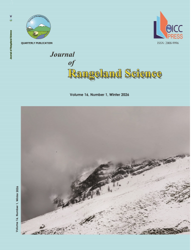

J. Rangeland Sci. 2026; 16(1) : 57-66

Journal of Rangeland Science (JRS)

https://doi.org/10.57647/jrs-2026-1601.05

Management and Maintenance of Semi-arid Rangelands via Symbiosis Between Mycorrhiza Fungi and Range Plant Species

Mohammad Matinizadeh[1,*], Elham Nouri1[1], Mohammad Bayranvand[2], Adel Jalili[1], Tahereh Alizadeh[1], Maryam Teimouri,[1] Alireza Eftekhari[1]

[1]*Research Institute of Forests and Rangelands, Agricultural Research Education and Extension Organization (AREEO), Tehran, Iran*
[2]*Kerman Agricultural and Natural Resources Research and Education Center, Agricultural Research Education and Extension Organization (AREEO), Kerman, Iran*

[*]**Corresponding author:** Matini@rifr-ac.ir

Original Research

Received:
06 August 2024
Revised:
07 April 2025
Accepted:
01 June 2025
Published in Issue:
31 March 2026

© 2025 The Author(s). Published by the OICC Press under the terms of the CC BY 4.0, Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

Abstract:

Understanding the symbiotic relationship between Arbuscular Mycorrhizal Fungi (AMF) and plants, particularly with soil nutrient and enzyme activity, is crucial for preserving semi-arid rangeland ecosystems. AMF is remarkable in nutrient acquisition and carbon cycling within these ecosystems. This study aimed to investigate the relationships among Root Colonization (RC), soil enzyme activity, and rhizosphere soil chemical properties in nine rangeland plant species. In the spring of 2019, soil and root samples were collected randomly from the rhizosphere of plant species [Acanthophyllum glandulosum, Astragalus gossypinus and Noaea mucronata (shrub growth); Centaurea virgate, Hypericum perforatum, Pterocephalus canus and Stachys inflata (forb growth); Melica persica and Stipa hohenackeriana (Grass growth)] in Kordan rangeland, Hashtgerd, Alborz province, Iran. Data were collected for RC% using the intersection method, soil enzyme activity by spectrophotometrically, Available Phosphorus (P) (by Olsen method), Organic Carbon (OC) (by wet oxidation method), and Exchangeable Potassium (K). There were significant differences among plant species for rhizosphere soil chemical properties, RC%, and enzyme activities. However, there were no significant differences for P and the activity of Acid Phosphatase (ACP) enzyme. Our results indicate that P. canus and C. virgata plants, characterized by moderate palatability, thrive in soils with balanced chemical properties, which promote AMF colonization and enzyme activity. There were positive and significant correlations between RC% and enzyme activities, except ACP. Additionally, strong positive correlations were found between Dehydrogenase (Deh) activity and both RC% and carbon content. The lowest RC% was observed in N. mucronata and A. gossypinus, potentially attributable to their competitive traits, which may reduce their reliance on mycorrhizal associations for nutrient acquisition and dispersal. Forb growth species exhibited more favorable rhizosphere functions than grass and shrub species. P. canus and C. virgata with the highest symbiotic association with AMF were suggested for the management and protection of semi-arid rangeland ecosystems in the study area.

Keywords: Arbuscular Mycorrhizal Fungi; Symbiosis; Soil Enzyme; Semi-arid rangelands

Cite this article: Matinizadeh M., Nouri E., Bayranvand M., Jalili A., Alizadeh T., Teimouri M. & Eftekhari A., (2026). ”Management and Maintenance of Semi-arid Rangelands via Symbiosis Between Mycorrhiza Fungi and Range Plant Species.” *Journal of Rangeland Science*, *16*(1), 57-66. https://doi.org/10.57647/jrs-2026-1601.05

1. Introduction

Semi-dried rangelands are among the most sensitive ecosystems to degradation, loss of soil quality and vegetation, which can be cases of high grazing pressures coupled with repeated drought (Hovland et al., 2019; Nouri et al., 2018). Hence, there is a vital need for the restoration of these rangelands to attain sustainability with suitable plant species (Binet et al., 2020). Semi-dried rangeland plants may benefit from Arbuscular Mycorrhizal Fungi (AMF) through increased nutrient uptake and moisture use efficiency, especially considering these benefits are greater in conditions of drought stress and lower soil nutrients (Hovland et al., 2019). AMF are one of the most important soil microorganisms, which form symbioses with many plant species in almost any terrestrial ecosystem (Delavaux et al., 2022; Krüger et al., 2012). Their presence is very critical for plant life and their competition in plant communities (Miyauchi et al., 2020; Wang et al., 2021). Mycorrhizae are symbiotic associations established between soil fungi and most vascular plants and are fundamental in optimizing plant fitness and soil quality (Dudinszky et al., 2019; Moshki et al., 2024).

Maintenance of plant community through ecological feedback patterns, such as facilitation of nutrient uptake by host plants and mediation of plant competition, suggests that AMF may be important facilitators in stressful semi-dried grasslands (Dudinszky et al., 2019). They increase the physiological condition of plants by the change in water movement and absorption (Augé, 2001; Heklau et al., 2023), improve nutrient balance in plants, especially P absorption, resistance against pathogens, and also improve soil structure (Hossein Jafari et al., 2019; Tedersoo et al., 2020). As one of the most abundant soil-plant symbionts, AMF is a living bridge for the transfer of nutrients from soil to plant roots and carbon from plant roots to soil (Parihar et al., 2020). The ability of AMF to increase hydraulic conductivity had a vital role in maintaining relatively high rates of photosynthesis and nutrient uptake in arid and semi-arid grasslands (Ambrosino et al., 2018; Barea et al., 2011; van der Heyde et al., 2017). Root Colonization (RC) of AMF with plants is beneficial for plant survival (Binet et al., 2020) soil quality (Zhang et al., 2021) and enzyme activities (Matinizadeh et al., 2024). The rhizosphere is one of the most important but least understood areas, which is made from plant roots surrounded by the soil (Delavaux et al., 2022). RC is a good indicator of a better understanding of organic matter decomposition, nutrient cycling, water storage, and distribution as well as a habit for AMF (Miyauchi et al., 2020; Ritz et al., 2009). The AMF activity in the rhizosphere changes in response to the changes in plants, microbial communities, environmental and edaphic conditions (Bayranvand et al., 2021a; Tedersoo et al., 2020). In the past, chemical properties of soil have been used to evaluate soil quality (Puglisi et al., 2006). The disadvantage was their slow reaction to environmental changes and it is detectable after a long period (Rousta et al., 2023). However, the soil biological properties are very sensitive and respond very quickly to even minor changes in environmental conditions (Pascual et al., 2000), making them so valuable in comparison to different species of rhizosphere. Some of the biological properties (products) are related to microorganisms and plants, such as soil enzyme activity (Bayranvand et al., 2021b).

