



Article

Performance of *Medicago sativa* Grown in Clay Soil Favored by Compost or Farmyard Manure to Mitigate Salt Stress

Sonia Mbarki ^{1,2,*} , Milan Skalicky ^{1,*} , Ons Talbi ³, Amrita Chakraborty ⁴, Frantisek Hnilicka ¹ , Vaclav Hejnak ¹ , Marek Zivcak ⁵, Marian Brestic ^{1,5} , Artemi Cerda ⁶ and Chedly Abdelly ³

¹ Department of Botany and Plant Physiology, Faculty of Agrobiological Sciences, Czech University of Life Sciences Prague, Kamycka 129, 165 00 Prague, Czech Republic; hnilicka@af.czu.cz (F.H.); hejnak@af.czu.cz (V.H.); marian.brestic@uniag.sk (M.B.)

² Laboratory of Valorisation of Unconventional Waters, National Institute of Research in Rural Engineering, Water and Forests (INRGREF). BP 10, Ariana 2080, Tunisia

³ Laboratory of Plant Extremophiles, Biotechnology Centre at the Technopark of Borj-Cedria Tunisia. BP 901, Hammamlif 2050, Tunisia; onstalbi_zribi@yahoo.fr (O.T.); abdelly.chedly@gmail.com (C.A.)

⁴ Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamycka 129, 165 00 Prague, Czech Republic; chakraborty@fld.czu.cz

⁵ Department of Plant Physiology, Slovak University of Agriculture, Nitra, Tr. A. Hlinku 2, 94901 Nitra, Slovak Republic; marek.zivcak@uniag.sk

⁶ Soil Erosion and Degradation Research Team, Department of Geography, University of Valencia, 46003 Valencia, Spain; artemio.cerda@uv.es

* Correspondence: mbarkisonia14@gmail.com (S.M.); skalicky@af.czu.cz (M.S.); Tel.: +420-224-382-520 (M.S.)

Received: 10 November 2019; Accepted: 3 January 2020; Published: 9 January 2020



Abstract: The use of saline water for the irrigation of forage crops to alleviate water scarcity has become necessary in semi-arid and arid regions and researchers have been seeking ways to offset the harmful results of soil salinity. Soil amendments with compost, manure and other organic material provide a valuable source of plant nutrients and appear to speed up soil recovery. The aim of this study was to compare the benefits of farmyard manure and a municipal solid waste (MSW) compost (40 mg ha⁻¹) for raising alfalfa (*Medicago sativa*, cv. Gabès) under salt-water irrigation. Both compost and manure improved plant mineral uptake and growth of alfalfa cultivated in clay soil. Using compost in clay soil increased the content of copper (Cu), cadmium (Cd), and zinc (Zn) in plant tissues compared to manure, while the bio-accumulation factor (BAF) of Cu, Pb and Zn was higher in plants grown with manure compared to MSW compost with salt stress. Compost addition could enhance alfalfa growth under salt stress, which depends on salt doses and can greatly improve the recovery effects in a cost-effective way, although additional amendment type should receive special attention in order to be used as a tool for sustainable agriculture.

Keywords: alfalfa; salinity; MSW compost; farmyard manure; nutrient content; heavy metal bioaccumulation

1. Introduction

Deforestation, soil erosion, loss of biodiversity, loss of soil fertility and salt accumulation on the soil surface are major causes of crop land degradation [1,2] that require close attention for achieving food security [3–5]. Soil salinization is one of the greatest concerns affecting crop production worldwide [6] and the salinity problem in sustainable development has been highlighted in developing viable plans for sustainability [7]. The use of saline groundwater for irrigation is a significantly disputed point in

semi-arid and arid regions due to the scarcity of rain during the summer. There is an urgent need to properly manage the water resources [8] and to develop sustainable ways for agriculture to reach the demands of an ever-rising population [9].

The poor quality and insufficiency of water available for irrigation seriously affects soil fertility and the crops grown there, leading to a decrease in agricultural productivity. Salty groundwater has become a continuous threat to sustainable agriculture in many regions [10]. Over the last 45 years, about 6% of the total land use across the globe has been affected by salinity [11].

