

Effect of manure and biochar on the aluminum, copper, and iron bioaccumulation by *Salicornia* species in soil

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Abstract

Experiments were conducted to investigate the ability of two species of *Salicornia persica* and *Salicornia perspolitana* to extract heavy metals, including aluminum, iron, and copper. In this study, manure and biochar were applied to improve performance. The two species of *S. persica* and *S. perspolitana* were grown outdoor in experimental pots. The effect of experimental treatments including manure and biochar on the two species was investigated. The results showed that biochar significantly influenced ($P < 0.05$) the accumulation of heavy metals in both *S. persica* and *S. perspolitana*. In biochar treatment, the values of heavy metals in roots and shoots were found to be 3327 mg/kg, 109.17 mg/kg for aluminum, 3527 mg/kg and 142.17 mg/kg for iron, and 73.93 mg/kg and 11.90 mg/kg for copper, respectively. In the manure treatment, the values of heavy metals in the roots and shoots were reported as 3993 mg/kg and 119.29 mg/kg for aluminum, 5542 mg/kg and 179.17 mg/kg for iron, and 78.67 mg/kg and 12.74 mg/kg for copper, respectively. In general, our findings showed that using biochar and manure in the soil allowed heavy metals to be stabilized, which reduced heavy metal accumulation in both *S. persica* and *S. perspolitana*. Heavy metal accumulation was higher in *S. perspolitana* than in *S. persica*.

1. Introduction

Many toxic elements, both elemental and biological, are stored in soils, including heavy metals and trace metals, referred to as just metals (Zimmerman and Weindorf 2010). Metals and metalloids with densities of more than 5 g/cm^3 are referred to as heavy metals (Oves et al. 2012). Some metals such as copper and iron are necessary elements for plants, animals, and humans because they play a role in a variety of metabolic functions, enzymatic activities, receptor sites, hormonal function, and protein transport at precise concentrations (Antoine et al. 2012). Other hazardous elements such as arsenic, cadmium, and lead are non-essential and have no beneficial role in plants, animals, or humans (Khan et al. 2015). Because metals are non-biodegradable and have a long half-life, biological organisms cannot decompose them, maintaining them in their body parts and environment, posing a health concern (Nabulo et al. 2011). Heavy metals can migrate from soil and water to plants and bioaccumulate, posing health hazards (Khan et al. 2013; Rattan et al. 2005).

Plant species differ in their heavy metal bioaccumulation, as indicated by their growth, reproduction, occurrence, and survival a metal-contaminated soil. Because all plant species have various methods of elemental uptake, different plant species have variable toxicity levels to the same contaminant in the same environment (Markert et al. 2003). Plant accumulation of heavy metals is influenced by metal concentrations and Phyto-availability and Phyto-variety, as various plants absorb metals at different rates (Yang et al. 2009). Varied heavy metals have different capacities for uptake by plants, and the same heavy metal might accumulate in different ratios in different plant species (Singh et al. 2010).

Plants such as *Salicornia* species can be utilized to detoxify or stabilize environmental pollutants in the matrix (soil, water, and sediments) by natural, biological, chemical, or physical activities. (Moosavi et al. 2013). *Salicornia* is an annual, halophyte plant belonging to the Chenopodiaceae family, which grows as

an herb with succulent and fleshy stems. *S. persica* is a tetraploid plant with a standing form that prefers dry environments. The annual *S. perspolitana* is characterized by a lying-down form on the ground. *Salicornia* can serve as a proper halophyte plant for phytoremediation of heavy metals due to its suitable roots as well as the ability to stabilize heavy metals (Khanlarian et al. 2020; Liang et al. 2017; Pedro et al. 2013; Rhee et al. 2009; Van Oosten et al. 2015). Mesa-Marín et al. (2020) showed that *S. ramosissima* could accumulate high levels of heavy metals (Cu and Zn), primarily at the root. Also, Khanlarian et al. (2020) used *S. europaea* plant for phytoextracting Zn from zinc leach residue.

The presence of organic matter provides the conditions for increasing plant biomass production and stabilizing soil masses (Boguta and Sokołowska 2012). Biochar is a porous and carbon product obtained from pyrolysis of plant-derived organic materials (bark, rice husk, pinewood, etc.), enhancing soil fertility. Biochar also causes immobility and stabilization of metals and thus can reduce the concentration of heavy metals in the plant (Li et al. 2016). Biochar, as a bio-amendment with unique physicochemical properties such as high surface ratio (containing many functional groups), can stabilize metals and consequently reduce the bioavailability of metals to plants (Chen et al. 2018). Glaser et al. (2002) showed that increases in the water holding capacity after adding biochar to the soil were due to high amounts of organic matter.

