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Research and Full Length Article:

Relationship among Plant Measurements of *Salsola turcomanica* (Litv) and Soil Properties in Semi-arid Region of Golestan Province, Iran

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Abstract. In rangeland management, the ecological needs and response of plants to the environment is studied by investigating the relationship among measurements of plants and environmental factors. This study was conducted to investigate the relationship between plant density, vegetation cover and biomass of *Salsola turcomanica* with the soil physico-chemical properties in the fall of 2018. For this purpose, in three areas (area with high, medium and low coverage of *S.turcomanica*), three transects of 100 m length were located at a distance of 100 m from each other. In each transect, 10 plots ($2m^2$) were systematically established. Then vegetation cover and the density of individual plants were recorded. Biomass was estimated via cutting and weighing method. Soil samples were systematically taken from center of each plot at the depth of 0-20cm. Some soil physical and chemical properties such as soil texture, bulk density, pH, EC, organic carbon, Absorbable P, exchangeable K and Na were measured. Data were analyzed by one-way analysis of variance and mean comparisons were made using the Tukey test. The relationships among plant measurements and soil properties were investigated using multiple regression analysis. The results demonstrated that soil acidity had the most influence on the vegetation cover of *S.turcomanica* ($p<0.05$), likewise soil acidity and soil exchangeable sodium content had the most influence on its biomass ($p<0.05$). Among the exchangeable cations, Ca had the highest value (1730 ppm) and Na had the lowest one (105 ppm). This plant grows in saline (EC < 21 ds/m) and alkaline (pH< 8.6) soils with low organic Carbon (C< %1). Considering its long growth period and adaptation of this species to harsh environmental conditions, its use in degraded saline and alkaline rangeland improvement operations is recommended.

Key words: *Salsola turcomanica*, Plant measurements, Soil properties

Introduction

Rangeland management requires the study of interactions among various biological, environmental and social factors (Niknahad-Gharmakher *et al.*, 2017). Knowledge of ecological factors such as soil properties, topography, climate, and disturbance influencing the plant species distribution is essential for the conservation, management, and rehabilitation of rangeland ecosystems. This knowledge is essential for the determination of ecological requirements of plant species and provides basic awareness for relevant authorities such as range managers in identifying suitable plant species for the rehabilitation of degraded rangeland (Ebrahimi and Ranjbar, 2016). Proper management of rangeland ecosystems requires understanding the relationship between ecological factors, including climate, topography, soil, vegetation and living organisms (Mesdaghi, 2001; Enright *et al*., 2005). Identifying these relationships in relation to the use of plant species in the improvement of degraded rangelands and in the management of natural ecosystems is necessary (Jafari *et al*., 2003). Plants differ in their requirements and tolerance to site conditions created by soil and landscape characteristics (Omoro *et al*, 2011). That is why the effects of environmental variables on plant species have been the subject of many ecological studies in recent years (Ramirez *et al*, 2007). This is an important issue which can provide valuable information in degraded ecosystems for the adoption of the effective measures and approaches for increasing sustainability and restoration of these ecosystems (Auestad *et al*., 2008). Plant characteristics, environmental factors or both of them affect plant distribution. Among environmental factors, climatic and soil factors play an important role in determining the habitat of plants. Physical and chemical properties of soils play an important role in the establishment, growth and distribution of plant species (Babaei *et al*., 2017). Canopy cover percentage and species diversity are more affected by changes in soil factors. The percentages of clay in soil texture and soil electrical conductivity are effective factors on vegetation components (Akbarlo *et al*., 2012). Moradi and Ahmadipour (2007) demonstrated that soil EC, pH and clay are more effective than other factors on vegetation cover and plant density in Vaz rangelands of Mazandaran province in Iran. Shokrollahi *et al* (2012) reported that the percentage of canopy cover and density of the plant species in Polur summer rangelands in Iran are influenced by soil properties (texture, Nitrogen, Phosphorous, pH) and physiographical factors. Zare *et al* (2011) declared that soil texture, EC, available Nitrogen, Potassium, organic carbon and lime are the main effective factors on the distribution of plant species in Shahriyar rangeland in Iran. Soil pH and clay ratio in soil texture have a major role on the distribution of *Daphne mucronata* in Malayer rangelands in Iran (Babaei *et al*., 2017). Farzadmehr *et al* (2019) stated that the most important environmental factors affecting distribution of plant communities in semi-arid rangelands of Bidokht in Iran are the percentage of clay and sand, soil carbon and potassium content, as well as, soil electrical conductivity. Soil pH, the percentage of silt and sand in the soil texture and its Potassium content are the most effective factors on *Astragalus gossypinus* density and cover (Fattahi *et al*., 2009).