Soil enzyme activity is a potential indicator to evaluate soil quality due to their high sensitivity to environmental factors and ease of measurement (Bandick & Dick, 1999). The higher activity of soil enzymes indicates a larger community of microorganisms and a higher decomposition rate of organic matter (Marinari & Antisari, 2010). Close relationships exist between AMF function and soil enzyme activity. Increases in fungal abundance and diversity are indicative of increased enzyme activity in soils (Matinizadeh et al., 2024). Soil enzymes produced by saprobic fungi, roots, and bacteria are the most important factors in the control of biochemical processes such as the decomposition of organic matter and the cycling of nutrients in the soil (Snajdr et al., 2013).

The beneficial effects of AMF are most pronounced under conditions of limited nutrient and water availability, making them crucial for the survival and restoration of plants in arid and semi-arid ecosystems or degraded areas. Symbiotic and free-living microorganisms play a critical role in the mineralization process of the nutrient supply. Despite numerous studies, the distribution of AMF and their contribution to plant conservation remains poorly understood in semi-arid ecosystems, especially in Iran. To predict plant survival, distribution, and diversity, understanding rhizosphere soil quality and plant dependence is essential. This study aimed to investigate the intricate relationships between mycorrhizal colonization, soil enzyme activity, and soil chemical properties in the rhizosphere of nine rangeland species.

2. Materials and Methods

2.1 Site description

Kordan rangeland is located 20 Km from Hashtgerd, Alborz province, Iran (35°57′ 21″ N, 50°51′17″ E) (Figure 1). The altitude is 1680 m. a.s.l. The dominant slope ranged from 25-35 % in the south-north direction. Having a semi-arid climate according to the Ambridge method, the annual average temperature is 14°C, and the annual precipitation is 373 mm. The list of studied perennial rangeland species is given in Table 1. The texture of the soil in this habitat was sandy loam, with the percentages of clay, silt, and sand being 8.8, 12, and 79.2, respectively.

2.2 sampling method

For each plant species, three soil samples were taken from the 0-20 cm depth of the rhizosphere in the spring of 2019. These samples were subsequently transported to the laboratory and stored at 4°C. Soils were sieved (2 mm mesh) and kept at the room temperature, 4°C for fungal experiments and -20°C to measure enzyme activity until further analysis. To assess RC by mycorrhizae, hairy roots were preserved in Formaldehyde, Acetic acid, Alcohol (FAA) fixative solution to maintain cellular structure.

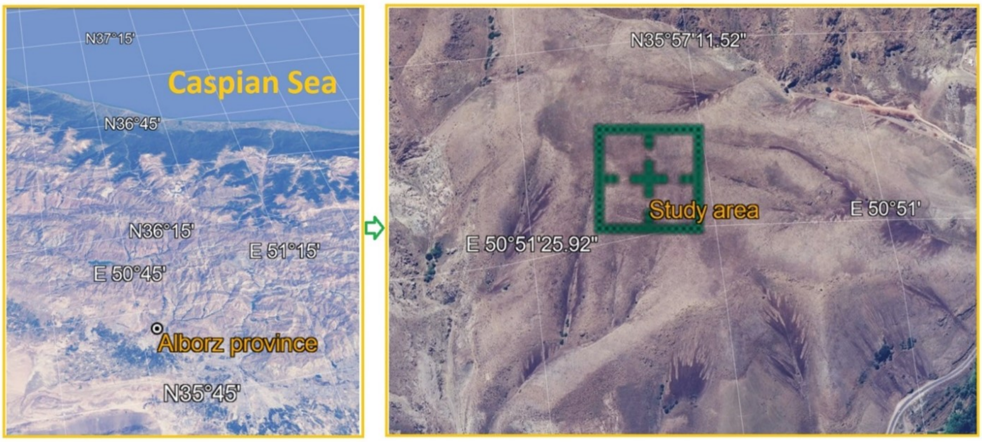

Figure 1. Location of the study area, semi-arid natural rangeland, in the Kordan rangeland, Alborz province, Iran.

Table 1. Plant composition of study area

Plant species	Family	Growth form
Acanthophyllum glandulosum Bunge ex Boiss.	Caryophyllaceae	Shrub
Astragalus gossypinus Fisch.	Fabaceae	Shrub
Noaea mucronata (Forssk.) Asch. & Schweinf.	Amaranthaceae	Shrub
Centaurea virgata Lam.	Asteraceae	Forb
Hypericum perforatum L.	Hypericaceae	Forb
Pterocephalus canus Coult. ex DC.	Caprifoliaceae	Forb
Stachys inflata Benth.	Lamiaceae	Forb
Melica persica Kunth	Poaceae	Grass
Stipa hohenackeriana Trin. & Rupr.	Poaceae	Grass

2.3 Soil chemical properties

The soil acidity (pH) was measured in saturation sludge (1:2.5 and 1:5 w/v, Orion Ionalyzer Model 901, pH) (Janzen, 1993). Available Phosphorus (P) extracted with 0.5 M $NaHCO_3$ was analyzed calorimetrically using the ascorbic acid molybdate method (Olsen & Sommers, 1982), and Exchangeable Potassium (K) was extracted with $NH_4C_2H_3O_2$ and analyzed on an atomic absorption spectrophotometer (Warncke & Brown, 1998) in soil samples. Organic Carbon (OC) content was determined using the potassium dichromate-sulfuric acid oxidation method, followed by the titration method (Walkley & Black, 1934).