A semi-arid climate in the Mediterranean area, together with insufficient capacity and inappropriate quality of water resources contribute to the rate of soil degradation and prevention of its recovery [12,13]. Another key environmental problem is the heavy metals that affect the earth [14,15]. Given the continued worldwide expansion of salt-affected lands, more recent needs to focus on soil bioremediation with organic materials like compost, manure and plants as alfalfa with deep roots that can absorb and remove heavy metal. Salinity negatively affects the soil's biological, chemical and physical properties resulting in loss of soil fertility, which in turn reduces crop productivity [16]. However, salinization can be managed by the proper use of soil amendments and better irrigation practices to optimize the use of water resources [17]. Crop yields in arid regions have significantly declined as a result of the loss of organic matter in soil. Application of green manures and municipal solid waste (MSW) compost can reduce negative effects and increase the carbon content and productiveness of saline soils [16,18]. Amendment of organic matter to remediate saline-sodic soils is increasingly considered to be a cost-efficient and more sustainable alternative to the application of expensive inorganic materials [19]. Saline soils generally have low organic matter and nitrogen (N), and in semi-arid and arid regions, the low quality of water and agricultural practices have influenced the sustainability of irrigation systems by reducing soil quality and fertility, causing significant farmland degradation and decline in plant productivity [20]. Increased research is needed to attain agricultural sustainability in such regions [21].

With regard to sustainable agriculture in salt-affected soils, two approaches can be chosen: planting salt-tolerant crops or using salt-specific soil recovery methods [22]. Various organic amendments such as garden compost, green manure, farmyard manure and municipal solid waste compost have been applied to the soil to enhance soil quality and crop yields. The effectiveness of composts has been assessed in the bioremediation of soil and increase of crop yield under salt stress conditions [16,23]. MSW compost has the potential to reduce dependency on expensive chemical fertilizers and increase crop yield in saline soils [24]. MSW compost from different origins and farmyard manure have been tested and found to be eminently suitable as soil additives [19].

Apart from its effectiveness in soil remediation and crop productivity, the phytotoxicity of organic soil amendments needs to be analysed to ensure their safe use in crop production systems under saline irrigation [24]. The successful use of MSW compost as an organic amendment is influenced by heavy metals content or organic contaminants. It is necessary to streamline their timing and application level to avoid further land degradation. The rehabilitation of salt-degraded soils is a promising strategy in combination with the introduction of various native perennial plant species and soil organic amendments addition. In arid and semi-arid regions, legumes are applied for the stabilization of loose soil and because of their nitrogen fixing abilities [25,26]. Several indigenous species of legumes for direct sowing have been reintroduced as a solution preventing soil erosion [27].

The application of organic fertilizer as MSW compost provides an effective and efficient low-cost approach using the recycling of available organic waste to eliminate the toxic effects of salt accumulated in the soil. On the other hand, excessive application of farmyard manure or some other organic amendments can lead to the secondary accumulation of salts in regions with abundant rainfall. These aspects need to be considered when selecting the doses and types of amendments to apply. In this study, we have presented the results of a pot experiment, where we investigated the results of the addition of manure and MSW compost to clay loam soil on the settlement of salt-tolerant alfalfa (*Medicago sativa* L.) in a saline soil by the selection of appropriate organic amendments. We also

evaluated the environmental hazard of compost-soil heavy metal using agriculture clay soil under a salt condition by assessing the heavy metals bioaccumulation in alfalfa.

