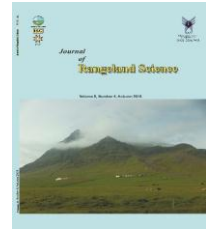Contents available at ISC and SID

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**Research and Full Length Article:**

# Effect of Halophyte Patches on Some Soil Properties of a Saline Rangeland of Urmia Lake Coast, Iran

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**Abstract.** Plants may induce small-scale heterogeneity in soil nutrients, forming fertile islands. However, this process may depend on plant spices, plant developmental stages and habitat conditions. Vegetation cover in arid and semi-arid regions is mostly in the form of plant patches and bare soil of inter-patch areas and this form of vegetation cover can be useful to study plants impact on soil to get applicable knowledge for predicting plants efficiency in restoration projects. This study was conducted in 2016 to study some soil properties in vegetation patches of some halophytes from Urmia Lake, Iran. The results showed that soil EC decreased from 10.32 (mS.cm$^{-1}$) in bare soil to 4.92 (mS.cm$^{-1}$) in vegetated areas. Also, significant increase of soil pH and phosphorous content was observed in vegetation patches that were 8.73 and 29.61 (ppm) respectively in comparison with bare soil with 8.51 and 12.81 (ppm) patches. As vegetation patches caused a decrease in soil evaluated cations, the main shoot succulent halophytes of *Salsola dendroides*, *S. nitraria*, *S. iberica* and *Halocnemum strobilaceum* which can uptake these ions were selected to measure their above ground biomass and root tissues content of these salts; the results showed a significant difference between plant species in their salt uptake and accumulating ability. *Halocnemum strobilaceum* had higher amount of sodium and magnesium in shoots that were 9.73 and 2.96 (mg.kg$^{-1}$), respectively. So, it had the most ability to absorb these salts by roots transporting them to shoots. In overall, these plants can improve soil nutrients and chemical conditions in their rhizosphere.

**Key words:** Cations, Nutrients, Rhizosphere, Soluble salts, Vegetation patches

## Introduction

In natural ecosystems, the soil isn't a homogenous phenomenon even in small scales (Smilauerova and Smilauer, 2002). As plants grow on a soil conditions, they also cause a variety of effects on soil structure, biota and abiotic condition (Eviner and Hawkes, 2008; Van de Voorde et al., 2011).

Plant-induced nutrient-rich zones resulting from a range of interacting physical and biotic concentrating mechanisms are named "fertile islands", "resource islands" or "islands of fertility" (Camargo-Ricalde and Dhillion, 2003). Formation of fertile islands is very common in arid and semiarid ecosystems (Vinton and Burke, 1995). It increases spatial heterogeneity in soil resources, and affects not only seedling establishment (Maestre et al., 2003) and plant–plant interactions (Aguiar and Sala, 1999) but also species distribution (Pan et al., 1998), diversity (Anderson et al., 2004) and productivity (Mou et al., 1995) of plant communities.

Accurate knowledge of spatial distribution of soil physical and chemical properties is needed for suitable management and proper use of rangelands (Asadian et al., 2017). In arid and semi-arid regions, vegetation cover is characterized by spatially discontinues patches of plants which are mainly shrubs and perennial species; this kind of vegetation cover forms fertile islands in soil with better chemical and physical conditions (Bochet et al., 1999; Maestre and Cortina, 2002; Caravaca et al., 2010; Li et al., 2011).

Plants show their influence on the ecosystems by their roots, stems, canopy cover, foliage and litter (Westoby and Wright, 2006). These vegetation patches are very useful to study plants impact on soil properties and get applicable knowledge to predict biological restoration plan efficiency in critical and degraded ecosystems. Also, Salinity is one of the main ecological problems in arid and semi-arid regions (Ranjbar Fordoei and Dehghani Bidgholi, 2016) and affects 76 million ha of soil in the world (Kamel and El-Tayeb, 2004; Pathak and Rao, 1998; Mohamed et al., 2011).

Climate changes, drought, decreases in estuarine freshwater flow, sea level rise, and storm surges have been suggested to increase the extent and severity of salinity in coastal wetlands globally. Ecological preservation of saline soils can be best managed by salt-tolerant plant species like halophytes for revegetation and rehabilitation (Busby et al., 2017).