Iran is characterized by an arid and semi-arid climate, with very low levels of precipitation (Saberi *et al*., 2017; Niknahad-Gharmakher *et al.*, 2017). It is estimated that salt-affected lands in arid and semi-arid regions cover about 25 million ha (15%) of the whole area in Iran, of which 8.5 million ha is severely affected and classified as saline or saline-alkali soil (Roozitalab *et al.*, 2018).

Salsola turcomanica (Litv) belongs to the genus Salsola that is the largest genus of sub-family Salsoloideae. This genus has about 100 species, of which 48 species are found in the

Iranica flora (Bakhshi-khaniki and Mohamadi, 2012). In addition to their halophytic nature which makes these plants very tolerant to the salinity and drought, high water use efficiency, high fodder value (especially for camels and goats) and biomass production potential, as well as, high seed production makes them potential candidates for land reclamation in arid and semi-arid ecosystems such as salt affected soils (Gintzburger *et al*., 2003; Hanif *et al.*, 2018 and Arrekhi *et al*., 2020). It has been reported that the habitat of *S. turcomanica* (from Gomishan in the north west to Chat in the north east of Golestan province, Iran) is flat saline and alkaline rangelands, at an altitude of -20 to 60 m above sea level with 170 to 343 mm mean annual rainfall (Khatir-Namani, 2007; Tavan *et al*., 2010, Bakhshi-khaniki and Mohamadi, 2012) *S. turcomanica*, along with *Halostachys caspica*, *Plantago coronopus* L, *Frankenia hirsuta*, and *Halocnemum strobilaceum* is an important and relatively palatable halophyte species with high dry matter digestibility and mineral content (ash) in the above mentioned rangelands (Pasandi *et al*., 2017; Arrekhi *et al*., 2021).

Application of salt and drought tolerant plant species is a key point in arid and semi-arid regions; therefore the investigation of relationship between soil properties with plant distribution indices of these species has tremendous importance (Zhang and Dong, 2010). Silakhori *et al* (2018) after the desertification assessment of Incheh-broun area in Golestan province using ESAs model stated that 77.95% of this area is classified in critical class, due to its poor drainage, heavy soil texture, poor vegetation cover, as well as, climatic factors. They recommended the biological and mechanical land improvement techniques such as plantation of species resistant to heavy and saline soils to prevent the advance of desertification processes.

Since in rangeland management, the ecological needs and response of plants to the environment is studied by investigating the relationship among measurements of plants and environmental factors, thus, the objective of this study was to investigate the relationship between density, cover and biomass of *Salsola turcomanica* with physico-chemical properties of soil to determine most effective variables affecting distribution of this species.

Material and Methods

Study area

This study was conducted in the north of Iran between Gomishan and Inche Borun. The study area is limited by Turkmenistan in the north, Gomishan and Agh Ghala farmlands in the south, Caspian Sea in the west and Agh Ghala to Inche Borun road in east. The area lies at 54°1´ to 54°2´ longitude and 37°8´ to 37°11´ latitude (Fig 1). The climate in this region is semi-arid and the average annual precipitation is 343 mm. Rainy seasons extends generally from October to May, and the dry season extends from June to October. Its mean annual temperature is 16.6ºC. The topography in this region is nearly flat. The minimum and maximum height above sea level is -24 and -11 m, respectively. The dominant vegetation type is *Polypogon monspeliensis*-*Halocnemum strobilaceum* (Niknahad-Gharmakher *et al*., 2015).