2.4 Mycorrhizal analysis

The roots were stained according to the method of Phillips and Hayman (1970) by clearing 2-cm root pieces in 10% KOH at 90°C for 2 h, bleaching in 7.5% H_2O_2 for 5 min and acidifying in 1% HCl for 5 min before staining in 0.05% Trypan blue in lactoglycerol at 90°C for 20 min and the percentage of colonization, the number of hyphae, arbuscule and vesicle (Figure 2) were determined by the method of intersection in which using the gridline intersect method on 100 intersections at 100 × magnification using an Olympus CH_2 dissecting microscope (McGonigle et al., 1990).

2.5 Soil enzyme activity assays

Homogenized soil samples (about 300 g fresh weight) were collected from the rhizosphere of each plant species and conserved at -20°C. Alkaline Phosphatase (ALP) and Acid Phosphatase (ACP) activities were determined on 1 g (wet weight) aliquots of the soil using p-Nitrophenyl Phosphate (pNPP) as an orthophosphate monoester analogue substrate and were reported on a soil dry weight basis. After the addition of a buffered (pNPP) solution, soil samples were incubated for 1 hour at 37°C. The nitrophenol released by phosphomonoesterase activity was extracted and determined photometrically at 400 nm and the results were recorded as μg ρ- nitrophenol g^{-1} dry soil h^{-1} (Schinner et al., 1996). Dehydrogenase (Deh) was specified using 2, 3, 5-Triphenyl Tetrazolium Chloride (TTC) as a substrate, and the results were recorded as μg Triphenyl Formazan (TPF) g^{-1} dry soil $16h^{-1}$. Samples and controls (by the addition of the substrate after the reaction ended) were put for analysis in triplicate and averaged. For the Deh assay, controls were carried out with Tris–HCl buffer instead of TTC (Gmbh et al., 1993). For assaying Urease (Ure), the incubation of the plates was performed at 37°C for roughly 2 hr. The colorimetric salicylate and nitroprusside reagent packets from Hach were applied to quantify the nitrogen released by the reaction. Urea was determined spectrophotometrically at 690 nm. Activity is shown as micrograms of nitrogen released per

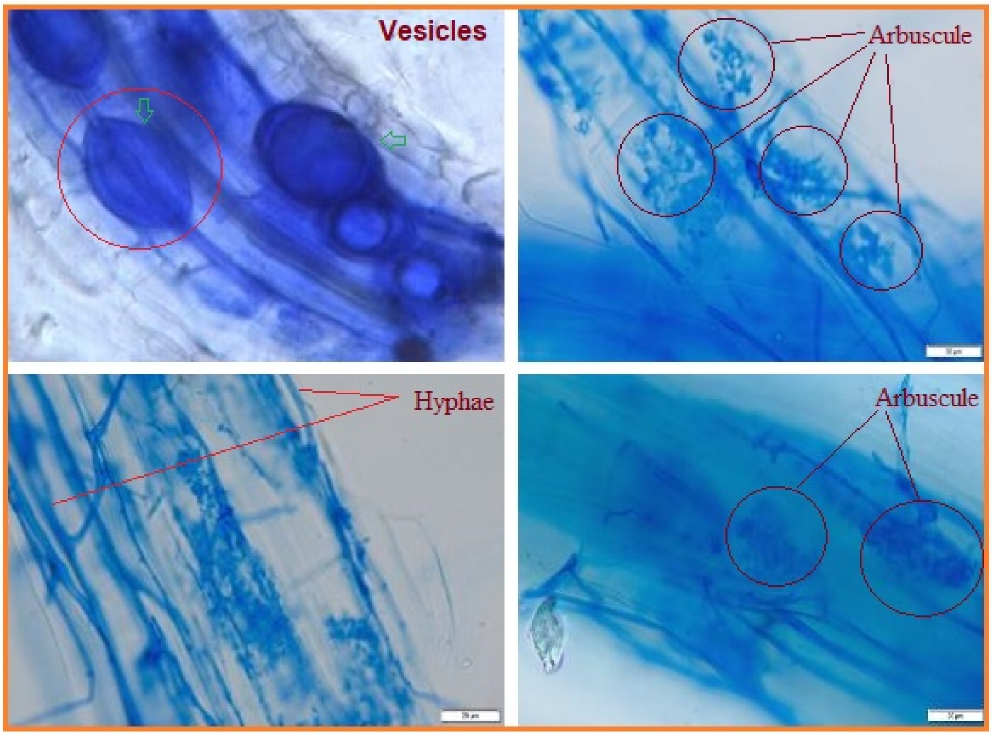

Figure 2. RC and the presence of AMF organs in the rhizosphere of plants in the study areas

gram of soil on 2 hours' basis (µg N g^{-1} dry soil $2h^{-1}$) (Schinner et al., 1996).

2.6 Data analysis

The data of the variables were checked for their normality with the Shapiro-Wilk test. If necessary, the variables were transformed by Log transformation. The measured properties were subjected to a one-way analysis of variance and the Tukey HSD test. Pearson's correlations and PCA were calculated to evaluate the relationship among the physical, chemical, and biological properties of rhizosphere soil. All analyses were done by R software (R Development Core Team, 2018).

3. Results

3.1 Soil chemical properties

Analysis of variance showed a significant difference ($P < 0.01$) in pH, OC content, and K in the rhizosphere soil of the studied plant species (Table 2). The means comparison showed the highest pH value in A. gossypinus and M. persica and the lowest pH value in S. hohenackeriana (Table 2). The lowest value of OC% was found in the rhizosphere of M. persica, C. virgata, and N. mucronata than in other species (Table 2). The means comparison showed the lowest K value in the rhizosphere of M. persica, while A. glandulosum, H. perforatum, and N. mucronata had the highest value of K. There was no significant difference in P in the rhizosphere of different species (Table 2).

3.2 Root colonization

There were mycorrhizal fungi structures (hyphae, arbuscules, and vesicles) in the roots of all studied species. The RC percentage of H. perforatum, P. canus and C. virgata plants had the highest value, while A. gossypinus and N. mucronata showed the lowest value (Figure 3).

