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Evaluating *Salicornia* as a Potential Forage Crop to Remediate High Groundwater-Table Saline Soil under Continental Climates

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Authors' contributions

This work was carried out in collaboration among all authors. Authors CY and MC designed the study and performed sample collection and processing. Authors MJF, AMK and GO processed and managed the analyses of the samples. Author IO managed the literature searches. Author KRI designed the sampling plan, performed statistical analyses and wrote the paper. All authors read and approved the final manuscript.

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ABSTRACT

Salicornia is a leafless C_3 annual halophyte with a greatest economic potential. A field study was conducted to evaluate *Salicornia* (*Salicornia europaea*) biomass production and feed quality and its effect on soil quality in the Mediterranean Karatas-Adana region of the Southern Turkey. *Salicornia* biomass, groundwater, and soils were randomly sampled from adjoining Unprotected (uncontrolled mixed grazing) and Protected (no grazing) sites. Results showed that the Protected site produced a higher amount of total (shoot and root), root, and shoot fresh biomass by 22, 45, and 12%, respectively as compared with the Unprotected site. Total, root, and shoot dry biomass production

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was also higher in the Protected site. Biomass collected from the Protected site had a significantly lower content of acid detergent fiber, but higher content of digestible dry-matter and relative feed values than in biomass collected from the Unprotected site. Iron (Fe) and zinc (Zn) contents were 1.9 and 1.8 times higher in the Protected site than in the Unprotected site. Groundwater and soil electrical conductivities were significantly lower in the Protected site than in the Unprotected site. While the soil microbial biomass, active carbon, and intermediate C pools were 36, 21 and 56% higher, respectively, the specific maintenance respiration rates were lower (by 23%) in the Protected site than in the Unprotected site. Results suggested that increased biomass yield of *Salicornia* with higher feed quality under Protection could be used as a forage crop to remediate coastal saline soils with a high water-table.

Keywords: Protected and unprotected sites; total biomass; feed quality; acid detergent fiber; relative feed values; nutrients; active carbon; microbial biomass; basal respiration; soil quality.

1. INTRODUCTION

Increasing salinity and decreasing fresh-water availability are two of the important factors contributing to agricultural land degradation, with about 20% of the irrigated and rain-fed lands are affected by various degrees of soil and water salinity worldwide [1,2]. Conventional soil-plant management practices, including extensive and deep plowing, frequent excessive or insufficient irrigation, poor drainage, and unregulated fertilization and reactive chemical use have accelerated soil and water salinity [3,4].

The United States Department of Agriculture has estimated that about 10 million hectares of productive agricultural lands worldwide are degraded annually to secondary soil salinity as a result of improper irrigation and lack of drainage facilities [4]. In Turkey, about 4.2 million ha of the agricultural lands are unsuitable for production due to soil and water salinity. There are more than 1.5 million ha of saline soils in Turkey, which equals to almost 6.3% of its total arable lands [5].

Salinity affects soil quality and consequently, plant physiological processes associated with survival and growth are also affected. While mild salinity has no direct adverse effects on plant growth, but high salinity affects plant’s growth by increasing the cell osmotic pressure [6]. A consistent decrease in freshwater availability with an associated increase in secondary soil salinity has focused attention on plants that are inherently salt-tolerant, but can achieve economically viable yields [7].

Salicornia (commonly known as glasswort dwarf, dwarf saltwort, pickle weed, or sea-asparagus) is a leafless, C_3, facultative succulent annual halophytes that has been utilized as food and fodder [8,9]. It has also been used for its medicinal and nutritional values and salt contents [8,9]. They are very capable to adapt and complete their life-cycles in highly saline soil-plant root environments [9].

Salicornia offers as a potential forage crop to grow in saline soil where other vegetative growths are sparse and livestock feed shortage is a major constraint [10-12]. When *Salicornia* biomass was used as a sole source of protein-rich fodder, the high ash content limited its nutritional and feed quality [13]. However, other research studies showed that *Salicornia* biomass can replace and/or supplement traditional forage components in feeds for ruminants at 25 to 30% inclusion rates [14-16].

In the Central Anatolian region of Turkey, *Salicornia europaea* grows abundantly near coastal marshy areas and inland saline soils [10]. *Salicornia* biomass as one of the complementary and/or supplementary sources of forage components in ruminant feed offers an opportunity to phyto-remediate and rehabilitate coastal soil-water ecosystems that are too saline for agronomic crops and traditional forages. Commercial farming of *Salicornia* is expected to create employment and business opportunities, support local economy, and make indirect contribution to climate change mitigation.