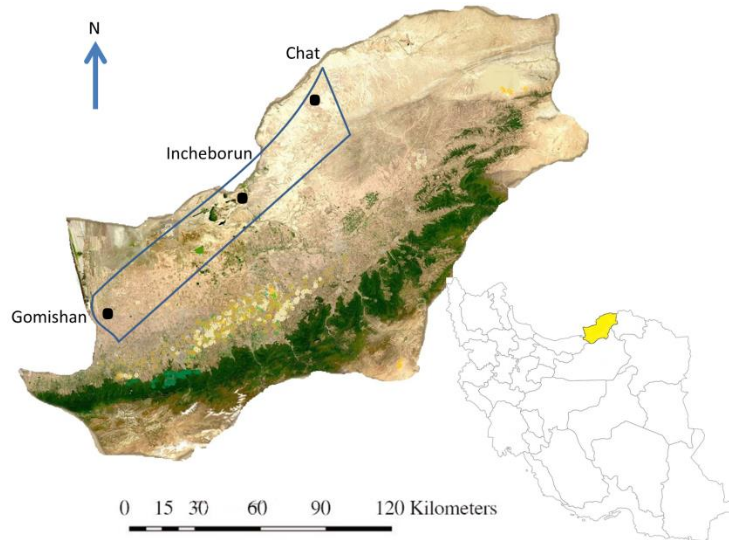

Fig. 1. Geographical location of the study area in Golestan province, Iran

Sampling Method

The distribution areas of *S. turcomanica* were delineated through field survey. Three key areas [high (more than 20%), medium (between 10 to 20 %) and low (less than 10%) coverage] were selected in the wild habitats of *S. turcomanica* with respect to its distribution pattern. In each key area three transects of 100 m length were located with 100m interval from each other. In each transect, ten plots ($2m^2$) were established systematically (Bonham, 1989) and used to estimate the cover and density of this species per unit area. For this, we noted the percentage of *S. turcomanica* and recorded the number of its individuals in each plot and used these data to cover and density estimation. Biomass was estimated using cutting and weighing method. Soil samples were taken from the center of each plot at the depths of 0–20 cm based on the rooting depth of *S. turcomanica*. In total, 30 soil samples were collected in each key area. In the seed maturity stage, leaf and stem of *S. turcomanica* were used to measure their mineral content (Na^+, K^+, Ca^{2+} and Mg^{2+}). In addition, in the laboratory, some soil physical and chemical properties such as percentage of soil texture components, bulk density, pH, EC, percentage of organic carbon, Absorbable P, exchangeable K and Na were measured. The soil texture was determined by Bouyoucos hydrometric method of Gee and Bauder (1986). Soil bulk density determined by Clotting and paraffin methods (Black, 1986), EC and pH were determined in water (soil to water ratio of 1:5), potentiometrically (McLean, 1982). Organic C and Absorbable P were determined by Walkley-black (Nelson and Sommers, 1996) and Olsen methods (Page *et al*., 1987). The concentration of exchangeable K and Na were determined by Photometric film Method (Ruzicka *et al*., 1977). The concentration of exchangeable Ca and Mg was determined using titration method (Page *et al*., 1987).

Statistical analysis

After a test of the uniformity of data (Verdoodt *et al.*, 2009), data analysis was performed by one-way analysis of variance and Tukey test at a significance level of 1%. The relationship between plant measurements (vegetation cover, density and aerial biomass) as dependent variables with some soil physical and chemical properties as (soil texture, bulk density, pH, EC, organic carbon, absorbable phosphorus, exchangeable potassium and sodium) as independent variables were investigated. To predict variations of dependent variable through independent variables and determining the contribution of each of them the Multiple Regression Analysis (stepwise) was used. All statistical analysis was performed using SPSS[16] software.

Fig. 2. Sites with high, medium and low coverage of *S. turcomanica*

Results

The results demonstrated that biomass of *S. turcomanica* (g/m^2) in the site with the highest coverage was more than twice as much biomass as in the other sites. In addition, the coverage of *S. turcomanica* in the site with high coverage was 10.70 and 14.2% higher than the sites with medium and low coverage, respectively ($P<0.05$).

The results revealed that the site with the highest coverage had significantly lower pH and higher (OC, absorbable P, exchangeable Na and K) than the other sites. The lowest coverage was noted in the site with the highest bulk density (Table 1).