3.3 Enzymes activity

Variance analysis showed that the activity of all enzymes differed significantly ($P < 0.01$) except for ACP activity (Table 3). Means comparison showed the highest and lowest activity in the rhizosphere of N. mucronata and P. canus, respectively. The highest Ure activity was observed in the rhizosphere of P. canus, S. hohenackeriana, and H. perforatum, while the lowest activity was detected in A. gossypinus rhizosphere. The maximum and minimum activity of Deh was determined in the rhizosphere of P. canus and N. mucronata, respectively (Table 3).

3.4 Relationship among soil properties, enzyme activity, and RC

According to Pearson correlation coefficient values, there were correlations between some of the soil physico-chemical properties with soil enzyme activity and RC. There was a significant positive correlation between soil OC and Deh activity (r=0.41*) and a negative correlation between K with ALP activity (r=-0.43*). The RC was strongly correlated with the activities of ALP (r=0.61**), Deh (r=0.54**) and Ure (r=0.43*) enzymes, but did not have a significant correlation with soil OC, P and K (Table 4). Overall, the correlation re-

https://doi.org/10.57647/jrs-2026-1601.05

Table 2. Comparison of chemical variables determined in the rhizosphere soil of the studied plant species

Plant species	Soil properties			
	pH	OC(%)	P(mg/kg)	K(mg/kg)
Acanthophyllum glandulosum Bunge ex Boiss.	8.17±0.03b	4.15±0.71a	14.19±0.53a	31.93±2.52a
Astragalus gossypinus Fisch.	8.31±0.06a	3.58±0.15a	21.51±8.61a	12.89±1.58b
Noaea mucronata (Forssk.) Asch. & Schweinf.	8.23±0.03ab	1.96±0.14b	13.15±0.09a	31.68±2.16a
Centaurea virgata Lam.	8.13±0.02b	2.36±0.11b	12.68±0.73a	14.81±0.75b
Hypericum perforatum L.	8.2±0.04ab	3.56±0.29a	11.04±0.79a	33.34±2.36a
Pterocephalus canus Coult. ex DC.	8.22±0.03ab	4.12±0.62a	15.79±0.71a	20.21±1.36b
Stachys inflata Benth.	8.15±0.03ab	4.12±0.29a	10.44±0.17a	13.24±1.91b
Melica persica Kunth	8.32±0.06a	1.94±0.47b	13.79±1.65a	2.54±0.53c
Stipa hohenackeriana Trin. & Rupr.	8.07±0.02b	1.94±0.47b	11.65±0.50a	2.54±0.53 c
DF	18	18	18	18
F-values	4.790**	39.580**	1266	28.170**

Values are means of 3 replicates ± (S.E.); F-values are given according to one-way ANOVA; **, significant at $P \leq 0.01$. In each column, means marked by the same letters are not significantly different.

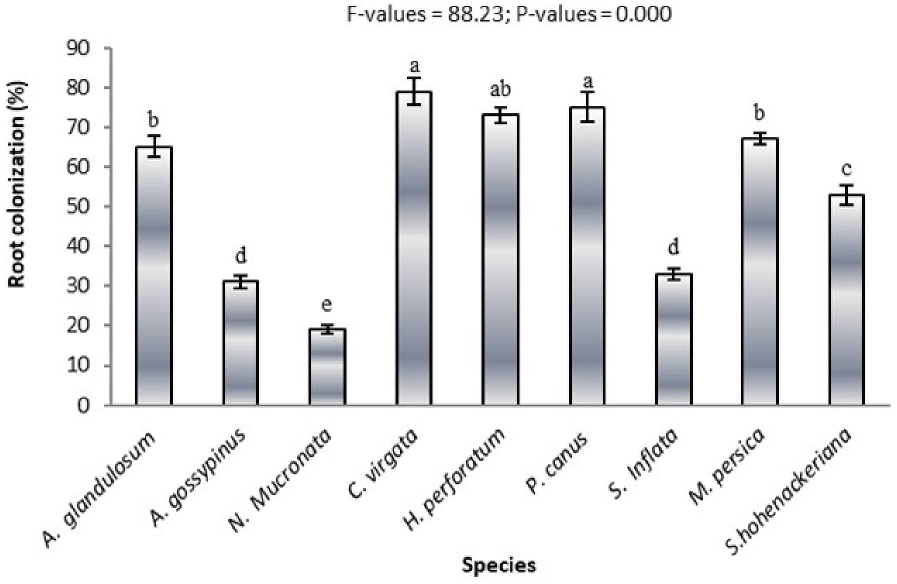

Figure 3. RC(%) of different plant species; Bars are means of 3 replicates (S.E.); Means marked by the same letter are not significantly different at P= 0.01 according to the Tukey HSD test.

Table 3. The activities of soil enzymes among the studied species

Plant species	Enzyme activities			
	ACP ($\mu g pNP.g^{-1} dm.h^{-1}$)	ALP ($\mu g pNP.g^{-1} dm.h^{-1}$)	Deh ($\mu g TPF.g^{-1} dm.16h^{-1}$)	Ure ($\mu g N.g^{-1} dm.2h^{-1}$)
Acanthophyllum glandulosum Bunge ex Boiss.	147.70±37.3a	476.01±46.1b	64.47±6.1ab	570.84±63.3 bc
Astragalus gossypinus Fisch.	154.19±31.3a	446.39±23.9bc	38.84±3.3b	541.27±60.9c
Noaea mucronata (Forssk.) Asch. & Schweinf.	103.87±6.2a	363.62±5.8c	25.03±1.04c	686.70±72.1ab
Centaurea virgata Lam.	106.40±11.2a	589.05±59.6a	41.87±3.9b	764.57±76.3ab
Hypericum perforatum L.	140.43±14.0a	525.86±7.9b	51.95±0.5b	838.29±65.5a
Pterocephalus canus Coult. ex DC.	145.73±16.3a	671.39±30.6a	92.75±3.1a	905.17±12.7a
Stachys inflata Benth.	109.01±8.6a	553.53±46.2ab	53.43±5.6b	605.91±76.9bc
Melica persica Kunth	112.89±4.3a	581.19±2.5a	69.70±8.9a	669.08±14.4bc
Stipa hohenackeriana Trin. & Rupr.	144.64±6.5a	543.59±52.4ab	72.80±7.9a	841.20±50.9a
DF	18	18	18	18
F-values	1239	5955**	15.270**	4782**

Values are means of 3 replicates ± (S.E.); F-values are given according to one-way ANOVA; **, significant at $P \leq 0.01$. in each column, means marked by the same letter are not significantly different;

sults indicate that increased enzyme activity was associated with higher RC and arbuscular mycorrhizal fungi proliferation (Table 4).