Different types of biochar, which have various characteristics, were used for the immobilization of heavy metals in soil (Manyà and Gascó 2021; Paz-Ferreiro et al. 2014a; Paz-Ferreiro et al. 2014b). Cárdenas-Aguar et al. (2017) investigated the effect of biochar addition on copper contaminated soil and reported the significant remediation in metal bioavailability, high microbial biomass, and growth of vegetable species. Lu et al. (2018) concluded that biochar is appropriate for the remediation of contaminated soil. Lu et al. (2015) found that using *Amaranthus tricolor* L with biochar to soil could improve soil biology. The findings of Gasco et al. (2019) too implied that biochar is a viable option in contaminated soils.

Organic fertilizers (manure) are also considered as one of the critical factors influencing soil fertility. The primary sources of organic matter in the soil are animal waste, crop residues, sewage sludge, and municipal waste compost, which today have received much attention due to the importance of organic agriculture and the need to reduce environmental problems in sustainable agriculture. Manures facilitate root penetration in the soil, increase root dry weight by improving soil physical properties, and play an essential role in controlling mobility, bioavailability, uptake, and disposal of metals (Shahid et al. 2017). In the research of Haroon et al. (2019), results indicated that heavy metals were reduced by applying manure in different types and ratios.

An ideal plant for environmental cleanup should have a high biomass yield and good pollutant tolerance, accumulation, and degradation capability, depending on the type of pollutant. Furthermore, the phytoremediation capability was limited by the low biomass and slow growth rate of plants in severely contaminated soil (Mahar et al. 2016; Yan et al. 2020). In other words, this approach can be used in places where metal pollution is low to moderate (Mahar et al. 2016). Biochar and manure are two examples of soil amendments that can help improve plant growth or crop yields while minimizing the

amount of mineral fertilizer utilized (Antoniadis et al. 2017; Hafez et al. 2019; Huang et al. 2020; O'Connor et al. 2018). These amendments, on the other hand, operated as an adsorbent in soil by electrostatic attraction, complexation, ion exchange, precipitation, and physical adsorption (O'Connor et al. 2018). Pollutants are absorbed and removed more easily by the adsorbent in pollution treatment systems when the concentration of pollutants is high. Removal and absorption are slow at lower concentrations of pollutants in the source (Amini and Younesi 2009; Amini et al. 2008). The phytoremediation process followed a similar pattern. It means that when the amount of pollutants in the soil is significant, the plant's ability to remove them is enhanced (Bhat et al. 2016; Kaviani et al. 2019; Saleem et al. 2020). To establish the ability of plants for phytoremediation, researchers should investigate the accumulation and transfer of low concentrations of metals from soil to plant parts in the presence of amendments.

Our goal is to recognize whether *S. persica* and *S. perspolitana* could transmit Al, Fe, and Cu from the soil to the roots and shoots of plants in the presence of biochar and manure. Because these elements are not hazardous metals, their harmful effects take a long time to manifest and can be taken by plants at any concentration. Other studies identical to the current study have been carried out in which the concentration of Fe and Cu elements was lower than international standards (Baldantoni et al. 2014; El Rasafi et al. 2021; Lorestani et al. 2011; Poschenrieder et al. 2001). However, the findings of this study will aid in the understanding of *salicornia*'s heavy metal uptake and bioaccumulation to utilize this plant in a phytoremediation process to eliminate these metals from contaminated soils.

2. Materials And Methods

2.1 Experiments

The experiments were assessed by two *S. persica* and *S. perspolitana* in contaminated soil by manure and biochar. The research was carried out from 2018 to 2019 in the laboratory and growth chamber of the Faculty of Natural Resources and Environment, Ferdowsi University of Mashhad, Iran. The soil samples for this experiment were taken from a depth of 0–40 cm, located at 25 km apart from the northeast of Mashhad city (36° 29' 92" N and 59° 31' 16" E), then passed through a 2-mm sieve after air-drying.

2.2 Physical and chemical properties of soil, manure, and biochar

Soil texture was determined by hydrometric method, pH by pH-meter (20+, Crison, Spain), and soil EC by EC-meter (4510, Jenway, England). Total nitrogen was measured using a Kjeldahl method (V50), soil phosphorus by a spectrophotometer (DR 5000), and available potassium by a flame photometer (Jenway PFP7). The amount of soil organic carbon was calculated by the combustion method (Park et al. 2017).

The completely rotten manure used in this study was prepared from Ferdowsi University of Mashhad, Iran. The applied biochar was a mixture of eucalyptus, poplar, and ironwood chips prepared at 500 ° C at

Tarbiat Modares University, Faculty of Natural Resources and Marine Sciences, Noor city, Iran. Some samples of manure and biochar were analyzed before the experimental treatment.