The main cations that cause salinity and ion toxicities are $Na^+$, $Ca^{2+}$, $Mg^{2+}$ and $K^+$ as a micro-element is essential for plant nutrients but increases soil salinity in relatively high amounts and affects plant growth adversely (Kotuby-Amacher et al., 2000; Dikilitas and Karakas, 2011). Selection and cultivation of salt tolerant plants are developing for increasing plant products and improving saline soils (Mahmood, 1998). Halophytes are well-known plants that can tolerate salt concentrations that kill 99% of other plants (Flowers and Colmer, 2008). Saline soils can be reclaimed biologically by halophytes, and especially accumulators can eliminate salts and toxic ions from soil (Ravindran et al., 2007; Yensen and Biel, 2006; Manousaki and Kalogerakis, 2011).

Remediation is a strategy to clean up pollutants and toxic ions from the plant root zone in order to reduce vegetation stress and enhance productivity. This strategy involves biological management of soil and water which often leads to increased soil infiltration and leaching of excess salts out of the root zone. Several methods of soil remediation have been proposed that can be classified into the two main groups of based remediation and green remediation. Green remediation is the use of vegetation to remove or decrease environmental contaminants such as heavy metals, trace elements and organic compounds in soil (Nouri et al., 2017).

Phytodesalination is a biological approach that aims to rehabilitate sodic and saline soils by ions hyperaccumulating halophytes. It is based on the capacity of such species to accumulate saline ions in their shoots (Jlassi *et al.*, 2013).

Shoot succulent halophytes are very suitable to use for this purpose because of their salinity resistance, high ability to absorb and accumulate ions of saline soils and high biomass production that can be utilized as a forage source (Rabhi *et al.*, 2010).

Our objective in this study was to determine soil physical and chemical properties affected by vegetation patches in comparison with bare soil of inter-patches of halophytes from Urmia Lake basin in Iran and also the ability of these halophytes to reclaim and improve the saline soil that is affected by Urmia Lake saline water.

## Materials and Methods

The site chosen for field experiment was located in south-west of Urmia lake basin in Iran (37°24′ 30″ to 37°25′ 46″ N and 45°15′ 47″ to 45°17′ 47″ E). This ecosystem is representative habitat of saline lands around Urmia Lake in West Azerbaijan province (Fig. 1). The average annual rainfall of the area is 299 (mm) most of which falls during autumn and winter seasons. The climate is semi-arid based on Emberger classification method and the height is 1402 m (a.s.l).
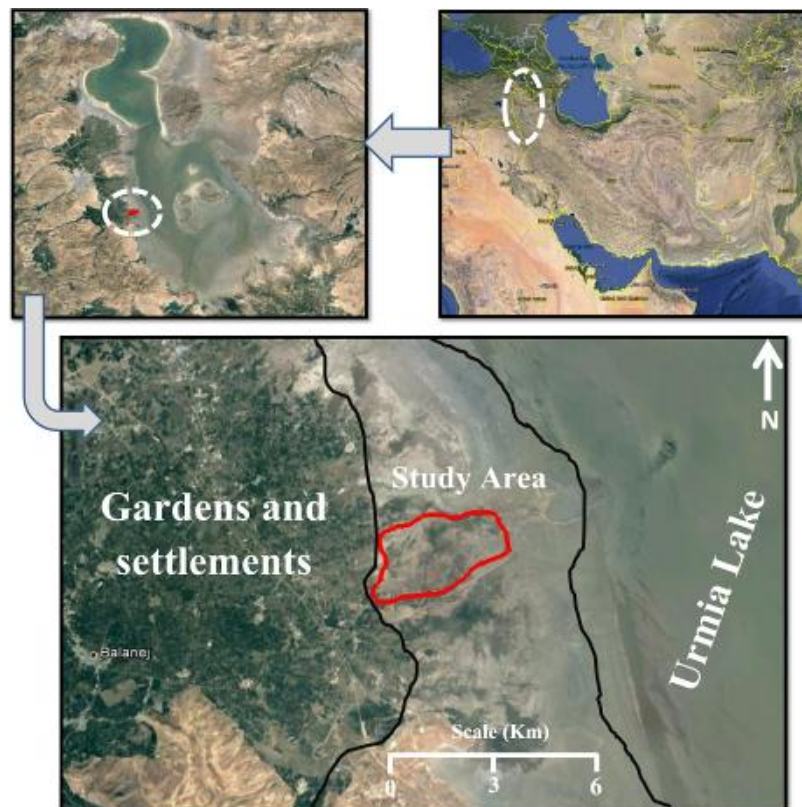