3.5 PCA analysis

As shown in Figure 4, the Principal component analysis (PCA) indicated that the first and second axes explained 59.1% of the variation in the data. The first and second components accounted for 36.3% and 22.8% of the total variation, respectively. In the biplot of PC1, 2, nine rangeland species and soil properties were scattered in the first axis; the arrows represent the soil enzyme activity, OC, and RC. ALP, Deh, and Ure are positively correlated with the first axis. The arrows in the second axis represent pH, ACP, and P, which were positively correlated with the second axis. in the other hand, the species of H. perforatum, P. canus, and S. hohenackeriana were correlated with the first axis; therefore, they were affected by RC, OC, ALP, Deh, and Ure. Similarly, the species of A. glandulosum and A. gossypinus are correlated with the second axis, and as a result, they were affected by pH, ACP, and P (Figure 4).

4. Discussion

Soil properties are determined mostly by the quality and quantity of organic matter, which originates from plant species and vice versa (Yang et al., 2018). Although the biological properties (i.e., RC and soil enzyme activity) are more sensitive indicators and respond rapidly to minor environmental changes in soil (Nouri et al., 2018; Pascual et al., 2000). Results indicated there was a significant variation in pH, OC, and K (Table 2) of different species. The rhizosphere of M. persica, S. hohenackeriana, C. virgata and N. mucronata had the lowest OC compared to other species. M. persica is low demanding, compatible with moderate palatability and grows with a small amount of organic matter. Also, (Ketabi et al., 2010) showed that M. persica is a widely distributed, adaptable, and well-established range plant in most rocky foothills. N. mucronata has a vast distribution (1.1 million ha) and C. virgate has a smaller distribution (100000 ha) in Iran rangeland (Fayaz et al., 2012). In addition, C. virgate plant has low palatability and is considered as an aggressive species. These two species, with compatibility to the low organic matter, grow fast in rangelands that have lost native and palatable species with reduced organic matter (Eftekhari et al., 2021). Finally, they could be the dominant species due to their compatibility with the new conditions. N. mucronata is more likely to invade degraded rangeland, while C. virgata prefers to invade degraded agricultural lands because often these lands have more organic matter than the destroyed rangeland (Eftekhari et al., 2021). A. glandulosum had higher soil OC and K content and moderate RC and enzyme activities against other species, whereas their rhizosphere biological condition was better than another shrub plant species (i.e., A. gossypinus and N. mucronata) in this study. This is due to the A. glandulosum root being a source of saponin (Dabestani et al., 2021), which shows potential as a natural antibacterial. A. glandulosum showed a strong correlation with K, OC, and ACP. This indicates that the availability of these nutrients and the activity of soil enzymes play a crucial role in plant growth and health. For instance, to promote the growth of species like A. glandulosum, it may be beneficial to focus on soil fertility and organic matter content. Saponin is known as a defense system of plants against pathogenic microorganisms. Furthermore, saponin has antifungal, anti-inflammatory and adjuvant properties (Najjar-Tabrizi et al., 2020). Qian et al. (Qian et al., 2024) depicted that Arbuscular mycorrhizae is more conducive to increasing hormone levels, nutrient absorption, and total saponin content in P. polyphylla and also facilitates saponin accumulation under moderate drought stress. The highest RC was observed in P. canus, H. perforatum and C. virgata plants. Their fairly good distribution can be related to their symbiosis with mycorrhizal fungi. P. canus habitat is sunny, dry, rocky crevices, mostly found in Western Asia. These species, including P. canus and C. virgata, show strong correlations with ALP, Ure, Deh, and RC. This suggests that these species rely heavily on microbial activity and nutrient-cycling processes for their growth and survival. These species are known to exhibit various biological activities, such as antioxidant activities that are correlated with the leaves' chemical content and antibacterial activities (Vahedi et al., 2011). Besides, H. perforatum, a plant that has been used for its medicinal effects, can adapt to a range of environmental conditions by changing its metabolic profile. some factors, such as soil features (i.e., OC) and rhizosphere, environmental conditions, and phenological stages, can impact their bioactive compounds content (Gönenç et al., 2020; Saffariha et al., 2021). The higher carbon content in the leaves and roots of this plant can help its symbiosis with mycorrhizal fungi (Nouri et al., 2020). Therefore, with the help of the mentioned factors, it can attack the destroyed farms and rangeland, respectively. The lowest RC was observed in the rhizosphere of N. mucronata and A. gossypinus plants. So, N. mucronata is a highly aggressive species with the ability to attack damaged ecosystems with a low amount of organic matter (Fayaz et al., 2012). No or less dependency on symbiosis with different species of mycorrhizal fungi in N. mucronata indicates their resistance to unsuitable environmental conditions (Eftekhari et al., 2021). N. mucronata species appear to be less influenced by soil properties, suggesting a higher degree of tolerance to varying soil conditions. The vast distribution of C. virgata, along with high symbiosis with different kinds of mycorrhizal fungi, can be supported in competition with other species and make conditions favorable for growth. The plant species A. gossypinus also had the lowest coexistence percentage, perhaps due to its coexistence with Rhizobium bacteria (Khojasteh et al., 2013). Therefore, it is also more affected by the factors of pH and P. A. gossypinus, as a legume species, has nitrogen fixation capability and has a good tolerance to environmental variables. With the

Table 4. The correlation coefficient (r) between soil enzyme activities, RC and soil chemical properties

Parameters	pH	OC	P	K	RC
ACP	0.11	0.26	0.28	0.19	0.14
ALP	-0.07	0.23	-0.15	-0.43*	0.61**
Deh	-0.11	0.41*	-0.04	-0.24	0.54**
Ure	-0.26	0.04	-0.31	0.18	0.43*
RC	-0.15	0.02	-0.11	- 0.04	1.00