While the natural growth characteristics of *Salicornia* greatly influenced by saline soil-water ecosystems, the effects of management practices and site conditions which determine adaptation, survival and biomass production needs to be determined before starting any commercial ventures [17]. However, limited information is available to evaluate the effects of management practices and site conditions on *Salicornia* survival, adaptation, growth, biomass production, and feed quality.

The objective of the study was to evaluate the biomass production, feed quality, and phytoremediation capability of naturally grown *Salicornia europaea* in the Protected sites, as compared with the Unprotected and open grazed sites in coastal saline soils with a high groundwater table in the Mediterranean Karatas-Adana region of the Southern Turkey.

2. MATERIALS AND METHODS

2.1 Study Location and Existing Vegetation

The study was conducted at the state-owned Bebeli natural pasture range (~ 18 km^2) in the Karatas-Adana region (lat.36°37'28.58"N and long. 35°29'29.87"E) of the Southern Turkey. The area has a relatively flat surface (<1% slope) and is characterized by a high groundwater table due to seasonal flooding under Mediterranean semi-arid climate [18]. The soil is a Oymakli silty clay (Typic Xerofluvent) with 13.7 to 25% $CaCO_3$, 12 to 22% sand, 28 to 46% silt, and 36 to 54% clay, respectively at 0 to 30-cm depth [10]. Average annual rainfall is 670±42 mm that occurs mainly from November to April [19]. Annual mean temperature is 19.1°C with a frost-free period of 2 to 3 days.

Existing vegetation is dominated by *Salicornia europaea* along with sparse growth of *Allium scabriflorum, Agropyron junceum, Atriplex spp., Bassia spp., Cakile maritime, Cares spp., Centaurea calcitrapa, Cynodon dactylon, Erigeron spp., Glaux maritime, Halimione spp., Hordeum marinum, Inula aucherana, Juncus spp., Kochia prostrate, Limonium sinuatum, Paspalum paspaloids, Plantago maritimum, Polypogon monspeliensis, Puccinela spp., Salsola kali, Tamarix spp., Trifolium fragiferum,* and *Verbance officinalis* [10].

2.2 Sampling Method and Processing of Soil, Plant and Ground-Water Samples

In late November 2014, three sampling locations (100-m x 100-m) each in both Unprotected- and Protected sites within the pasture range were randomly selected. The Unprotected site is the unfenced area of the pasture range where local villagers allowed their small animals (mostly lamb and goat) for grazing [18]. Existing natural vegetative systems including *Salicornia europaea* are in degraded condition due to uncontrolled grazing practices. In contrast, the Protected site is separated from the Unprotected site by a 5-m wide and 2-m deep irrigated canal where *Salicornia europaea* is thriving due to protection from grazing [18].

In each sampling location, four random quadrats (9 m^2 each) were selected in east, west, north and south directions. A total of 12 sampling quadrates were selected in each site. Within each quadrat, all the *Salicornia* plants were cut at the base with a scissor and collected in large polyethylene bags. The root biomass was dug-out to a 30-cm depth and placed in separate

Fig. 1. Location of the sampling sites in the Karatas region of the Southern Turkey [Picture to the left is the Unprotected site with animal hoop marks; picture to the right is the Protected site; and picture in the middle is the canal, which separates two sites]

polyethylene bags. Both fresh shoot and root samples were weighted and air-dried at room temperature (25+20C) for 7-day followed by oven-drying at 650C until a constant weight was obtained. A portion of the oven-dried shoots was ground, 0.25-mm sieved, and analyzed for feed quality and nutrient contents.

A composite soil consists of 9 cores (3 * 3 at X and Y directions) from each quadrat at 0 to 30-cm depth was sampled using a soil core sampler (2.54 cm internal dia.) prior to collection of *Salicornia* root and groundwater samples. The collected field-moist soils were sieved through a 2-mm mesh to remove small pieces of rocks and large organic debris. A portion of the sieved field-moist soil was analyzed for microbial biomass and associated biological properties. Another portion of the field-moist soil was air-dried at room temperature (25±2℃) for 7-day and analyzed for chemical and physical properties. Using a soil auger (2.54 cm internal dia.), a borehole was dug in each plot. Groundwater depth was measured by using groundwater level meter with an attached electrode. Water samples were collected in acid-washed clean-dry plastic bottles and placed in a cooler prior to analysis.