2. Materials and Methods

2.1. Experimental Setup

The collection of clayey, loamy soil was performed in the Mornag region in the North East of Tunisia (36°40'45.52" N, 10°17'31.02" E) (0–20 cm deep). The soil was collected just before cultivation and after harvesting and sieved at 2 mm. The MSW compost was obtained using a mixture of separated and shredded organic material from garden waste and household rubbish by aerobic fermentation. The pilot composting station was located in Beja, approximately 100 km west of Tunisia. The cow manure used in the experiment originated from the research agriculture station in the region of Mornag, Tunisia. Table 1 lists the characteristics of compost (Co), manure (M), and clay soil (C). We also checked the inorganic contaminants in the plants as a result of different management, which is a main risk when you add organic amendments. Two weeks after sowing, the stepwise addition of 50–100 mM NaCl to the essential nutrient solution started. The following treatments were performed in six replicated pots: (1) clay soil irrigated with distilled water (C); (2) clay soil supplied with 50 mM NaCl solution (C + S1); (3) clay soil irrigated with 100 mM NaCl solution (C + S2); (4) clay soil amended with MSW compost and supplied with distilled water (Co); (5) clay soil amended with MSW compost and supplied with 50 mM NaCl solution (Co + S1); (6) clay soil amended with MSW compost and supplied with 100 mM NaCl solution (Co + S2); (7) clay soil amended with farmyard manure and irrigated with distilled water (M); (8) clay soil amended with manure and supplied with 50 mM NaCl (M + S1); and (9) clay soil amended with manure and irrigated with 100 mM NaCl solution (M + S2).

Table 1. The characteristics of clay soil, farmyard manure (M), and municipal solid waste compost (MSWC). Data are means of three repeats \pm SE. Nd = not determined.

| | Clay Soil | Farmyard Manure | MSW Compost |
|------------------------------|--------------------|---------------------------------|---------------------------------|
| Clay (%) | 34.9 | Nd | Nd |
| Silt (%) | 23.7 | Nd | Nd |
| Sand (%) | 39.8 | Nd | Nd |
| pH | 8.27 \pm 0.01 | 7.70 \pm 0.23 | 8.12 \pm 0.01 |
| CE ($\mu\text{s cm}^{-1}$) | 305.33 \pm 13.37 | (3.43 \pm 0.44) $\times 10^3$ | (8.18 \pm 0.22) $\times 10^3$ |
| N (g kg ⁻¹) | 1.06 \pm 0.05 | 14.26 \pm 0.33 | 13.2 \pm 1.02 |
| P (g kg ⁻¹) | 1.36 \pm 0.08 | 14.3 \pm 1.01 | 17.05 \pm 0.07 |
| K (g kg ⁻¹) | 0.51 \pm 0.03 | 6.85 \pm 0.02 | 7.2 \pm 0.02 |
| C (g kg ⁻¹) | 11.09 \pm 1.03 | 149.6 \pm 0.53 | 143.35 \pm 3.12 |
| C/N | Nd | 10.64 | 10.43 |
| Zn (mg kg ⁻¹) | 109.07 \pm 1.12 | 166.33 \pm 0.38 | 384.20 \pm 28.4 |
| Cu (mg kg ⁻¹) | 50.56 \pm 0.43 | 45.35 \pm 0.13 | 90.54 \pm 8.08 |
| Pb (mg kg ⁻¹) | 42.58 \pm 0.96 | 56.54 \pm 0.30 | 112.72 \pm 2.5 |
| Cd (mg kg ⁻¹) | 3.83 \pm 0.1 | 4.62 \pm 0.31 | 11.66 \pm 0.04 |

2.2. Physicochemical Properties of Soil, Compost and Manure

The organic matter, N content, and concentration of several ions in soil and compost extracts were determined. The pH and EC (electrical conductivity) of the soil and compost suspension were measured. Sodium (Na) and potassium (K) were extracted, and the proportioning of the ions was carried out on the filtrate by flame spectrophotometry with a standard Corning photometer. Total nitrogen (N) was determined by the Kjeldahl method. Cu, Pb, Cd and Zn (see Table 1) were extracted using fluorhydric and nitric acids and the concentrations were assessed by atomic absorption spectrophotometry (Perkin-Elmer 3110) [28,29].