*, **, significant at $P \leq 0.05$ and $P \leq 0.01$, respectively

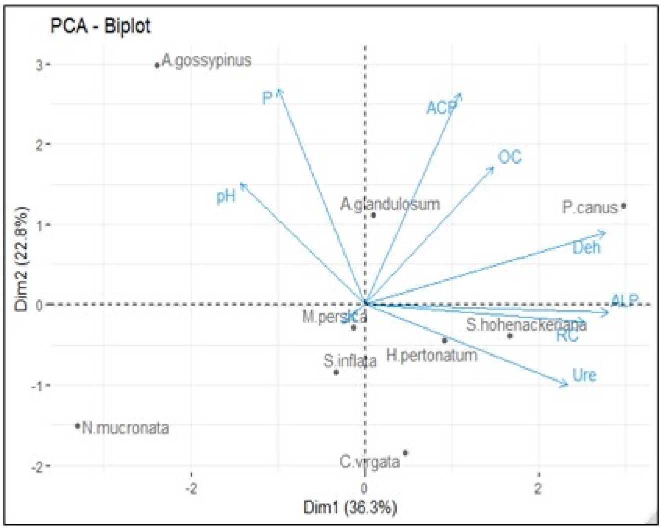

Figure 4. Scatter plot of nine range species for the first two principal components. The first and second components accounted for 36.3% and 22.8% of the total variation, respectively. Arrows represent different soil properties.

management and establishment of this species, in addition to soil conservation, the opportunity to reproduce and preserve another valuable plant species will be provided (Ahmadi et al., 2017; Ghasemi Arian & Dashti, 2024).

It seems that the role of microorganisms in phosphate mineralization is dramatically important for these rangeland species and their activity is effective in P supply for plant and their function (Dick, 1994). Previous studies have proved the negative correlation between phosphatase activity and P, which is in agreement with our findings on the A. gossypinus plant. The rhizosphere of this species with the highest P concentration had the least phosphatase activity and RC percentage (Álvarez Lopeztello et al., 2019). Besides, there was a high correlation with P, as well. There was a negative correlation between K and ALP activity, confirming the previous explanation. The most Ure activity was detected in the rhizosphere of P. canus, S. hohenackeriana and H. perforatum, while A. gossypinus rhizosphere had the lowest Ure activity. A. gossypinus exhibits strong correlations with P and pH, suggesting that its growth and development are significantly influenced by these factors. A. gossypinus belongs to leguminous plants. Probably because of symbiosis with nitrogen-fixing bacteria, this plant does not need external nitrogen sources, explaining less activity of Ure in its rhizosphere (Maharjan et al., 2017). A. gossypinus may be more sensitive to changes in soil pH and nutrient availability, while species like N. mucronata may be more resilient.

Deh activity is considered an important biological activity indicator in soil (Burns & Dick, 2002). The least activity of four studied enzymes in the rhizosphere of N. mucronata indicates this species does not need mycorrhizal symbiosis, making it popular in the damaged rangelands as an alternative species of extinct native species. The results obtained on Deh activity in this study conform to ALP activity results, which are secreted by microorganisms.

5. Conclusions

Understanding and preserving the plant-AMF symbiosis are crucial for sustainable rangeland management. This study investigated AMF colonization and rhizosphere soil enzyme activities in various plant species within a semi-arid rangeland. Our findings revealed significant variation in RC and enzyme activity among plant species. P. canus exhibited the highest levels, while N. mucronata showed the lowest. C. virgata was positively influenced by RC and Ure activity, whereas A. gossypinus was sensitive to multiple soil chemical properties. Notably, forb species like P. canus and C. virgata demonstrated more favorable rhizosphere conditions compared to grass and shrub species. To conserve sensitive semi-arid rangelands and improve soil productivity, plant species exhibiting strong symbiotic associations with mycorrhizal fungi in the local habitat should be prioritized for preservation and replanting.

Authors contributions

All authors contributed to the design of the study and writing. Soil and root sampling, Material preparation, data collection and analysis were performed by EN, TA, MM and AE. The soil properties, enzyme activities and identification of fungal data were analyzed and interpreted by EN and TA. The data was analyzed by EN and MB. The manuscript was written by MM, EN, MB, MT, AJ and TA. All authors read and approved the final manuscript.

Availability of data and materials

The data that support this study will be shared upon reasonable request to the corresponding author.

Conflict of interests

I certify that there is no actual or potential conflict of interest concerning this article. This study was financially supported by the Research Institute of Forests and Rangelands, Agricultural Research Education and Extension Organization (AREEO), Tehran, Iran.

References

Álvarez Lopeztello, J., del Castillo, R. F., Robles, C., & Hernández Cuevas, L. V. (2019). Spore diversity of arbuscular mycorrhizal fungi in human-modified neotropical ecosystems. *Ecological Research*, *34*(3), 394–405.

Ahmadi, J., Farzam, M., & Lagzian, A. (2017). Investigating effects of a prescribed spring fire on symbiosis between mycorrhiza fungi and range plant species [(In Persian)]. *Journal of Rangeland Science*, *7*(2), 138–147.

Ambrosino, M. L., Cabello, M. N., Busso, C. A., Velázquez, M. S., Torres, Y. A., Cardillo, D. S., Ithurrart, L. S., Montenegro, O. A., Giorgetti, H., & Rodriguez, G. (2018). Communities of arbuscular mycorrhizal fungi associated with perennial grasses of different forage quality exposed to defoliation. *Journal of Arid Environments*, *154*, 61–69.

Augé, R. M. (2001). Water relations, drought, and vesicular-arbuscular mycorrhizal symbiosis. *Mycorrhiza*, *11*, 3–42.

Bandick, A. K., & Dick, R. P. (1999). Field management effects on soil enzyme activities. *Soil Biology and Biochemistry*, *31*, 1471–1479.

Barea, J. M., Palenzuela, J., Cornejo, P., Sánchez-Castro, I., Navarro-Fernández, C., Lopéz-García, A., Estrada, B., Azcón, R., Ferrol, N., & Azcón-Aguilar, C. (2011). Ecological and functional roles of mycorrhizas in semi-arid ecosystems of southeast spain. *Journal of Arid Environments*, *75*(11), 1292–1301.

Bayranvand, M., Akbarinia, M., Salehi Jouzani, G., Gharechahi, J., Kooch, Y., & Baldrian, P. (2021a). Composition of soil bacterial and fungal communities in relation to vegetation composition and soil characteristics along an altitudinal gradient. *FEMS Microbiology Ecology*, *97*(1), flaa201.