**Fig. 1.** Location of experimental field in Urmia Lake coast in West Azerbaijan province of Iran

Soil and plant samples were collected in August 2016 which is the driest month in the region so that salt and nutrient amounts in plants and soil are not affected by rainfall and samples were collected randomly. For this purpose, vegetation patches, inter-patches and soil sampling points along four transects of 150 m parallel to the direction of the slope were selected randomly. Soil samples were collected in four different vegetation patches from two depths of 0-15 and 15-30 cm, the bare soil of inter patches was also collected from four different points. The

soil samples were mixed. In other words, from three random points including first, middle and end of each transect, the soil samples were taken and mixed. Finally, four soil samples were transferred to the laboratory. For collecting plant samples, the main palatable halophytes with succulent shoots were cut with four replications and each replicate also included at least five stands along the transects of these shrubs including *Salsola dendroides*, *S. nitraria*, *S. iberica* and *Halocnemum strobilaceum.*

Soil samples were air dried in room temperature and grind, and then passed through 2mm sieve. Finally, pH and EC were measured by the saturated extract of v:v with electronic pH meter and EC meter. Phosphorus was measured by Olsen method (Olsen and Sommers, 1982), nitrogen by Kjeldahl method, organic material by Walkley and Black method (1934 a, b), and particle size distribution (clay%, silt% and sand percent) by hydrometer method. Also, soluble salts including $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ in the soil samples were measured by atomic absorption spectrophotometer and flame photometer (Lanyon and Heald, 1982). For analyzing plant samples, the shoots and roots were dried and wet ash by $HNO_3$ digestion and $Na^+$, $K^+$, $Ca^{2+}$ and $Mg^{2+}$ concentrations were measured by atomic absorption spectrophotometer and flame photometer (Liu *et al.*, 2006).

To analyze the parameters among species, one-way ANOVA was conducted and means comparison was made by Duncan method. For Independent samples, T-Test was used for comparing the soil properties between the vegetation patches and bare soil.

## Results

Analysis of the variance for soil properties in surface layer (0-15cm) showed significant differences of EC, phosphorus, silt, sand, $Na^+$, $K^+$ and $Mg^{2+}$ between patches and inter-patches (Table 1). In this soil layer (0-15cm), the EC was 4.91 ($mS.cm^{-1}$) and 10.32 ($mS.cm^{-1}$) in vegetation patches and bare soil of inter patches, respectively. The bare soil had significantly higher values of sand, $Na^+$, $K^+$ and $Mg^2$ than that for the patch site. The patch site had significantly higher values of P, and silt than the inter-patch sites. For P, higher and lower values of 29.61 and 12.81 (ppm) were obtained in vegetation patches and bare soil of inter patches, respectively (Table 1). For soil cations, higher and lower values of Na+ with 97.25 (Meq/L) and 54.57 (Meq/L) were obtained in bare soil and vegetative patches, respectively. Also, the concentration of $K^+$ and $Mg^{2+}$ was significantly ($p<0.05$) lower in soils of vegetation patches, and $Ca^{2+}$ amount was 27.25 and 13.5 (Meq/L) in bare soil and vegetation patches, respectively (Table 1).

In soil analysis of second depth (15-30cm) of profile except EC and Mg, no other significant differences between patches and inter-patch areas were not observed (Table 1). The inter-patch has the highest EC and Mg values as compared to the patch.

**Table 1.** Analysis of variance and mean (Mean ± SE) of soil properties in vegetation patches and inter-patch areas in upper surface (0-15cm depth) second profile (15-30cm depth) of saline rangelands around Urmia Lake