2.3 Analysis of *Salicornia* Shoot Biomass

Total N content of shoot biomass was determined by using the Thermo-Fisher® automated total C and N analyzer. For P, Fe, Mn, Cu and Zn analysis, a 1-g sample of dry shoot biomass was burned at 480℃ for 4-hr. followed by dissolution with 0.1 M hydrochloric acid and distilled deionized water mixture. After filtration, the clear aliquots were analyzed for nutrient contents using Perkin-Elmer® Integrated Coupled Plasma Spectrophotometry analyzer. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) contents of *Salicornia* shoot biomass were determined using Ankom fiber analyzer [20]. The digestible dry-matter (DDM), dry-matter intake (DMI), and relative feed values (RFV) were determined [21].

$$DDM = (88.9 – (0.779 \times ADF) \qquad (1)$$

$$DMI = (120 / NDF) \qquad (2)$$

$$RFV = (DDM \times DMI) / 1.29 \qquad (3)$$

Total N concentration of the *Salicornia* shoot biomass was multiplied with the coefficient of 6.25 to for crude protein contents. Ash content was calculated by loss of ignition after burning the dry shoot-biomass of *Salicornia* at 450℃ for a 4-hr. period, until a constant weight was obtained.

2.4 Incubation of *Salicornia* Biomass with Water

To mimic the effects of *Salicornia* litter-fall under natural condition on any changes in pH or electrical conductivity of soil (ECs) or water (ECw), a short-term laboratory incubation study was conducted. A 2-g chopped fresh sample of shoot biomass taken in a 50-mL plastic tube was mixed with 20-mL of distilled deionized water followed by shaking for 5-min. After shaking, the suspension pH and ECw were measured (at T_0). The plastic tube mouth was loosely plugged with cotton for allowing air exchange and placed in the incubator at 25℃ under dark for a 11-day period. The suspension pH and ECw at 0 (T_0), 1, 3, 7 and 11-day were measured. The pH and ECw in incubated distilled deionized water (without any *Salicornia*) were also measured as a control.

2.5 Soil and Groundwater Analysis

Soil total microbial biomass (SMB) was determined by using the rapid microwave irradiation and extraction method [22]. Basal respiration (BR), as a measure of antecedent biological activity, was determined by incubating un-amended field-moist soil at 25±1℃ in the dark for a period of 15 days [23]. Soil metabolic quotient (qR) as the ratio of SMB-C over total organic C (TOC) was calculated [24]. Specific maintenance respiration (qCO_2) rates were calculated as the BR rates over SMB-C content [24]. The TOC content was measured by following Walkley and Black method using the rapid microwave digestion and spectrophotometry [25]. Active and intermediate C fractions were determined on air-dried soil after modifying the neutral 0.02 M $KMnO_4$ oxidation method [26]. Bouyoucos hydrometer method was used for particle size analysis; glass electrode method for pH; electrical conductivity meter for ECs, and standard core method for determining soil bulk density.

Groundwater EC (ECw) was measured by using a field EC meter. Using the relationship between the EC and TDS of drainage water for the local region [18]; the TDS in groundwater was calculated as:

$$TDS\ (mg/L) = 616.48 * ECw \qquad (4)$$

The relationship between ECw and osmotic pressure of the groundwater was calculated [27].

Osmotic pressure (πw, kPa) = 36 x ECw (dS/m) at 25°C (5)

2.6 Prediction of *Salicornia* Biomass Salt Accumulation

By modifying the standardized relationship between total dissolved solids (TDS) and EC [27], the TDS in the *Salicornia* shoot biomass was calculated, based on steady-state EC of the biomass-distilled deionized water suspension from incubation study. The TDS values were multiplied with the total dry shoot biomass weight to calculate the salt content in the *Salicornia* shoot biomass as follows:

TDS (g/kg) = [(640*EC) * (water added, 0.02 L) / (biomass used, 0.002 kg)] (6)

Biomass salt (kg/ha) = [(TDS, g/kg) * (total shoot biomass, Mg/ha) / (1000*ha)] (7)

Where, EC is the steady-state EC of *Salicornia* biomass-distilled water suspension after subtracting the distilled deionized water EC at the end of the incubation (as described above), 0.02-L is the volume of the distilled deionized water used, 0.002-kg is the amount of the fresh shoot biomass of *Salicornia* taken, 640 is a standardized coefficient to estimate a TDS (g/kg) value from an EC (dS/m) measurement, and 1000 is the conversion factor.