Bayranvand, M., Akbarinia, M., Salehi Jouzani, G., Gharechahi, J., & Baldrian, P. (2021b). Distribution of soil extracellular enzymatic, microbial, and biological functions in the c and n-cycle pathways along a forest altitudinal gradient. *Frontiers in Microbiology*, *12*, 660603.

Binet, M. N., Marchal, C., Lipuma, J., Geremia, R. A., Bagarri, O., Candaele, B., Fraty, D., David, B., Perigon, S., Barbreau, V., & Mouhamadou, B. (2020). Plant health status effects on arbuscular mycorrhizal fungi associated with lavandula angustifolia and lavandula intermedia infected by phytoplasma in france. *Scientific Reports*, *10*, 20305.

Burns, R. G., & Dick, R. P. (2002). *Enzymes in the environment: Activity, ecology, and applications*. Marcel Dekker.

Dabestani, M., Yeganehzad, S., & Miller, R. (2021). A natural source of saponin: Comprehensive study on interfacial properties of chubak (acanthophyllum glandulosum) root extract and related saponin. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *630*, 127594.

Delavaux, C. S., Ramos, R. J., Sturmer, S. L., & Bever, J. D. (2022). Environmental identification of arbuscular mycorrhizal fungi using the lsu rdna gene region: An expanded database and improved pipeline. *Mycorrhiza*, *32*, 145–153.

Dick, R. P. Soil enzyme activities as indicators of soil quality (J. W. Doran, D. C. Coleman, D. F. Bezdicek, & B. A. Stewart, Eds.). In: In *Defining soil quality for a sustainable environment* (J. W. Doran, D. C. Coleman, D. F. Bezdicek, & B. A. Stewart, Eds.). Ed. by Doran, J. W., Coleman, D. C., Bezdicek, D. F., & Stewart, B. A. Madison, Wisconsin, USA: Soil Science Society of America, 1994, pp. 107–124.

Dudinszky, N., Cabello, M. N., Grimoldi, A. A., Schalamuk, S., & Golluscio, R. A. (2019). Role of grazing intensity on shaping arbuscular mycorrhizal fungi communities in patagonian semiarid steppes. *Rangeland Ecology and Management*, *72*(4), 692–699.

Eftekhari, A., Fayaz, M., Khodagholi, M., Mozaffarian, V., Jafari, A. A., Masomi, A. A., Ehsani, A., Nateghi, S., Bayat, M., Khalifehzadeh, R., Zandi Esfahan, E., Khaksarian, F., Ghodarzi, M., & Mehrabi, A. (2021). *Rangeland ecosystems monitoring in different climatic regions of iran* (Final Project, Iran, 1226 pp. (In Persian)). Research Institute of Forests and Rangelands.

Fayaz, M., Ashouri, P., Nemati, H., & Namazy, B. (2012). *Ecological regions of iran* (Final Project, Iran, 214 pp. (In Persian)). Research Institute of Forests and Rangelands.

https://doi.org/10.57647/jrs-2026-1601.05

Gönenç, T. M., Ozturk, M., Türkseven, S. G., Kirmizibayrak, P. B., Günal, S. E., & Yilmaz, S. I. (2020). Hypericum perforatum l.: An overview of the anticancer potencies of the specimens collected from different ecological environments. *Pakistan Journal of Botany*, *52*(3), 1003–1010.

Ghasemi Arian, A., & Dashti, M. (2024). Effects of soil and topography variables on canopy cover of dorema ammoniacum d. don in soltan mohammad rangeland, sabzevar, iran. *Journal of Rangeland Science*, *14*(3), 1–11.

Gmbh, E. U., Bundesanstalt, S. B., & Maikornes, P. (1993). A modified method for determining dehydrogenase activity (ttc reduction) in soil following herbicide application [(In German)]. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes*, *45*(9), 180–185.

Heklau, H., Schindler, N., Eisenhauer, N., Ferlian, O., & Bruelheide, H. (2023). Temporal variation of mycorrhization rates in a tree diversity experiment. *Ecology and Evolution*, *13*(4), e10002.

Hossein Jafari, S., Sepehry, B. A., Soltanloo, C. H., & Karimian D, A. A. (2019). Effect of topography and soil properties on the distribution of ferula pseudalliacea (bitter asafetida) in yazd province, iran [(In Persian)]. *Journal of Rangeland Science*, *9*(2), 184–194.

Hovland, M., Mata-González, R., Schreiner, R. P., & Rodhouse, T. J. (2019). Fungal facilitation in rangelands: Do arbuscular mycorrhizal fungi mediate resilience and resistance in sagebrush steppe? *Rangeland Ecology and Management*, *72*(4), 678–691.

Janzen, H. (1993). *Soluble salts in soil sampling and methods of analysis*.

Ketabi, H. Z., Shahmoradi, A., Dashti, M, Paryab, A, Hosseini-Bamrood, G., & Zarekia, S. (2010). Autecology of melica persica kunth. in khorasan region.

Khojasteh, F., Chahouki, M. A. Z., Azarnivand, H., & Kikvidze, Z. (2013). Life form and preference can drive spatial relationships among plant species in semi-arid rangelands of middle iran. *The Rangeland Journal*, *35*(1), 63–69.

Krüger, M., Krüger, C., Walker, C., Stockinger, H., & Schüßler, A. (2012). Phylogenetic reference data for systematics and phylotaxonomy of arbuscular mycorrhizal fungi from phylum to species level. *New Phytologist*, *193*(4), 970–984.

Maharjan, M., Sanaullah, M., Razavi, B. S., & Kuzyakov, Y. (2017). Effect of land use and management practices on microbial biomass and enzyme activities in subtropical top- and sub-soils. *Applied Soil Ecology*, *113*, 22–28.

Marinari, S., & Antisari, L. V. (2010). Effect of lithological substrate on microbial biomass and enzyme activity in brown soil profiles in the northern apennines (italy). *Pedobiologia - Journal of Soil Ecology*, *53*(5), 313–320.

Matinizadeh, M., Nouri, E., Bayranvand, M., Kolarikova, Z., & Janoušková, M. (2024). Arbuscular mycorrhiza and rhizosphere soil enzymatic activities as modulated by grazing intensity and plant species identity in a semi-arid grassland. *Rhizosphere*, *30*, 100893.