Table 1. Mean comparisons of *S. turcomanica* measurements and soil properties in different sites

Variable	Sites			
	High coverage	Medium coverage	Low coverage	No coverage
Plant density	1.0 ^{b}	0.8 ^{b}	0.6 ^{b}	0.0
Biomass (g/m^2)	87.5 ^{c}	39.4 ^{b}	32.9 ^{ab}	0.0
Cover (%)	22.6 ^{c}	11.9 ^{b}	8.4 ^{b}	0.0
pH	7.9 ^{a}	8.2 ^{b}	8.3 ^{b}	8.6 ^{c}
EC (ds/m)	16.1 ^{a}	17.8 ^{a}	18.1 ^{ab}	21 ^{b}
Organic Carbon (%)	0.5 ^{b}	0.4 ^{a}	0.4 ^{a}	0.4 ^{a}
Phosphor (ppm)	4.0 ^{b}	3.6 ^{a}	3.6 ^{a}	3.6 ^{a}
Sodium (ppm)	39.5 ^{c}	27.5 ^{b}	29.4 ^{b}	21.3 ^{a}
Potassium (ppm)	27.7 ^{b}	19.8 ^{a}	20.7 ^{a}	23.4 ^{b}
Bulk Density (g/cm^3)	1.0 ^{a}	1.0 ^{a}	1.2 ^{b}	1.3 ^{b}
Silt (%)	17.5 ^{a}	17.6 ^{a}	12.8 ^{a}	15.6 ^{a}
Sand (%)	57.8 ^{a}	55.6 ^{a}	60.9 ^{a}	58.1 ^{a}
Clay (%)	24.7 ^{a}	26.9 ^{a}	26.3 ^{a}	26.4 ^{a}

Means followed by the same letters in each row are not significantly different ($P<0.01$).

Regression analysis

Regression analysis of density, cover percentage and biomass were made on soil properties of *S. turcomanica*. The result indicated that there was a linear relationship between density, cover percentage and biomass with soil properties (Tables 2-4).

The relationships between plant densities, cover percentage and biomass with soil properties are presented in Table 2. Higher values of coefficients of R and R^2 indicate strong correlation between the observed value of the dependent variable (plant cover and biomass) and predicted value (soil properties). For plant density, the values of R^2 and adjusted R^2 were much lower, indicating weak relationships between plant density and soil parameters (Table 2). Therefore, for plant density, none of the soil properties were entered in the final model and soil properties had no significant effect on density *S. turcomanica*.

Table 2. Regression analysis of variance of density, cover percentage and biomass regression models of *S. turcomanica* with soil parameters

Dependent Variable	DF	SS	MS	F values	P values	R	R^2	Adjusted R^2
Plant Cover	10	2641	264.09	7.374	0.000	0.847	0.718	0.620
Biomass	10	41895	4189.5	4.358	0.001	0.775	0.600	0.463
Density	10	4.461	0.446	2.401	0.032	0.673	0.453	0.264

The regression coefficients (b) of cover percentage and biomass and soil properties of *S. turcomanica* are presented in Tables 3 and 4.

For cover percentage, the value of soil acidity was not zero and it was entered in the final model, so soil pH was negatively effective on the vegetation cover of *S. turcomanica* (Table 3).

For biomass, the value of soil acidity and Na content were not zero and both of them were entered in the final model. So soil pH negatively and Na positively were effective on the biomass of *S. turcomanica* (Table 4).

Table 3. Regression coefficient (b) between cover percentage as dependent variable (Y) with soil parameters (X1, X2 and….) in *S. turcomanica*

Variables	Unstandardized coefficients β	Std. Error	Standardized β	T Values	P Values	Equation	R^2
Constant	238.815	57.702	-	4.531	0.000		
pH	-22.240	5.583	-0.684	-3.984	0.000	Y= 238.81 -22.24 pH	72

Table 4. Stepwise regression coefficients (b1 and b2) between biomass as dependent variable (Y) and with soil parameters (X1, X2 and….) in *S. turcomanica*

Variables	Unstandardized coefficients β	Std. Error	Standardized β	T Values	P Values	Equation	R^2
Constant	730.36	237.05	-	2.675	0.012		
pH	-80.82	28.92	-0.571	-2.794	0.009		
Na	1.80	0.87	0.369	2.054	0.049	Y=730.3 -80.8 pH + 1.8Na	60

Mineral content of *S. turcomanica* ash

In the seed maturity stage, leaf and stem of *S. turcomanica* were used to measure their mineral content (Na^+, K^+, Ca^{2+} and Mg^{2+}). According to the results (Fig 3), the mineral content of leaves for Ca, Mg, K, and Na ions were 1640 ppm, 537 ppm, 335ppm and 105ppm, respectively. There was a significant difference ($p<0.05$) among concentration of measured ions and Ca had the highest and Na had the lowest concentration. Similarly, the mineral content of stems (Fig 4) for Ca, Mg, K, and Na ions were 1730 ppm, 543ppm, 585ppm and 230ppm, respectively. The concentration of Ca was significantly ($p<0.05$) higher than other ions and the concentration of Na was the lowest one. No significant difference ($p<0.05$) was observed between the concentration of Mg and K ions.