2.7 Statistical Analysis

Significant differences in *Salicornia* biomass yield and feed quality, groundwater quality, and soil properties between sites (Protected vs. Unprotected) were assessed by using PROC GLM model of the 1-way analysis of variance (ANOVA) procedure of the SAS [28]. However, the effect of *Salicornia* biomass-water suspension on pH and EC values over time were analyzed by a 2-way ANOVA procedure. Before conducting ANOVA, data were subjected to a test of normality and homogeneity of variance. For all statistical analyses, significant effects of predictors on dependent variables were evaluated and separated by the F-protected least significant different (LSD) test at $p \leq 0.05$, unless otherwise mentioned. Regression and correlation analyses were performed using SigmaPlot®.

3. RESULTS AND DISCUSSION

3.1 *Salicornia* Biomass Production and Feed Quality

Salicornia total (shoot and root) fresh biomass (TFB), root biomass (FRB), and shoot biomass (FSB) were 2.2, 2.7, and 2.1 times higher, respectively in the Protected site than in the Unprotected site (Table 1). Likewise, the total dry biomass (TDB), root- (DRB) and shoot biomass (DSB) were higher in the Protected site. *Salicornia* biomass collected from the Protected site had a significantly lower ADF content (23 vs. 28%), but higher DDM contents (71 vs. 67%) and RFV's (146 vs. 126) than that of biomass collected from the Unprotected site (Table 2). The NDF, DMI, protein and ash contents of *Salicornia* biomass did not vary significantly between two sites.

Among the nutrients, Fe and Zn contents in *Salicornia* biomass varied significantly between two sites (Table 3). The biomass Fe and Zn contents were higher by 1.9 and 1.8 times, respectively in the Protected site than in the Unprotected site. The N, P, Mn, and Cu contents in *Salicornia* biomass did not vary significantly between Protected and Unprotected sites.

Significantly higher biomass yield, DDM, RFV, Fe and Zn but lower ADF contents of *Salicornia* in the Protected site than in the Unprotected site was due to greater adaption and improved site condition under protection. Several studies have reported that well-adapted *Salicornia* produced higher biomass yields on sites even at seawater salinity levels [9,29,30]. Results from a 6-year old field trial reported as much as 1.7 kg of dry biomass production m^{-2} for *S. bigelovii*, when grown with seawater [31]. Similarly, an average of 14.9 kg fresh biomass m^{-2} was obtained for *S. persica*, when grown on sand dune soil, using irrigation with a moderate saline water of 10 dS m^{-1} [32].

Several other studies reported that biomass of similar halophytes like *Salicornia* had protein contents ranging from 6 to 12%, with ADF ranging from 26 to 37%, and NDF from 40 to 60%, even when irrigated with highly saline drainage water [33]. It is also stated that managed halophytes, including *Salicornia* had a greater amount of edible biomass with increased DDM's, which is an available energy indicator in any feeds often recommended for ruminants [34].

Table 1. Total, shoot and root biomass of *Salicornia europaea* in both Protected and Unprotected sites in the south-western Mediterranean region of Turkey

Sampling Site	TFB Mg/ha	FRB Mg/ha	FSB Mg/ha	FSB/ FRB	TDB Mg/ha	DRB Mg/ha	DSB Mg/ha	DSB/ DRB
Protected	17.2±1a[¥]	4.4±0.5a	12.8±1a	2.9±0.4b	6.3±0.5a	1.5±0.3a	4.8± 0.5a	3.2±0.2a
Unprotected	7.7±0.6b	1.6±0.3b	6.1±0.7b	3.8±0.4a	3.9±0.4b	1±0.2b	2.9±0.2b	2.9±0.3a

Mg=Mega-gram (metric ton), TFB=Total fresh biomass, FRB=Fresh root biomass, FSB=Fresh shoot biomass, TDB=Total dry biomass, DRB=Dry root biomass, and DSB=Dry shoot biomass.