2.3. Plant Material, Growing Conditions and Sampling

The study was realized as a pot experiment in a greenhouse at an experimental station in Mornag, Tunisia. Seeds of alfalfa (*Medicago sativa* L.), cultivar Gabès, were sowed in containment pots with 2 kg of clayey loamy soil with or without the addition of manure or compost with the doses corresponding to 40 mg ha⁻¹ and supplied with water to reach 66% of the field capacity along with the addition of 0, 50 and 100 Mm NaCl. The amendments were applied before sowing. The aboveground biomass was cut every 40 days. The soil water status was assessed by the gravimetric method. The weight of pots was controlled every two days and the pots were watered manually to 66% of water holding capacity (field water capacity). Alfalfa shoots and roots were collected 40 days after sowing. Plant samples were dried at 60 °C, crushed, and demineralized with nitric acid 0.5% to determine the P, K and Na content. The determination of ion content was performed by the flame, spectrophotometry analysing the standard photometer corning analysing the filtrate of the product of the extraction. The proportioning of P was carried out by colorimetry, on the vegetable extracts decolorized by activated charcoal according to the method of Fleury and Lederer [30].

The determination of concentration of heavy metal content (Zinc (Zn), Lead (Pb), Copper (Cu), and Cadmium (Cd)) was performed, as well. The dried samples of plant shoots and roots were ground into a powder. From each sample, 500 mg was added into the mix containing 2 mL of concentrated HCl (30%) and 6 mL of concentrated HNO₃ (65%). The digestion of the samples was performed in an autoclave for 66 min at 132 °C and the product was determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICPE-9000, Shimadzu, Japan).

The bioaccumulation factors (BAF of shoots) of Zn, Cu, Cd and Pb were calculated as:

BAF = Cshoot/Csoil [31]. Csoil and Cshoot represented the metal concentrations in the soil (mg kg⁻¹) and the plant shoots (mg kg⁻¹), respectively.

2.4. Statistical Analysis

Statistical analyses were carried out using SPSS software, v.22. Data were statistically analysed with a one-way ANOVA test, and a comparison of means was performed by Duncan's multiple range test (DMRT) at $p < 0.05$ level indicating significance.

3. Results

The present study demonstrated that MSW compost could be used as a natural solution to intensify plant production in food and fodder plant agriculture and improve soil characteristics [32].

3.1. Plant Biomass Production and Mineral Status

Alfalfa is widely cultivated as a forage crop due to its excellent forage quality characteristics, forage yield potential, and high adaptability. In Tunisia, alfalfa, especially cultivar Gabès, is the most commonly grown legume crop for forage production. Our results revealed the interaction effects of compost amendment and the salinity of irrigation water on plant yield. MSW Compost and farmyard manure amendments increased alfalfa productivity at a similar rate of 40% compared to the control treatment. In the clay soil, we observed a two to three times increase in the alfalfa plant biomass from the first cut to the third cut (Figure 1A). However, saltwater irrigation decreased the yield in this soil. Salt stress was more pronounced at 100 mM NaCl. The percent of DW decrease compared to the control irrigated with distilled water was 55% for the clay soil in variant S2. The irrigation with salty water negatively affected plants due to a reduction in osmosis and increase in ion toxicity [33]. Salt stress and nutritional imbalance affect physiological status and are responsible for harmful effects on plant biomass production [34]. MSW compost increased plant biomass of alfalfa by 40% in soils without salt stress. Reported yields of plant dry weight were always higher than the control, indicating that growth was enhanced in the presence of organic amendments (Figure 1A,B). Plants fed with MSW

compost at 40 mg ha⁻¹ showed approximately equivalent increases on shoot and root productivity compared to manure treatment.