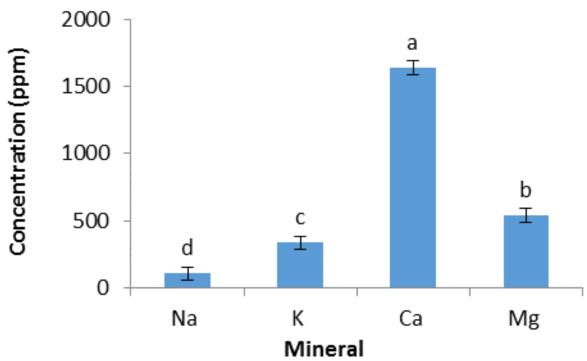

Fig. 3. Mineral concentration in the leaf of *S.turcomanica*

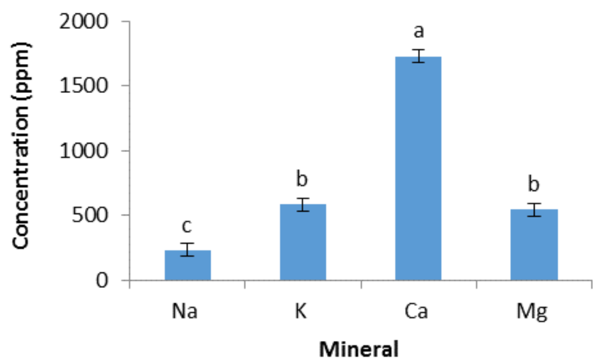

Fig. 4. Mineral concentration in the stem of *S.turcomanica*

Phenology

Mean of monthly temperature and precipitation and phenological stages and of *Salsola turcomanica* is presented in Table 5. In the study sites the plant life cycle of *S. turcomanica* starts in the beginning of January with germination and then seedling emergence. The vegetative stage generally extends since beginning of January until the end of July. The flowering stage happens when flower buds appear in the end of July. This phenological stage extends till mid of September and thereafter the seeding stage starts with appearance of brown seeds. This stage extends to the mid of November. In the mid of November seeds are completely ripen and plant shed its seeds. In the December the shrubs are completely dried out and their roots get cut off by little shake.

Table 5. Mean of monthly temperature and precipitation and penological stages and of *Salsola turcomanica*

Stages	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling emergence	■											
Vegetative stage		■	■	■	■	■	■					
Flowering stage								■	■			
Seeding										■	■	
Complete dryness												■
Temperature average (°C)	7.7	8.4	10.7	15.6	21.5	25	27.4	27.8	24.5	19.1	13.5	9.4
Precipitation average (mm)	41	34	56	34	23	12	13	13	24	42	42	47

Discussion

The results revealed that the soil of studied area is poor in organic matter, with alkaline acidity and high salinity (Table 1). The R values indicate that the strength of the linear regression model for predicting vegetation cover and biomass of *S. turcomanica* by soil parameters is 85% and 77%, respectively. This result is in agreement with result of Fattahi *et al* (2009) who stated that the strength of the linear regression model using soil parameters for predicting cover and biomass of *Astragalus gossypinus* was more than 83%. R^2 values indicate that soil parameters had a greater role in explaining the variance of cover percentage and biomass changes. This finding is in accord with Babaei *et al* (2017) and Fattahi *et al* (2009).

According to β values (Tables 3 and 4), soil properties affect the cover percentage and biomass of *S. turcomanica*. So, soil pH and Na content are effective on biomass. Also, only soil pH is effective on cover percentage of *S. turcomanica*. Our results are in accordance with Moradi and Ahmadipour (2007). The zero value of β for plant density indicates that soil properties do not affect *S. turcomanica* density.