| Properties | Depth | Patch | Inter-patch | T-Test | Sig |
|---|---|---|---|---|---|
| pH | 0-15cm | 8.73±0.070 | 8.51±0.088 | 0.334 | 0.094 [ns] |
| | 15-30cm | 8.58±0.10 | 8.43±0.04 | 1.210 | 0.225[ns] |
| EC (mS.cm$^{-1}$) | 0-15cm | 4.91±1.07 | 10.32±1.92 | 3.033 | 0.049[*] |
| | 15-30cm | 5.40±1.31 | 9.85±2.52 | 6.816 | 0.0185[*] |
| N (%) | 0-15cm | 0.074±0.017 | 0.068±0.017 | 0.816 | 0.93[ns] |
| | 15-30cm | 0.096±0.01 | 0.099±0.01 | 0.401 | 0.861[ns] |
| P (ppm) | 0-15cm | 29.61±7.04 | 12.81±1.95 | 5.870 | 0.041 [*] |
| | 15-30cm | 25.09±9.07 | 26.14±10.14 | 0.009 | 0.941[ns] |
| OM (%) | 0-15cm | 1.034±0.18 | 0.988±0.23 | 0.417 | 0.881[ns] |
| | 15-30cm | 1.32±0.17 | 1.20±0.15 | 0.011 | 0.633[ns] |
| Silt (%) | 0-15cm | 40.00±3.74 | 37.0±9.25 | 6.122 | 0.0374[*] |
| | 15-30cm | 36.5±7.55 | 37.0±5.97 | 0.168 | 0.960[ns] |
| Sand (%) | 0-15cm | 36.50±5.85 | 47.0±2.71 | 3.41 | 0.0482[*] |
| | 15-30cm | 40.00±7.07 | 42.50±7.22 | 0.19 | 0.813[ns] |
| Clay (%) | 0-15cm | 23.50±4.03 | 16.0±4.24 | 0.031 | 0.247[ns] |
| | 15-30cm | 23.50±3.92 | 20.50±3.20 | 0.000 | 0.575[ns] |
| Na$^+$ (Meq/L) | 0-15cm | 54.57±9.23 | 97.25±5.53 | 0.201 | 0.037 [*] |
| | 15-30cm | 57.65±9.03 | 74.35±10.73 | 0.12 | 0.279[ns] |
| K$^+$ (Meq/L) | 0-15cm | 1.80±0.24 | 3.75±0.58 | 2.388 | 0.021[*] |
| | 15-30cm | 2.25±0.51 | 3.77±1.01 | 1.293 | 0.228[ns] |
| Mg$^{2+}$ (Meq/L) | 0-15cm | 21.75±7.38 | 103.75±25.93 | 42.70 | 0.0026[**] |
| | 15-30cm | 32.25±9.51 | 53.25±18.08 | 41.70 | 0.033[*] |
| Ca$^{2+}$ (Meq/L) | 0-15cm | 13.5±3.17 | 27.25±6.25 | 1.070 | 0.098[ns] |
| | 15-30cm | 16.25±4.60 | 19.25±2.32 | 1.547 | 0.582[ns] |

*ns, \*, \*\*: non-significant and significant at 0.05 and 0.01 probability levels, respectively*

As soluble salts including the cations of Na$^+$, K$^+$, Ca$^{2+}$ and Mg$^{2+}$ were affected in vegetation patches, their accumulated amount was measured in root and shoot tissues of main shoot succulent halophyte species including *Salsola dendroides*, *Salsola nitraria*, *Salsola iberica* and *Halocnemum strobilaceum.* Result showed that they had differences in their ability to absorb and accumulate cations in their shoot and root tissue.

There were significant differences in concentration of Mg$^{2+}$ (p<0.05) and K$^+$ (p<0.01) in shoot tissues of these halophytes; our results showed that among four species studied, *Salsola dendroides* exhibited greater accumulation of K$^+$ in each gram of shoot dry matter that was equal to 1.80 (mg). The least ability for absorbing and accumulating K$^+$ was related to *Salsola iberica* and *Halocnemum strobilaceum* that were equal to 1 and 1.13 (mg) salt in each gram of shoot dry matter. Means comparison of Mg$^{2+}$ showed that the highest amount was accumulated in above ground biomass of *Halocnemum strobilaceum* and the lowest amount was measured in *Salsola dendroides* (Table 2).

Evaluation of these four cations' concentration in root dry matter of investigated halophytes showed that there was a significant difference in concentrations of Na$^+$, Mg$^{2+}$, Ca$^{2+}$ (p<0.01) between four species (Table 3).

The highest amounts of Na$^+$ and Mg$^{2+}$ were measured in root tissue of *Salsola nitraria* as the highest concentration of K$^+$ was measured in root tissue of *Salsola dendroides*.