2.3 Preparing soil samples and planting seeds

To simulate the soil in terms of texture and salinity to natural habitat soil characterized by a clay-sandy loam texture and an EC of 1800 dS/m, soil samples were moistened to field capacity and maintained at this constant moisture content for 15 days. Then biochar and manure were added to each soil sample with three replicates at the level of 1% (10 g amendment per 1 kg of soil). Soil samples were mixed well for each pot to ensure that soil conditions were homogeneous in all parts. Seeds of *S.persica* and *S.perspolitana* were purchased from Ala-Ava-Gen Company in Tehran, Iran.

2.4 Plant cultivation

At the end of the soil contamination period and adding manure and biochar to the contaminated soil, several 12 seeds of *salicornia* were planted at a depth of 0.5 cm in each pot. After one month of planting, because of lack of proper germination of seeds in contaminated soil, the seedlings of *S. persica* and *S. perspolitana* were replanted in a mixture of coco peat and perlite (1: 1) in a growth chamber with a temperature between 25–30 ° C and a photoperiod of 16 h of light and eighth of darkness. Hoagland solution (containing nutrients) was used every two weeks in the early stages of growth. After five months, seedlings of the same size were selected and transferred to the treated soil in the pots. The seedlings of the two species of *S. persica* and *S. perspolitana* were harvested after six months of growth. After harvesting, the roots and shoots were washed first with drinking water and then with distilled water. Figure 1 depicts some of the steps involved in *Salicornia* planting and harvesting. Experimental treatments included plant species (2 levels) and soil amendments at three levels (manure, biochar, and control) with a total number of experimental units (number of pots) of 18.

2.5 Analytical methods

To determine heavy metals in soil, fertilizer, and biochar, the first 1 g of them with a ratio of (3:1) hydrochloric acid 37% and nitric acid 70% were mixed and stirred for 12 hours at room temperature. Then, the initial acid digestion content was placed in a heater for 3 hours at 130°C. The final solution was passed through filter paper (Alghanmi et al. 2015). Concentrations of heavy metals including iron, aluminum, and copper were determined by inductively coupled plasma optical emission spectrometry (ICP-OES, model SPECTRO ARCOS-76004555). The functional groups of biochar were determined using Fourier-transform infrared spectroscopy (FTIR) (model AVATAR 370, Thermo Nicolet, USA). A completely randomized factorial design with three replicates was applied to evaluate the results of this study. Statistical analysis of data, including ANOVA and mean comparison of the major and interaction effects with Tukey test at the significance level of 0.05, were performed using Minitab 16 software. Graphs were obtained using Excel software.

3. Results And Discussion

3.1 Physical and chemical properties of the soil, manure, and biochar

The physical and chemical parameters of soil and additives are presented in Table 1. The soil studied in this investigation was characterized by heavy texture (Sandy clay loam soil), low salinity (EC of 1.8 dS/m), and approximately alkaline pH (8.14) with an organic carbon content of 2.56%. The manure contained high organic carbon content of 56% with total nitrogen, phosphorus, and potassium values of 2.95%, 0.62%, and 0.94%, respectively. For biochar, the values of carbon, hydrogen, nitrogen, oxygen, and sulfur were 73.41%, 2.71%, 0.37%, 23.51%, and 0%, respectively. The results of the elemental analysis indicated that most biochar is composed of carbon and oxygen.

Table 1
Physical and chemical properties of soil and amendments.

Physical and chemical properties	Soil	Manure	Biochar
Soil texture	Sandy clay loam	-	-
Sand (%)	62	-	-
Clay (%)	23	-	-
Silt (%)	15	-	-
Organic carbon (%)	2.56	56	73.41
EC (dS/m)	1.8	7.03	934
pH	8.14	7.97	7.73
Total nitrogen (%)	0.032	2.95	0.37
Available phosphorus (%)	0.0013	0.62	0.048
Available potassium (%)	0.0127	0.94	0.34
Total Sodium (%)	-	0.48	0.16
Total Calcium (%)	-	2.3	0.60
Cation exchange capacity	8.1	-	-
Metals			
Fe (mg/kg)	34549.9	5272.41	1072.55
Al (mg/kg)	18254.8	2042.95	211.99
Cu (mg/kg)	30.84	43.74	5.680

3.2 Biochar surface properties and micromorphology

Active factor groups at the biochar surface were determined using FTIR spectroscopy (Fig. 2). Heavy metals are absorbed on the surface or inside the cavities of biochar which prevents the diffusion of these contaminants. The peaks observed at 3425 cm^{-1} indicate strong tensile vibrations between the hydroxyl (O-H) groups of the water molecule or the phenolic groups (Liu et al. 2018). The band observed in 3033 cm^{-1} belonged to the aliphatic-CH₂ functional groups (Bandara et al. 2017). The band 1591 cm^{-1} shows the aromatic C = C bond and -COO- (Yang et al. 2016). Moreover, the band for aromatic C = O (carbonyl) was found in 1431 cm^{-1} (Meier et al. 2017)[21]. Also, 751, 813, and 874 cm^{-1} represent the aromatic CH group (Song et al. 2012). In addition, the band 1230 cm^{-1} belonged to the CO-aromatic and OH-phenolic groups (Dong et al. 2017).