McGonigle, T. P., Miller, M. H., Evans, D. G., Fairchild, G. L., & Swan, J. A. (1990). A new method that gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. *New Phytologist*, *115*(3), 495–501.

Miyauchi, S., Kiss, E., Kuo, A., Drula, E., Kohler, A., Sánchez-García, M., Morin, E., Andreopoulos, B., Barry, K. W., Bonito, G., & Buée, M. (2020). Large-scale genome sequencing of mycorrhizal fungi provides insights into the early evolution of symbiotic traits. *Nature Communications*, *11*, 5125.

Moshki, A., Nouri, E., & Matinizadeh, M. (2024). Soil bio-physicochemical properties changes in response to grazing intensity and seasonal variations in an arid rangeland ecosystem of iran. *Ecopersia*, *12*(3), 307–316.

Najjar-Tabrizi, R., Javadi, A., Sharifan, A., Chew, K. W., Lay, C. H., Show, P. L., Jafarizadeh-Malmiri, H., & Berenjian, A. (2020). Hydrothermally extraction of saponin from acanthophyllum glandulosum root – physico-chemical characteristics and antibacterial activity evaluation. *Biotechnology Reports*, *27*, e00507.

Nouri, E., Moshki, A., Matinizadeh, M., Zolfaghari, A., & Rajaei, S. (2018). Symbiosis relationship between some arbuscular mycorrhizal fungi (amf) and salsola laricina and its effect on improving plant growth parameters. *Rostaniha*, *19*(2), 130–137.

Nouri, E., Moshki, A., Matinizadeh, M., Zolfaghari, A. A., & Rajaei, S. (2020). Variations in the diversity of the arbuscular mycorrhizal fungi and its symbiosis under the influence of different levels of grazing in rangelands [(In Persian)]. *Iranian Journal of Range and Desert Research*, *27*(4), 619–628.

Olsen, S., & Sommers, E. (1982). Phosphorus soluble in sodium bicarbonate. *Methods of soil analysis, part*, *2*, 404–430.

Parihar, M., Rakshit, A., Meena, V. S., Gupta, V. K., Rana, K., Choudhary, M., Tiwari, G., Mishra, P. K., Pattanayak, A., Bisht, J. K., & Jatav, S. S. (2020). The potential of arbuscular mycorrhizal fungi in c cycling: A review. *Archives of Microbiology*, *202*(7), 1581–1596.

Pascual, J. A., Garcia, C., Hernandez, T., Moreno, J. L., & Ros, M. (2000). Soil microbial activity as a biomarker of degradation and remediation processes. *Soil Biology and Biochemistry*, *32*(13), 1877–1883.

Puglisi, E., Del Re, A. A. M., Rao, M. A., & Gianfreda, L. (2006). Development and validation of numerical indexes integrating enzyme activities of soils. *Soil Biology and Biochemistry*, *38*(7), 1673–1681.

Qian, S., Zhang, Q., Li, S., Shi, R., He, X., Zi, S., & Liu, T. (2024). Arbuscular mycorrhiza and plant growth-promoting endophytes facilitate the accumulation of saponin under moderate drought stress. *Chinese Herbal Medicines*, *16*(2), 214–226.

Ritz, K., Black, H. I., Campbell, C. D., Harris, J. A., & Wood, C. (2009). Selecting biological indicators for monitoring soils: A framework for balancing scientific and technical opinion to assist policy development. *Ecological Indicators*, *9*(6), 1212–1221.

Rousta, M. J., Matinizadeh, M., Zarafshar, M., & Nouri, E. (2023). Spate irrigation slightly ameliorates an arid soil's quality, but tree planting enhances its characteristics. *Soil and Tillage Research*, *229*, 105658.

Saffariha, M., Jahani, A., & Jahani, R. (2021). A comparison of artificial intelligence techniques for predicting hyperforin content in hypericum perforatum l. in different ecological habitats. *Plant Direct*, *5*, e363.

Schinner, F., Öhlinger, R., Kandeler, E., & Margesin, R. (1996). *Methods in soil biology*. Springer Berlin Heidelberg.

Snajdr, J., Dobiásová, P., Urbanová, M., Petránková, M., Cajthaml, T., Frouz, J., & Baldrian, P. (2013). Dominant trees affect microbial community composition and activity in post-mining afforested soils. *Soil Biology and Biochemistry*, *56*, 105–115.

Tedersoo, L., Bahram, M., & Zobel, M. (2020). How mycorrhizal associations drive plant population and community biology. *Science*, *367*(6480), eaba1223.

Vahedi, H., Nasrabadi, M., Lari, J., & Halimi, M. (2011). Volatile constituents and antimicrobial activities of pterocephalus canus. *Journal of Medicinal Plants Research*, *5*(23), 5646.

van der Heyde, M., Ohsowski, B., Abbott, L. K., & Hart, M. (2017). Arbuscular mycorrhizal fungus responses to disturbance are context-dependent. *Mycorrhiza*, *27*, 431–440.

Walkley, A., & Black, I. A. (1934). An examination of the degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. *Soil Science*, *37*, 29–38.

Wang, Y., Li, Y., Li, S., & Rosendahl, S. (2021). Ignored diversity of arbuscular mycorrhizal fungi in co-occurring mycotrophic and non-mycotrophic plants. *Mycorrhiza*, *31*(1), 93–102.

Warncke, D., & Brown, J. Potassium and other basic cations (J. R. Brown, Ed.). In: In *Recommended chemical soil test procedures for the north central regional research publication* (J. R. Brown, Ed.). Ed. by Brown, J. R. Vol. 221. Missouri Agricultural Experiment Station, University of Missouri, 1998, pp. 31–33.

Yang, M., Yang, D., & Yu, X. (2018). Soil microbial communities and enzyme activities in sea-buckthorn (hippophae rhamnoides) plantation at different ages. *PLoS ONE*, *13*, e0190959.

Zhang, M., Shi, Z., Yang, M., Lu, S., Cao, L., & Wang, X. (2021). Molecular diversity and distribution of arbuscular mycorrhizal fungi at different elevations in mt. taibai of qinling mountain. *Frontiers in Microbiology*, *12*, 609386.