[¥]*Means separated by same lower case letter in each column were not significantly different at $p \leq 0.05$ between sampling sites*

Table 2. Acid- and neutral detergent fiber, digestible dry matter, dry matter intake, relative feed value and ash content of *Salicornia europaea* in both Protected and Unprotected sites in the south-west Mediterranean region of Turkey

Sampling Site	ADF %	NDF %	DDM %	DMI %	Protein %	Ash %	RFV %
Protected	22.7±3b[¥]	46.4±5.1a	71.2±4.2a	2.6±0.2a	7.4±1a	26±1.2a	146±8a
Unprotected	27.6±1.1a	49.9±4.6a	67.4±2.7b	2.4±0.3a	7±0.8a	25±2a	126±5b

ADF=Acid detergent fiber, NDF=Neutral detergent fiber, DM=Dry-matter, DDMR=Digestible dry matter, DMI=Dry matter intake, and RFV=Relative feed value.

[¥]*Means separated by same lower case letter in each column were not significantly different at $p \leq 0.05$ between sampling sites*

Table 3. Total nitrogen, phosphorus, iron, manganese, copper and zinc contents of *Salicornia europaea* shoot biomass in Protected and Unprotected sites in the south-west Mediterranean region of Turkey

Sampling Site	N %	P mg/kg	Fe mg/kg	Mn mg/kg	Cu mg/kg	Zn mg/kg
Protected	1.2±0.2a[¥]	20±5a	173±10a	63±5a	13±3a	5.1±0.5a
Unprotected	1.1±0.3a	18±3a	92±6b	42±6b	10±3a	2.8±0.4b

[¥]*Means separated by same lower case letter in each column were not significantly different at $p \leq 0.05$ between sampling sites*

Our results also suggested that *Salicornia* preferably uptake enough of those essential plant nutrients, which helped them capable to survive, adapt and grow in saline habitats. A significantly higher content of Fe and Zn in *Salicornia* biomass collected from the Protected site was most probably associated with greater water absorption and retention in the vacuoles to protect the plants from adverse effects of salt (osmotic pressure) on enzyme activities [6,35,36].

3.2 *Salicornia* Biomass Effects on Water pH and Electrical Conductivity

Salicornia fresh shoot biomass when mixed with distilled deionized water and incubated for a 11-day period, there were significant differences in the suspension pH and EC values (Fig. 2 and 3). The pH decreased over time and varied between two sites, without a significant site x time interaction. The suspension pH decreased more consistently with *Salicornia* biomass collected from the Protected site than the biomass collected from the Unprotected site (Fig. 2). While the suspension pH decreased non-linearly and inversely plateaued, the EC increased non-linearly for both sites, without a significant site x time interaction (Fig. 3).

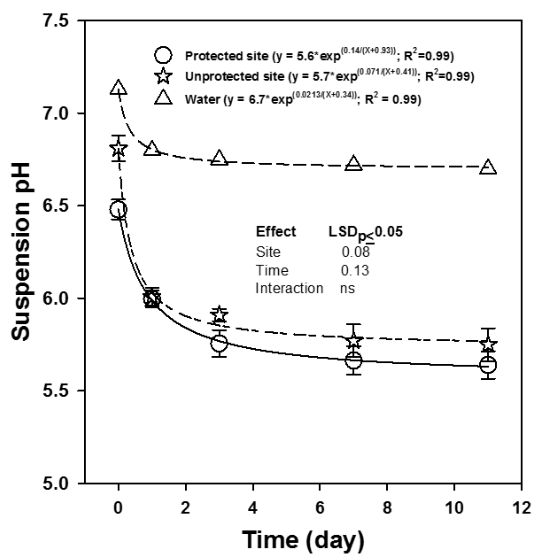

Fig. 2. Laboratory incubation of *Salicornia* fresh shoot biomass in distilled deionized water and its effect on suspension pH over time

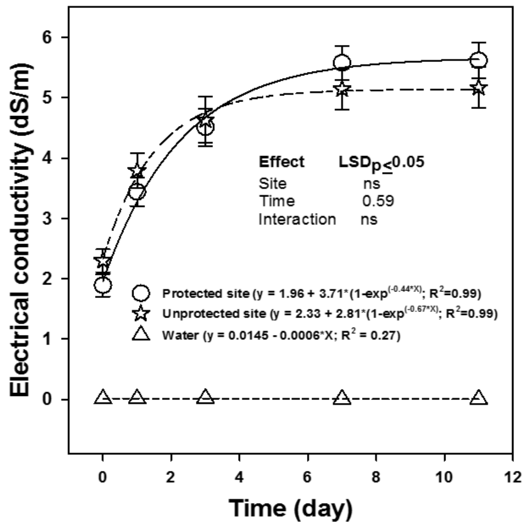

Fig. 3. Laboratory incubation of *Salicornia* fresh shoot biomass in distilled deionized water and its effect on suspension electrical conductivity (ECw) over time