3.3 Effect of manure and biochar on soil pH and EC

Figure 3 represents the effect of manure and biochar on soil pH and EC in the two species of *S.persica* and *S.perspolitana*. According to these results, the highest values of pH and EC in the soil were found for *S. persica* in biochar treatment with corresponding values of 8.77 and 385.3 dS/m, respectively. In addition, the lowest values of pH and EC in the soil were observed for *S. perspolitana* in biochar treatment with values of 8.39 and 237.3 dS/m, respectively.

The findings revealed that applying biochar and manure did not affect soil pH. Similar results were reported by Ozlu and Kumar (2018). They showed that manure application did not affect soil pH significantly increasing EC. Wei et al. (2011) used chicken manure to improve the phytoextraction of cadmium by *Rorippa globosa* and discovered that it did not significantly change the soil pH. Some salts are added to the soil because of organic matter, depending on the chemical composition. Several studies, including Hamza (2010), Smith et al. (2001), and Walker and Bernal (2008), have reported soil salinity due to the application of animal manure or compost.

Soil pH affects the bioavailability of metals to plants and controls the processes like uptake, excretion, and chemical forms of metals in the soil (Ashraf et al. 2017). There is a negative correlation between soil pH and mobility of heavy metals in soil and bioavailability of metals to plants so that at higher pH values ($\text{pH} > 8$), metals are sequestered within the soil matrix (Shahid et al. 2012). In general, metals are characterized by high solubility, high mobility, and bioavailability at low pH values and vice versa. The remediation process is facilitated by adding acidic agents to the soil so that the bioavailability of metal to plant roots is increased (Singh et al. 2015). Metal cations in acidic conditions are of the highest mobility metal anions are released into the soil solution due to compete for H⁺ ions. At high pH values, cations are sequestered or adsorbed to mineral surfaces and metal anions. At neutral or alkaline pH values, most of the metals in the soil are not available to plants (Chukwuma Sr 2014). Lowering the soil pH could increase competition between H⁺ and dissolved metals for ligands such as S²⁻, OH⁻, Cl⁻, So₄²⁻, CO₃²⁻ and phosphates. This increased competition would result in reduced adsorption capacity of metals in soil particles and lead to increased mobility of heavy metals and ultimately increased bioavailability of metals in soil particles (Mkumbo et al. 2012).

In the present study, biochar caused an increase in soil pH and EC. This increase in soil pH in biochar-amended soils has been widely reported in previous studies (Abujabhah et al. 2016; Bashir et al. 2018). Biochar leads to an increase in pH value because of having the highest amount of oxygen-containing functional groups. These amendments are mostly made from wood raw materials, which generally have a high percentage of cations (Na^+ , Ca^{2+} , Mg^{2+} , K^+). During the decomposition process, these cations form carbonates, oxides, and hydroxides and cause an increase in soil pH (Houben et al. 2013). Increased soil EC has also been reported in previous studies (Fellet et al. 2011; Lu et al. 2014). Soil EC in biochar treated soil indicates salinity due to sodium, magnesium, calcium, and carbonate in this amendment (Yadav et al. 2016). Biochar affects the physical and chemical properties of the soil. Nigussie et al. (2012). Studied the effect of biochar on soil properties and nutrient uptake by lettuce (*Lactuca sativa*) and showed that biochar caused increases in soil pH, EC, organic carbon, total nitrogen, available phosphorus, and cation exchangeable capacity. Increased soil pH due to biochar application has been reported by many authors, namely Duku et al. (2011) and Cao and Harris (2010). Beesley et al. (2010) showed that the application of biochar resulted in reduced bioavailability of metals, mainly due to the increase in soil pH, which serves as a factor decreasing the availability of metals in the soil, confirming the results of the present study. According to other authors, one reason for increased soil EC due to the use of organic fertilizers (manure and biochar) may be an increased in calcium, magnesium, and potassium resulting from the decomposition of these organic compounds (Courtney and Mullen 2008).

3.4 The effect of manure and biochar on the heavy metal accumulation

3.4.1 Aluminum

Figure 4 shows the results of the mean comparison of the interaction effect of manure and biochar on the aluminum accumulation in the roots and shoots of *S.persica* and *S.perspolitana*. According to these results, the effect of biochar and manure on the accumulation of aluminum in the roots and shoots of the two species was significant at a confidence level of 95%. The organic compounds (manure and biochar) used in this study positively affected the accumulation of aluminum in the roots and shoots of the two species. Accumulation of aluminum in the roots of *S.persica* increased by 21.33% and 77.10% and in the roots of *S.perspolitana* by 26.8% and 28.3% in biochar and manure treatments, respectively, compared to the control (without amendment). Also, the aluminum accumulation in the shoot of *S.persica* increased by 69.3% and 94.4%, and in the shoots of *S. perspolitana* by 8.9% and 13.4%, in the biochar and manure treatments, respectively, compared to the control (without amendment).