**Table 2.** Means comparison of cations concentration (mean ± SE) in shoot tissue of four main halophytes from Urmia Lake

| Species name | Na$^+$ | K$^+$ | Mg$^{2+}$ | Ca$^{2+}$ |
|---|---|---|---|---|
| *Salsola dendroides* | 8.66±0.53[a] | 1.80±0.05[a] | 2.03±0.16[bc] | 0.50±0.08[a] |
| *Salsola nitraria* | 9.00±0.30[a] | 1.53±0.06[b] | 2.74±0.02[ab] | 0.50±0.04[a] |
| *Salsola iberica* | 9.26±0.13[a] | 1.00±0.00[c] | 1.82±0.12[c] | 0.33±0.03[b] |
| *Halocnemum strobilaceum* | 9.73±1.45[a] | 1.13±0.66[c] | 2.96±0.48[a] | 0.32±0.06[b] |
| F test | 0.324[ns] | 44.12[**] | 93.78[**] | 4.35[*] |

*ns, \*, \*\*: non-significant and significant at 0.05 and 0.01 probability levels, respectively*
*Means of column followed by same letters has no significant differences based on Duncan method*

**Table 3.** Means comparison of cations concentration (mean ± SE) in root tissue of four main halophytes from Urmia Lake

| Species name | $Na^+$ | $K^+$ | $Mg^{2+}$ | $Ca^{2+}$ |
|---|---|---|---|---|
| *Salsola dendroides* | 1.56±0.03[c] | 0.21±0.01[a] | 0.87±0.07[b] | 1.2±0.00[a] |
| *Salsola nitraria* | 4.44±0.08[a] | 0.68±0.26[a] | 2.75±0.68[a] | 0.83±0.08[b] |
| *Salsola iberica* | 1.96±0.08[bc] | 0.33±0.06[a] | 1.00±0.09[b] | 1.1±0.05[a] |
| *Halocnemum strobilaceum* | 3.23±0.29[ab] | 0.28±0.06[a] | 1.55±0.08[b] | 1.03±0.03[a] |
| F test | 8.983[**] | 2.796[ns] | 7.848[**] | 5.879[*] |

*ns, \*, \*\*: non-significant and significant at 0.05 and 0.01 probability levels, respectively*
*Means of column followed by same letters has no significant differences based on Duncan method*

## Discussion

As it is obvious from the results, soil properties were affected significantly by the vegetation presence. Plants can modify their soil environment that is called rhizosphere effect (Kuzyakov *et al*., 2009; Jones *et al*., 2009).

In the soil samples of the first depth (0-15cm), EC was reduced due to plant-root action that helped to absorb more salts from soil and transportation of salts to shoot parts. Salt tolerant plants replace or supplement the chemical approach through root action which helps to increase calcite solubility and continuously decrease soil salinity. For soil pH, there was a significant difference between soil samples of patch and bare soil areas, and an increase in soil pH was observed in vegetated areas; this may be related to absorbance of neutral salts by plants that tend to lower pH (Gharaibeh *et al*., 2011).

Soil organic matter and nutrients of nitrogen and phosphorus were higher in vegetation patch areas that may be attributed to the positive effects of plant canopies. For soil particles of patches and bare soil in inter-patch areas, silt and clay amounts increased, and sand amount decreased numerically in vegetation patches. Sand increases soil permeability and causes the rapid drying out of soil (Abbasi-kesbi *et al*., 2017).

The incorporation of organic matter under the plant canopies leads to an increase in aggregate stability, reduction of splash erosion and soil compaction, soil bulk density and increase in porosity, leading to higher infiltration rates. As a result, nutrient and water storage at the root zone are greater and the plant biomass increases (Bochet *et al*., 1999).

The results obtained about organic matter and nutrients are in line with the results reported by Caravaca *et al*. (2010) who confirmed the increase in soil properties such as under canopy patches of some species like *Olea europaea*, *Pistacia lentiscus*, *Retama sphaerocarpa*, *Rhamnus lycioides*, *Rosmarinus officinalis* and *Stipa tenacissima*.

Vegetation patches that form fertile islands with better nutritional condition and lower amount of toxic ions lead to improved soil properties beneath the shrubs that are valuable for the stability of the soil surface and have ecological importance in highly resource-stressed ecosystems (Li *et al*., 2011). Soil soluble salts of $Na^+$, $K^+$, $Mg^{2+}$ and $Ca^{2+}$ decreased in soil of vegetation patches which show the considerable role of halophyte plants in absorbing inorganic salts from root zone. Ion uptake and transport from roots to shoots are important indicators of salinity tolerance in halophytes (Chen *et al*., 2010).

The absorption of salt requires osmotic regulations. A wide range of plant species grows naturally on the coastal and island saline areas such as salt marshes and salt deserts (halophytes), which survive salt concentration equal to or greater than that of seawater. The compartmentation of ions in the vacuoles and accumulation of compatible solutes in the cytoplasm and presence of genes for salt tolerance confer salt resistance to halophytes (Ravindran *et al*., 2007).