A significant non-linear decrease in pH values of *Salicornia* biomass-water suspension was possibly due to release of H+ from the dissolution of organic acids and atmospheric CO2 (H2O + CO2 = H2CO3) followed by chemical balancing of the acidic and basic cations. A more consistent decrease in suspension pH with *Salicornia* biomass collected from the Protected site than from the Unprotected site was associated with a higher content of acidic cations (e.g. Fe, Mn, Cu and Zn) and greater release of H+ from the dissolution of organic acids. Our results suggested that well-adapted *Salicornia* europaea under protection were capable to uptake a significant amount of soluble salts from the saline soil-groundwater ecosystems in response to accelerated transpiration and subsequently, accumulate salts in its vacuoles. Likewise, a significant temporal increase in suspension EC was expected as the soluble salts accumulated in the plant vacuoles may have released during incubation to make the suspension more saline, as compared to the initial suspension salinity.

3.3 Groundwater and Soil Properties

The groundwater depth between two sites did not vary significantly. On average a 1.4-m depth was measured in both sites at the end of drought season. The groundwater EC (ECw) was significantly lower by 40% in the Protected site than in the Unprotected site (Table 4). Likewise, the TDS contents and osmotic pressure (πw) of groundwater were lower under the Protected site.

Results showed that soil EC (ECs) between two sites varied significantly, with 65% lower ECs in the Protected site as compared to that in the Unprotected site. Total microbial biomass (SMB) and associated biological properties varied significantly between two sites (Table 5). In the Protected site, the SMB content was higher by 36% than in the Unprotected site. Similarly, the qR, a measure of the size of soil biologically labile C pool was higher by 55% in the Protected site than in the Unprotected site. While the BR did not vary significantly, the qCO2, a measure of

Table 4. Groundwater and soil characteristics in both Protected and Unprotected sites in the south-west Mediterranean region of Turkey

Sampling Site	GW cm	ECw ds/m	TDS g/L	πw kPa	pH water	pH soil	ECs ds/m	ρb g/cm³
Protected	138±11a[¥]	42±10b	26±2b	1524±97b	7.8±0.3a	7.2±0.3a	4.6±0.4b	1.15±0.5a
Unprotected	141±9a	70±6a	43±3a	2530±68a	7.7±0.3a	7.3±0.2a	13.3±1a	1.2±0.4a

GW=Groundwater depth, ECw=Groundwater electrical conductivity, TDS=Total dissolved solids, πw=Groundwater osmotic pressure, ECs=Soil electrical conductivity, ρb=Soil bulk density.
[¥]Means separated by same lower case letter in each column were not significantly different at p≤0.05 between sampling sites

Table 5. Soil microbial biomass and associated biological activities, and total organic, active and passive carbon pools in both Protected and Unprotected sites in the south-west Mediterranean region of Turkey

Sampling Site	SMB mg/kg	qR %	BR mg/kg/d	qCO_2 µg/mg/d	TOC %	POC %	IC mg/kg	AC mg/kg
Protected	67±10a[¥]	0.8±0.2a	39±6a	578±45b	0.98±0.2a	0.91±0.2a	268±30a	472±41a
Unprotected	49±5b	0.5±0.1b	37±7a	782±60a	0.86±0.2a	0.79±0.1a	172±12b	388±23b

SMB=Total soil microbial biomass, qR=Metabolic quotient, BR=Basal respiration rates, qCO_2=Specific maintenance respiration, TOC=Total organic carbon, AC=Active organic carbon, IC=Intermediate organic carbon, and POC=Passive organic carbon.
[¥]Means separated by same lower case letter in each column were not significantly different at p≤0.05 between sampling sites

microbial catabolism, was lower by 23% in the Protected site than in the Unprotected site. The TOC and passive organic C (POC) contents did not vary significantly, but both AC and IC contents were significantly different between two sites (Table 5). In the Protected site, the AC and IC contents were higher by 21 and 56%, respectively than in the Unprotected site. However, neither soil pH nor bulk density varied significantly between two sites.