3.4.2 Iron

Figure 5 shows the results of the mean comparison of interaction effects of manure and biochar on the accumulation of iron in the roots and shoots of *S.persica* and *S. perspolitana*. According to these results, the effect of biochar and manure on the accumulation of iron in the roots and shoots of the two species was significant at a confidence level of 95%. Biochar treatment harmed the iron accumulation in roots and shoots in both studied species. The decreases in iron accumulation in the root and shoot were found

to be 31.18% and 39.32% for *S. persica* and 25.66% and 0.05% for *S. perspolitana* compared to control (without amendment), respectively. On the other hand, manure treatment positively affected the accumulation of iron in roots and shoots in both species with increases in root and shoot by 24.99% and 2.30% in *S. persica* and 3.40% and 4.02% in *S. perspolitana*, respectively, compared to the control (without amendment).

3.4.3 Copper

Figure 6 shows the results of the mean comparison of interaction effects of manure and biochar on the accumulation of copper in the roots and shoots of *S. persica* and *S. perspolitana*. The organic compounds (manure and biochar) used in this study negatively influenced the accumulation of copper in the roots and shoots of the two studied species. In biochar and manure treatment, accumulation of copper in roots decreased by 13.66% and 6.40% in *S. persica* and by 5.2% and 1.4% in *S. perspolitana*, respectively, compared to the control. Also, the accumulation of copper in shoots in biochar and manure treatments decreased by 12.5% and 5.5% in *S. persica* and by 17.5% and 12.4% in *S. perspolitana*, respectively, compared to the control.

The findings of this study are consistent with those of other studies on the *Salicornia* species that have been published. For example, Kaviani et al. (2019) investigated the remediation of nickel-contaminated soil by *S. iranica*. Their findings showed that the nickel concentration increased in plant tissues as its concentration in soil significantly increased. Similar results were reported for lead accumulation with mentioned above species. In other words, at 1000 mg/kg lead in soil, the maximum absorption rate and concentration in *Salicornia* shoot tissues were observed (Kaviani et al. 2017). Besides, Khanlarian et al. (2020) stated that *S. europaea* has a great capacity to accumulate zinc, lead, nickel, and cadmium in its tissues. Also, Mesa-Marín et al. (2020) demonstrated that *S. ramosissima* could accumulate significant arsenic, cadmium, copper, nickel, lead, and zinc at its root.

The results of the present study showed that biochar and manure as amendments would lead to increased plant growth and thus increased root and shoot dry weight in both species. On the other hand, organic matter and biochar reduced the accumulation of metals in plants. COO- functional groups in solid and soluble organic matter form stable complexes with metals. Therefore, the possibility of forming stable complexes of organic matter and metal increases with increasing the amount of organic matter in the soil (Reichman 2002). Plants can not absorb large metal complexes, so the bioavailability of metals to plants would be reduced by adding organic matter to the soil. The presence of organic matter also could increase soil cation exchangeable capacity; as a result, nutrients are absorbed by plants. An increase in soil organic matter leads to decreased uptake of heavy metals by plants. Soils with relatively low organic matter concentrations are exposed to trace element contamination. Rehabilitation of soils contaminated with heavy metals using organic matter would reduce the availability of metals to plants (Laghlimi et al. 2015). According to the results of the present study, the growth rate of the two studied species increased by applying biochar and manure treatments. In general, organic compounds could improve soil organic carbon, crop productivity, and soil quality (Lehmann et al. 2009).

3.5 Determining TF, BCF, BAC indices

The potential of plants for remediation was assessed after heavy metal concentrations in the plants, and soil samples were determined. Some indices, such as TF, BAC, and BCF, can be used for this purpose. TF "translocation factor" refers to the ratio of metal content in plant shoots to root concentration. The bioconcentration factor (BCF) is a ratio of metal concentration in plant roots to soil metal concentration. BAC stands for biological accumulation coefficient, which is the ratio of metal concentration in plant shoots to soil metal concentration. TF index greater than one and BAC values greater than one indicate that these plants are suitable for remediation of contaminants. Plants with a TF value are lower than one, but a BCF value higher than one is suitable for the phytostabilization process (Yoon et al. 2006). The results of the effect of the studied treatments on the accumulation of metal (Tables 2, 3, 4) show that the TF index for heavy metals was lower than 1 in all treatments confirming the phytostabilization ability of *S.persica* and *S.perspolitana*.