Soil acidity affects the nutrient availability for plant roots (Babaei *et al*., 2017). As soil pH rises above 8, soil nitrogen and phosphorus availability decreases. This can lead to a reduction in plant cover and biomass. Shokrollahi *et al* (2012) stated that soil available Nitrogen and Phosphorous influence canopy cover the plant species. Based on β coefficients (Tables 3, 4), pH, which has a negative sign, is inversely related to the cover percentage and biomass of *S. turcomanica*. That is, as this variable increases, the percentage of cover and its biomass decrease. The results (Table 4) demonstrated that Na content is directly related to biomass, that is, as this variable increases, the biomass increase. *S.turcomanica*, like other halophyte species, has high ash content (Arrekhi *et al*., 2021), so it's dense sowing and harvesting for livestock feeding probably can effect on soil salinity in the long term. Because of their high seed and forage production, the species of Salsola genus have an important role in vegetation composition of dry and saline rangelands (Hanif *et al.*, 2018). Nearly 80% of our studied area has been classified in the critical class of desertification (Silakhori *et al.* 2018). Considering the phenology of *S. turcomanica* (Table 5) indicates this species can be used to create vegetation cover and forage production in the dry months of the year in the studied area (Arrekhi *et al.*, 2020 and Arrekhi *et al*., 2021).

It can be concluded that according to the obtained results, soil acidity had the most influence on the cover percentage of *S. turcomanica*, likewise soil acidity and soil exchangeable sodium content had the most influence on the biomass of this plant species. Since soil in the studied region is saline-alkaline with very low organic matter and with regard to high percentage of ash in the forage of this plant and considering long growth period and adaptation of this species to harsh environmental conditions, using this plant species in rangeland improvement operations is recommended.

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بررسی روابط معیارهای گیاهی گونه سالسولا ترکمانیکا(*Salsola turcomanica*) با خصوصیات خاک در منطقه نیمه خشک استان گلستان، ایران

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چکیده. در مدیریت مرتع، نیازمندی‌های اکولوژیک و واکنش گیاهان به محیط از طریق بررسی ارتباط معیارهای گیاهی گیاهان با عوامل محیطی مطالعه می‌گردد. با توجه به مسطح بودن منطقه مورد مطالعه، تحقیق حاضر به منظور بررسی ارتباط تراکم، درصد پوشش و بیوماس سالسولا ترکمانیکا (*Salsola turcomanica*) با خصوصیات فیزیکی - شیمیایی خاک در پاییز ۲۰۱۸ انجام شد. بدین منظور، در سه منطقه (دارای پوشش زیاد، متوسط و کم *S.turcomanica*)، ۳ ترانسکت ۱۰۰ متری با ۱۰۰ متر فاصله از یکدیگر مستقر گردید. در هر ترانسکت، ۱۰ پلات ۲ مترمربعی بطور سیستماتیک مستقر شد و درصد پوشش *S.turcomanica* و تعداد پایه‌های گیاهی آن ثبت گردید. بیوماس نیز از طریق قطع و توزین محاسبه شد. نمونه‌های خاک از مرکز هر پلات و از عمق ۲۰-۰ سانتی متر برداشت شدند. در آزمایشگاه، درصد اجزای بافت خاک، جرم مخصوص ظاهری، اسیدیته، هدایت الکتریکی، فسفر قابل جذب، سدیم و پتاسیم تبادلی تعیین گردید. داده های جمع آوری شده مورد تجزیه واریانس یک طرفه قرار گرفتند و مقایسه میانگین صفات با روش توکی با استفاده از نرم افزارSPSS نسخه ۱۶ انجام شد. به منظور بررسی ارتباط معیارهای گیاهی *S.turcomanica* با خصوصیات خاک از تحلیل رگرسیون چندمتغیره استفاده شد.. نتایج نشانگر آن است که اسیدیته خاک بیشترین تاثیر را بر درصد پوشش *S.turcomanica* دارد ($P < ۰/۰۵$) و اسیدیته خاک و مقدار سدیم قابل تبادل خاک با بیوماس بیشترین ارتباط را دارند ($P < ۰/۰۵$). در بین کاتیون‌های تبادلی، کلسیم بیشترین (۱۷۳۰ پی پی ام) و سدیم کمترین (۱۰۵ پی پی ام) مقدار را داشتند. این گونه گیاهی در خاک های شور (با شوری کمتر از ۲۱ دسی زیمنس بر متر) و قلیایی ($pH < ۸/۶$) داری کربن آلی پایین ($C < ٪۱$) می‌روید. با توجه به دوره رشد طولانی و سازگاری این گونه گیاهی به شرایط نامساعد محیطی، استفاده از آن در عملیات اصلاح مراتع تخریب یافته دارای خاک های شور و قلیایی توصیه می‌گردد.

کلمات کلیدی: *Salsola turcomanica* ، معیارهای گیاهی، خصوصیات خاک