Significantly lower values of ECw and ECs suggested that increased ground cover (living mulch effect) provided by the well-adapted and dense vegetative growth of *Salicornia* in the Protected site may have reduced soil temperature and evaporative stress than in the Unprotected site. In contrast, sparse and poor vegetative growth of *Salicornia* in the Unprotected site may have caused a greater upward movement of saline groundwater, and subsequent accumulation of soluble salts under high evaporative stress. The consequent effects of higher salt accumulation increased both ECw and ECs values. Moreover, the upward salt movement processes may have occurred more frequently to cause higher levels of soil and groundwater salinity in the Unprotected site than in the Protected site.

The adverse effects of higher ECw and ECs on soil biological and chemical properties were more in the Unprotected site than in the Protected site, due to accelerated dispersion of soil aggregates, greater loss of labile C, and increased microbial catabolism [3]. The decreased TOC, AC and IC contents in the Unprotected site was due to reduced microbial efficiency and enzyme activities, as influenced by higher ECw and ECs [36,37].

Our results also suggested that soil desiccation coupled with increasing groundwater TDS, πw, and ECs was responsible for the smaller size of SMB and qR pools with higher qCO_2 in the Unprotected site [3,23]. As the qCO_2 reflects SMB physiological efficiency, the higher qCO_2 values suggested that the SBM was more stressed in the Unprotected site, and consumed more energy (i.e. labile C) for cell maintenance than C assimilation and cell growth [3]. Despite a decreased size of SBM pool with increased qCO_2, it is evident that substantial microbial activities still persisted at both sites, which can be attenuated by the C and N availability and greater presence of salt-tolerant microorganisms [3,23].

3.4 Phytoremediation of Salt

Based on the results of the laboratory incubation studies, we calculated that *Salicornia* biomass accumulated 426 to 475 kg salt/ha from the Protected site as compared to only 182 to 237 kg salt/ha from the Unprotected site (Fig. 4), with a mean values of 443 and 211 kg salt/ha, respectively.

The difference in biomass salt content (232 kg/ha) between two sites was significant, suggesting that if we manage rotational grazing or selectively harvest *Salicornia* biomass annually, we would remove substantial amounts of salts from the saline soil-water ecosystems. Moreover, harvested *Salicornia* biomass as a supplemental diet would provide sufficient amounts of salt to the animals. Otherwise, the senesced litter-fall of *Salicornia* would recycle soluble salts from the saline soil-groundwater ecosystems, contributing to accelerated secondary soil salinization. Management of *Salicornia europaea* could be one of the novel and holistic approaches for sustainable phytoremediation of saline soil-groundwater ecosystems in response to expected climate change effects.

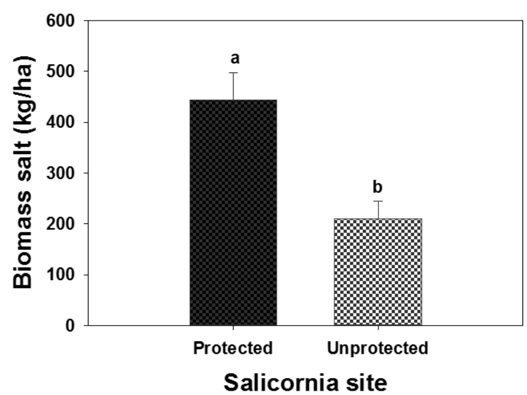

Fig. 4. Salt content in fresh shoot biomass of *Salicornia europaea* in both Protected and Unprotected sites of the in the south-west Mediterranean region of Turkey

4. CONCLUSION

A significantly higher amount and quality of *Salicornia* biomass produced in the Protected site than in the Unprotected site. Similarly, biomass produced in the Protected site had a higher content of digestible dry-matter, nutrient element, and relative feed values with a lower content of acid detergent fiber. Higher yield and quality of *Salicornia* biomass was due to increased vegetative ground cover and improved soil quality under protection from grazing. With managed grazing or selective annual harvesting of *Salicornia* biomass as a forage crop, it is possible to phyto-remediate a substantial amount of salts from the coastal saline soil-water ecosystems. Otherwise, the salt-laden senesced *Salicornia* biomass would recycle more frequently to contribute for secondary soil salinization. Despite higher groundwater and soil salinities, an increased biomass yield with higher feed quality of naturally grown *Salicornia* under management protection could supplement and/or replace conventional animal feeds, phyto-remediate saline soil-water systems, and improve ecosystem services in response to expected climate change effects.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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