Table 2
Results of Mean comparison of TF, BCF and BAC indices related to aluminum in *S.persica* and *S.perspolitana*

BCF	BAC	TF	amendments	Species
0.12	0.003	0.02	control	<i>S.persica</i>
0.15	0.0057	0.037	biochar	
0.22	0.0066	0.029	manure	
0.16	0.0056	0.034	control	<i>S.perspolitana</i>
0.210	0.0062	0.029	biochar	
0.213	0.0064	0.03	manure	

Table 3
Results of mean comparison of TF, BCF and BAC indices related to iron in *S.persica* and *S.perspolitana*

BCF	BAC	TF	amendments	species
0.12	0.0046	0.036	control	<i>S.persica</i>
0.08	0.0027	0.032	biochar	
0.157	0.0047	0.030	manure	
0.158	0.0054	0.0343	control	<i>S.perspolitana</i>
0.11	0.0054	0.046	biochar	
0.16	0.0056	0.0345	manure	

Table 4
Results of mean comparison of TF, BCF and BAC indices
related to copper in *S.persica* and *S.perspolitana*

BCF	BAC	TF	amendments	species
3.03	0.4247	0.13	control	<i>S.persica</i>
2.6	0.37	0.141	biochar	
2.8	0.4009	0.141	manure	
2.29	0.48	0.21	control	<i>S.perspolitana</i>
2.17	0.4003	0.184	biochar	
2.25	0.4249	0.188	manure	

The phytoremediation results showed that both *S.persica* and *S.perspolitana* could absorb heavy metals from the soil with higher uptake of metals in the roots of both species compared to shoots. Considering that the TF index was not higher than 1 for any of the treatments, it can be concluded that *S.persica* and *S.perspolitana* are not capable of extracting of aluminum, iron, and copper from the soil. These results agree with Khanlarian et al. (2020), which showed that the *S. europaea* had TFs of more than one for zinc. Plant species that have commonly been used to stabilize heavy metals include *Agrostis tenuis* (zinc and copper), *Zygophyllum fabago* (zinc and copper) (Ghosh and Singh 2005), which are consistent with findings of the present study. In addition, the BCF factor for copper was higher than one and for aluminum and iron was lower than one. The BCF amounts confirm that *S.persica* and *S.perspolitana* can be a hyper-accumulator plant for copper and a moderate accumulator for aluminum and iron. Khanlarian et al. (2020)'s study also proved that *S. europaea* could almost be a moderate accumulator for zinc according to the BCF levels.

Manure and biochar have caused changes in remediation indices for various heavy metals. For aluminum and iron, with the addition of biochar and manure, the amount of BCF and BAC increased significantly while copper was reduced. In other words, concentrations of iron and aluminum in the plant tissues (root and stem) were increased with fertilization. The effect of organic amendments on heavy metals accumulation in plant tissue varies depending on plant species, organic amendments, and metal type (Medyńska-Juraszek et al. 2020). Medyńska-Juraszek et al. (2020) also found that compost application increased the accumulation of copper in spinach and dill, whereas biochar application frequently reduced the content of trace elements in tissues.

Using phytoremediation methods, contaminants are prevented from entering the groundwater, and also wind erosion is reduced due to the presence of plant roots. In areas with high concentrations of contaminants, this process may be impaired due to its high toxicity, and in these conditions, the addition of organic compounds such as fertilizers, compost, etc., into the soil is recommended. Phyto-extraction involves the uptake of contaminants (primarily metals) from the soil by plant roots and transferring these metals to plant shoots for accumulation. This process is the most efficient remediation method for removing heavy metals from the soil. Sublimation uses plants to absorb organic and inorganic

contaminants from water and soil and transfer them as steam to the atmosphere. This method does not remove contaminants from the environment but transfers them to the air through soil and water. Therefore, this method is recommended to prevent the spread of contaminants into soil and groundwater (Chibuike et al. 2014).

4. Conclusions

The goal of this study was to see how much aluminum, iron, and copper could bioaccumulate in the shoots and roots of *S.persica* and *S.perspolitana*. *Salicornia*'s bioaccumulation performance for the above-mentioned components was also investigated using manure and biochar as soil amendments. The results showed that the accumulation rate of these metals in the roots of both *S.persica* and *S.perspolitana* species was higher than the shoots. Metal accumulation in the roots of *S. perspolitana* was higher than in the roots of *S. persica*. Furthermore, metal deposition in *S. perspolitana* shoots was higher than *S. persica*. Biochar and manure had different effects on the accumulation of iron and aluminum metals in the roots and shoots of *S.persica* and *S.perspolitana*. In general, biochar treatment had a significant impact on lowering heavy metal accumulation than manure treatment. Therefore, these kinds of soil amendments can assist to immobilize metals in the soil and prevent them from entering the plant.