These cations decrease in soil by the effect of some halophyte species like *Leptochloa fusca*, *Sesuvium*

*portulacastrum*, *Suaeda maritima*, *Excoecaria agallocha*, *Clerodendrum inerme*, *Ipomoea pescaprae* and *Heliotropium curassavicum* reported by Akhter *et al.* (2003); Ravindran *et al.* (2007); Rabhi *et al.* (2010) and the decrease in salinity of the soil in vegetated areas suggests that halophytes are able to desalinize their root zone. This decrease is probably due to the salt ascension because of their uptake by roots (Rabhi *et al.*, 2009).

Phytoremediation as an emerging solution which refers to the use of green plants for the removal of harmful elements or rendering them harmless is cost-effective, and environmental-friendly and can be applied to large-scale soils (Moameri *et al.*, 2017).

## Conclusion

Among the four studied species, *Halocnemum strobilaceum* seems to be the most convenient to be used for desalination in arid and semi-arid regions where precipitation is low to leach salts from rhizosphere. As this species showed the highest amount of main salts like sodium and magnesium in above ground biomass, the cations' accumulated amount was lower in root tissue so that *Halocnemum strobilaceum* can be used efficiently to reclaim saline soils by harvesting shoots.

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# اثر لکه‌های گیاهان هالوفیت بر برخی خصوصیات خاک مراتع شور اطراف دریاچه ارومیه

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**چکیده.** گیاهان ممکن است سبب ایجاد ناهمگنی‌های کوچک مقیاس در حاصلخیزی خاک گردند که سبب تشکیل جزایر حاصلخیز می‌شوند. به هر حال این فرآیندها به گونه‌های گیاهی، میزان توسعه گیاهی و شرایط رویشگاهی وابسته است. پوشش گیاهی مناطق خشک و نیمه خشک بیشتر به شکل لکه‌های گیاهی و لکه‌های خاک لخت اطراف این لکه‌ها است. این شکل از پوشش گیاهی می‌تواند به منظور مطالعه تاثیر گیاهان بر خاک و دستیابی به اطلاعات کاربردی جهت پیش‌بینی کارایی گیاهان در پروژه‌های اصلاح و احیاء مورد استفاده قرار گیرد. این تحقیق با هدف بررسی خصوصیات خاک لکه‌های متشکل از برخی گیاهان هالوفیت دریاچه ارومیه در مرداد ماه سال ۱۳۹۵ انجام گرفت. نتایج حاصل نشان داد که هدایت الکتریکی خاک از ۱۰/۳۲ (میلی‌موس) در خاک لخت به ۴/۹۲ (میلی‌موس) در لکه‌های گیاهی کاهش یافت. همچنین افزایش قابل توجه pH (۸/۷۳) و فسفر (۲۹/۶۱ پی‌پی‌ام) در لکه‌های گیاهی نسبت به خاک لخت اطراف که به ترتیب دارای مقادیر pH و فسفر، ۸/۵۱ و (پی‌پی‌ام) ۱۲/۸۱ بود، مشاهده شد. همچنین از آنجا که لکه‌های گیاهی سبب کاهش مقادیر کاتیون‌های خاک شدند، بنابراین مهمترین گونه‌های هالوفیت لکه‌ها با قابلیت جذب این یون‌ها *Halocnemum strobilaceum* *Salsola* *S. nitraria dendroides* و *S. iberica* انتخاب شدند و مقادیر نمک در بافت‌های هوایی و ریشه آنها اندازه‌گیری شد. نتایج حاصل بیانگر تفاوت معنی‌دار گونه‌های مورد بررسی در جذب نمک و توانایی انباشت آن در بافت‌های گیاه بود. گونه *Halocnemum strobilaceum* مقادیر بالاتر سدیم (۹/۷۳ میلی‌گرم در کیلوگرم) و منیزیم (۲/۹۶ میلی‌گرم در کیلوگرم) را در بافت‌های هوایی گیاه خود انباشت کرده بود و بنابراین دارای توانایی بیشتری در جذب این نمک‌ها از طریق ریشه و انتقال آنها به بافت‌های هوایی بود. در مجموع این گیاهان می‌توانند سبب افزایش مقادیر مواد مغذی و بهبود شرایط شیمیایی خاک در محیط اطراف ریشه شوند.

**کلمات کلیدی:** کاتیون‌ها، مواد مغذی، ریزوسفر، نمک‌های محلول، لکه‌های گیاهی