}$, and 0 kg N $ha^{-1}$. The general mean is 2.4 mm $day^{-1}$. If the condition is true take the left, otherwise, take the right.

The average $K_c$ values for the initial and midseason growth stages of rainfed Guinea grass were 8% - 62% lower than values reported for irrigated subtropical conditions by Sanches et al. (2019) and de Oliveira et al. (2018). The initial $K_c$ is primarily influenced by the number of wetting events received (Allen et al., 1998), with the crop ET being mainly affected by direct evaporation from the soil surface. As the wetting of the soil surface increases following rainfall events, the evaporation also increases, resulting in significant differences in the initial Kc values between semi-arid and subtropical conditions where rainfall amounts are higher. On the other hand, the midseason $K_c$ is mainly influenced by prevailing weather conditions and crop characteristics such as relative humidity, wind speed, and crop height (Allen et al., 1998). It is important to note that the steward structure parameters of Guinea grass are significantly influenced by the harvesting time. The study by Sanches et al. (2019) aimed to simulate rotational grazing systems with a pre-established residue height of 30 cm for Guinea grass, while our study had no-cutting cycles with a peak height of 172 cm. These differences. justify the slight variations in the peak $K_c$ values between our study and Sanches et al. (2019). Additionally, despite the insignificant differences in seasonal rainfall amounts, the seasonal $K_c$ varied significantly between the first and second seasons. This indicates the significant impact of dry spells on $K_c$, with longer dry spell lengths in the second season resulting in a lower Kc value. These dry spells also had a significant impact on the seasonal leaf area index (LAI). Singh et al. (2019) have found a strong exponential relationship between the Kc of wheat and its LAI. Lastly, the different applied seeding rates (SR) did not show any significant effects on the seasonal $K_c$ averages. however, the seasonal $K_c$ increases generally as the seeding rate increases, except for the SR3.5. This holds also for the effect of the applied soil N fertilization. This is well-agreed with the result of Lamede et al. (2021) who claimed the insignificant impacts of the nitrogen fertilization on the percentages of leaves of *Guinea grass.*

### 3.2 Water use efficiency of rainfed Guinea grass

The water footprint, WFP, is used to measure the water use efficiency of Guinea grass. This indicator takes into account both biomass production and $ET_a$. In Tables (1 through 5), we can see how biomass production is influenced by various factors such as rainwater harvesting (RWH), seeding rate (SR), seedling fertilizer (SF), and the season. The implementation of RWH practices has had a significant impact on biomass production, increasing average soil moisture contents by 35% - 48% compared to conventional tillage (CT). As a result, the production of fresh biomass has increased by 341% - 381% compared to CT. While the seeding rate did not have a significant effect on biomass production, the highest seeding rate of 3.5 kg ha$^{-1}$ did result in the highest biomass production. The season also plays a role, with the first season showing higher biomass production compared to the second season. It is important to note that RWH practices were implemented to minimize seasonal differences in soil moisture contents compared to CT. Therefore, when designing RWH practices for establishing Guinea grass in arid and semi-arid environments, it is crucial to consider the detrimental effects of dry spells.

Table (7) presents a comparison of the estimated water footprint (WFP) of rainfed Guinea grass in the semi-arid environment of Sudan, based on dry biomass production. The seasonal WFP for the RWH treatments is calculated to be 0.25 m$^3$ kg$^{-1}$, whereas for the CT, it is 1.72 m$^3$ kg$^{-1}$ on average. This indicates that RWH systems require only 0.25 m$^3$ of water to produce one kilogram of dry biomass, while the CT conditions require six times more water to produce the same amount of biomass. In other words, RWH systems have managed to save 86% of the green water consumption of rainfed Guinea grass in the semi-arid environment. The estimates of WFP also reveal slight seasonal differences, with 0.22 m$^3$ kg$^{-1}$ for the first season and 0.27 m$^3$ kg$^{-1}$ for the second season. These differences can be attributed to variations in dry spells. As the duration of dry spells increases, water consumption also increases, resulting in lower biomass production and ultimately, relatively poor water use efficiency.

## 4. Conclusion

1. Rainfed pastures play a crucial role in ensuring food security and financial stability in semi-arid environments.
2. However, the occurrence of frequent droughts has significantly hindered the effectiveness of these pastures. To address this issue, there has been a growing trend of using exotic nutritive and drought-tolerant species like Guinea grass to improve degraded pastures.
3. Most studies on Guinea grass, however, have focused on irrigation-based approaches. Nevertheless, the introduction of Guinea grass into rainfed semi-arid environments has been positively influenced by the implementation of cost-effective in-situ rainwater harvesting (RWH) practices.
4. RWH practices have yielded encouraging results in conserving three essential resources for semi-arid pastures, namely green water, soil hydrological condition, and vegetation biomass production. By diverting non-productive water uses such as evaporation towards productive ones like transpiration, the applied RWH packages have significantly enhanced the water use efficiency of rainfed-based Guinea grass.
5. Seasonal actual crop evapotranspiration ($ET_a$) rates under ranfed conditions enhanced with RWH practices were ranged from 1.93 to 3.29 mm day$^{-1}$. The estimates obtained from this research will aid in the sustainable design of RWH systems for establishing Guinea grass under rainfed conditions.
6. The importance of considering the negative effects of dry spells on water usage and

7. biomass production cannot be underestimated when designing RWH systems
8. Seeding rates have the most significant impacts on variations in $ET_a$, followed by RWH, and fertilization.
9. The importance of considering the negative effects of dry spells on water usage and biomass production cannot be underestimated when designing RWH systems.
10. The conclusions drawn from this study, which also examined the impact of different seeding rates and nitrogen fertilization on Guinea grass, were limited due to the use of linear models. Therefore, it is crucial to conduct more detailed studies using multiple-layer models to gain a better understanding of the non-linear interactions that occur in arid and semi-arid environments.

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