Declarations

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Informations

- The authors confirm that the data presented in the manuscript are available
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Figures



Figure 1

Representative photos of *Salicornia* (a) seed, (b) green seedlings in cultivation tray, (C) plant grown in contaminated soil, and (C) plant after harvesting.

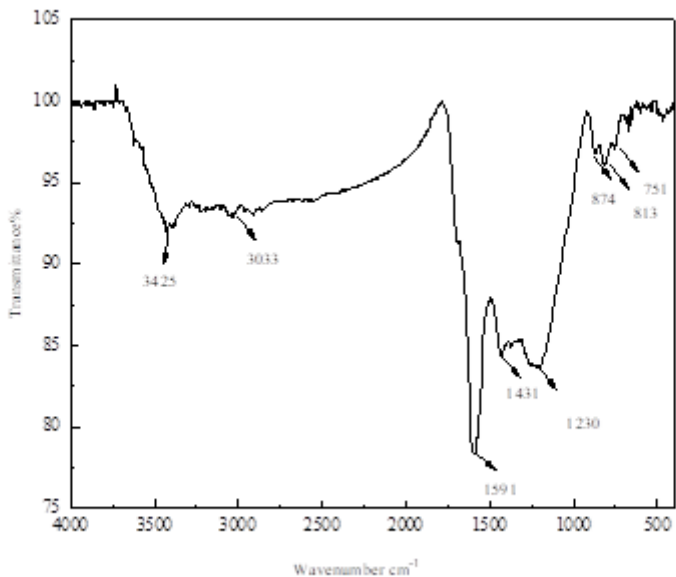


Figure 2

The Infrared Spectrum (FTIR) of Biochar

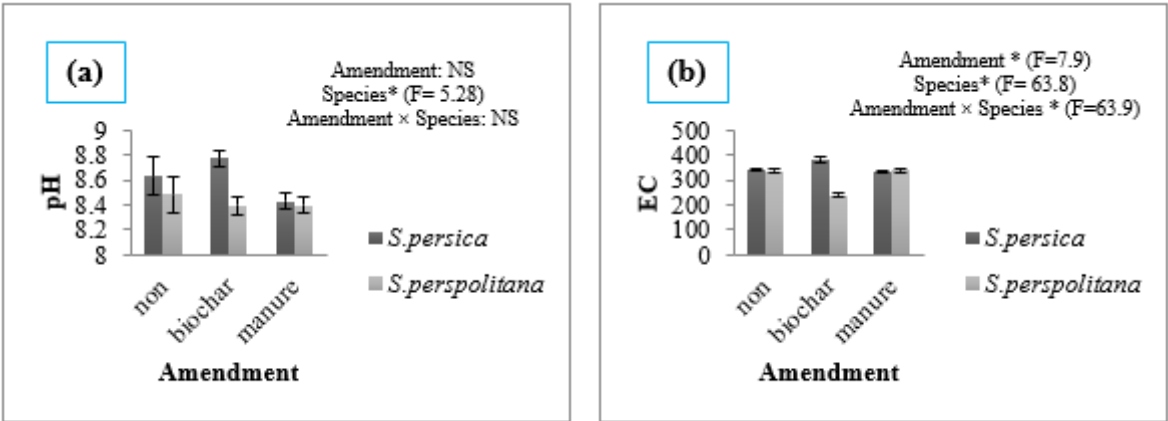


Figure 3

The effect of soil amendment and species on (a) soil pH and (b) soil EC. Error bars represent the standard deviation of the means. The asterisk (*) denotes the significance of the effect ($p < 0.05$), while F values denote the magnitude of the effect.

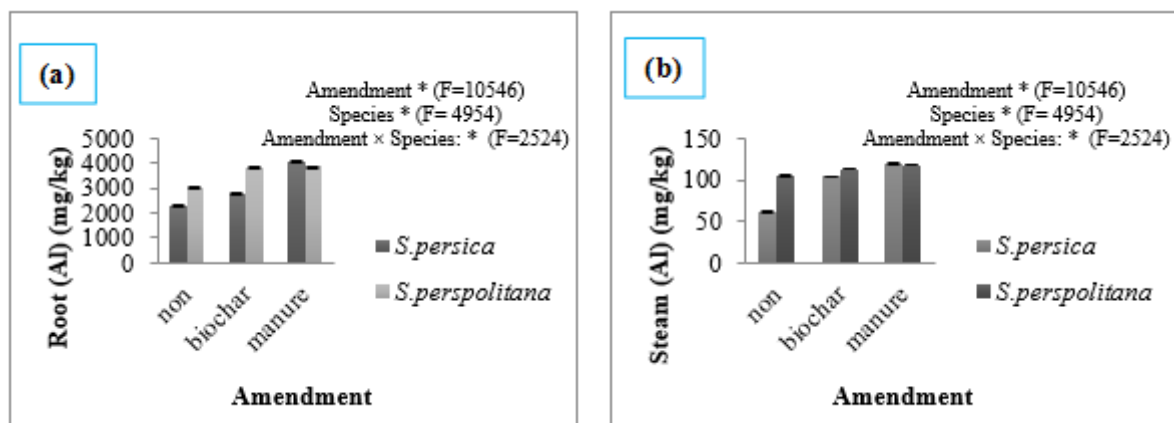


Figure 4

The effect of soil amendment and species on the accumulation of aluminum in (a) the roots and (b) the shoots. Error bars represent the standard deviation of the means. The asterisk (*) denotes the significance of the effect ($p < 0.05$), while F values denote the magnitude of the effect.

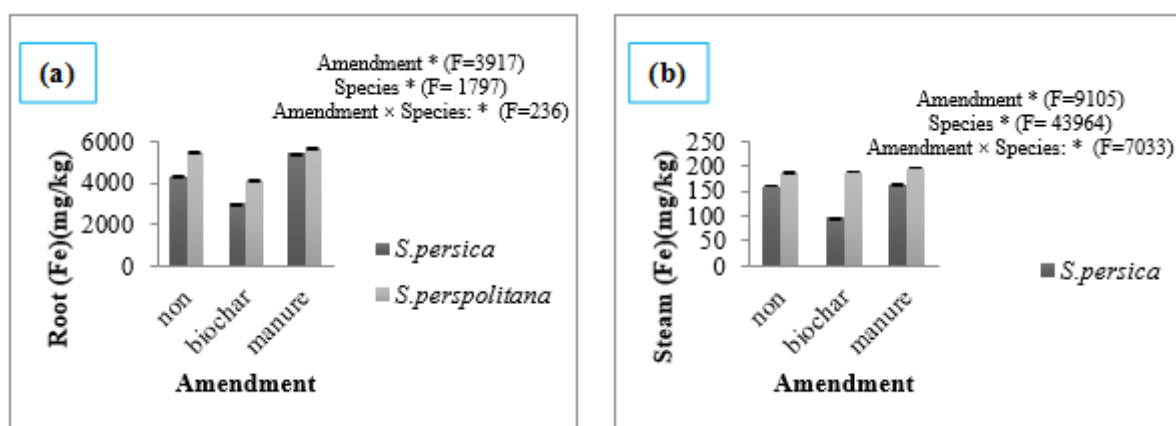


Figure 5

Effect of soil amendment and species on the accumulation of iron in (a) the roots and (b) the shoots. Error bars represent the standard deviations of the means. The asterisk (*) denotes the significance of the effect ($p < 0.05$), while F values denote the magnitude of the effect.

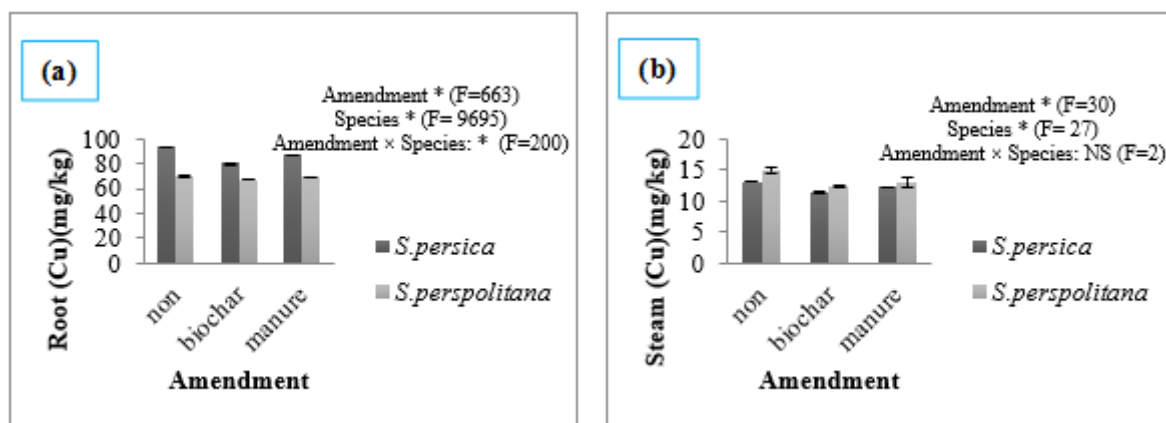


Figure 6

The effect of soil amendment and species on the accumulation of copper in (a) the roots and (b) the shoots. Error bars represent the standard deviations of the means. The asterisk (*) denotes the significance of effect ($p < 0.05$), while F values denote the magnitude of the effect.