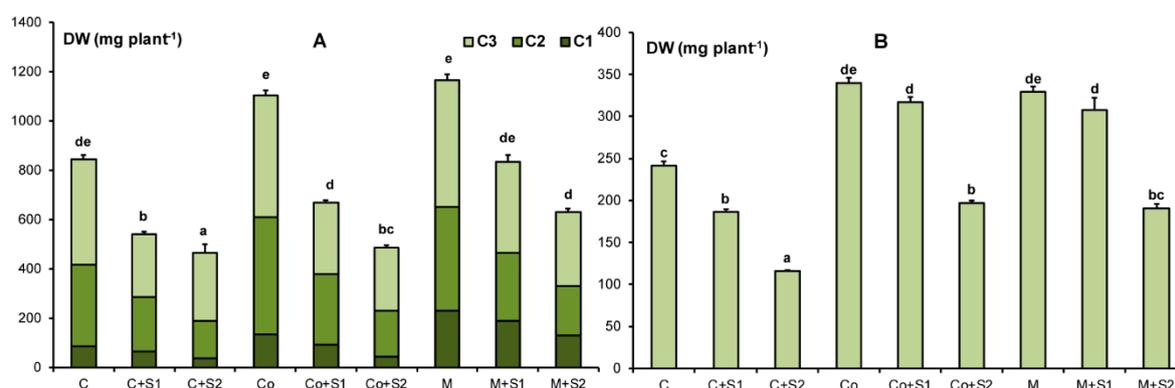


Figure 1. Growth of alfalfa in conditions of clay soil amended or not with MSWC or farmyard manure (40 mg ha⁻¹) and irrigated or not with saline water at (0, 50 mM, 100 mM NaCl). (A) The quantity of aboveground biomass expressed as dry matter per plant (mg plant⁻¹). (B) The quantity of root biomass expressed as dry matter (mg plant⁻¹). C—Control treatment. M—Soil amended with farmyard manure (40 mg ha⁻¹). Co—soil amended with compost (40 mg ha⁻¹). +S1, +S2—variants irrigated with 50 mM NaCl and 100 mM NaCl solution, respectively. C1, C2 and C3 represent three subsequent harvests of above ground biomass done at approximately 40-day intervals. The first harvest (C1) was performed 45 days after sowing. Data are means of six repeats \pm SE. The different letters (abcd) represent a significant difference between treated samples. $p < 0.05$ by Duncan's multiple range test.

Meena et al. [24] found that amendment with organic compost mitigated ion toxicity from saline stress by capturing sodium ions, which were preferentially adsorbed onto clay-humic complexes, while releasing potassium, calcium and magnesium ions from organic matter into the soil solution.

Under saltwater provision, either manure and compost amendments led to an increase in the biomass of alfalfa in the second and third cut, but without significant effect in the first harvest (Figure 1A). In the first year after application, only a fraction of nutrients from manure or compost become available to plants [35]. Kusmiyati et al. [36] found that plant growth was higher with applications of manure to saline soil, and the effect was evident at the second cutting.

Salt stress increased the concentration of N in the aerial parts (Figure 2A), due to factors of dilution of plant production. Compost increased N concentration at high rates of NaCl. Plant shoots showed no significant differences in N for plants grown in the presence of manure with different doses of salt (Figure 2A). The phosphorus (P) content was increased by more than 50% in conditions of salinity and compost amendment, and the increase in P by more than 80% was observed when these two factors were combined (Figure 2B). Application of compost to the saline soil improved soil fertility, which, in turn, enhanced the yield of alfalfa cultivar Gabès and its nutritional status. Available N, P, K, micronutrients, and organic C are the best indicators of soil fertility. Amendment with biological nutrient resources, organic matter management, and slow-release fertilizer are key functions of organic amendments that might be the result of a high level of micro- and macro-nutrients [37]. The type of compost and the rate of compost application are essential factors that affect biomass production [38].

Na content was more accumulated in plant subjected to salt stress depending on the dose of NaCl applied (Figure 2B). The application of compost reduced Na accumulation in plant shoots in contrast to manure treatment at a high dose of NaCl (Figure 2B). Plants exposed to salt stress showed a high accumulation of Na that inhibited the nutrient uptake, particularly N, P, and K [39]. MSW compost amendment significantly enhanced plant growth under non-saline conditions (Figure 1A,B). Mbarki et al. [23] drew attention to the ameliorative effect of urban waste compost fertilizer on the growth of alfalfa plants under salt-water irrigation. As reported by several studies [40] plant development was positively linked with nutrient uptake. K⁺ concentration in shoots was decreased in

variants exposed to salt stress with the addition of either compost or manure treatment (Figure 2B). Massa et al. [41] mentioned that reduced potassium absorption by ornamental plants was foremost due to reduced plant biomass production under long-term saline stress. Moreover, enhanced concentration of potassium in the soil may help to counteract passive Na resulting in enhanced potassium ion flow into the symplast [42].

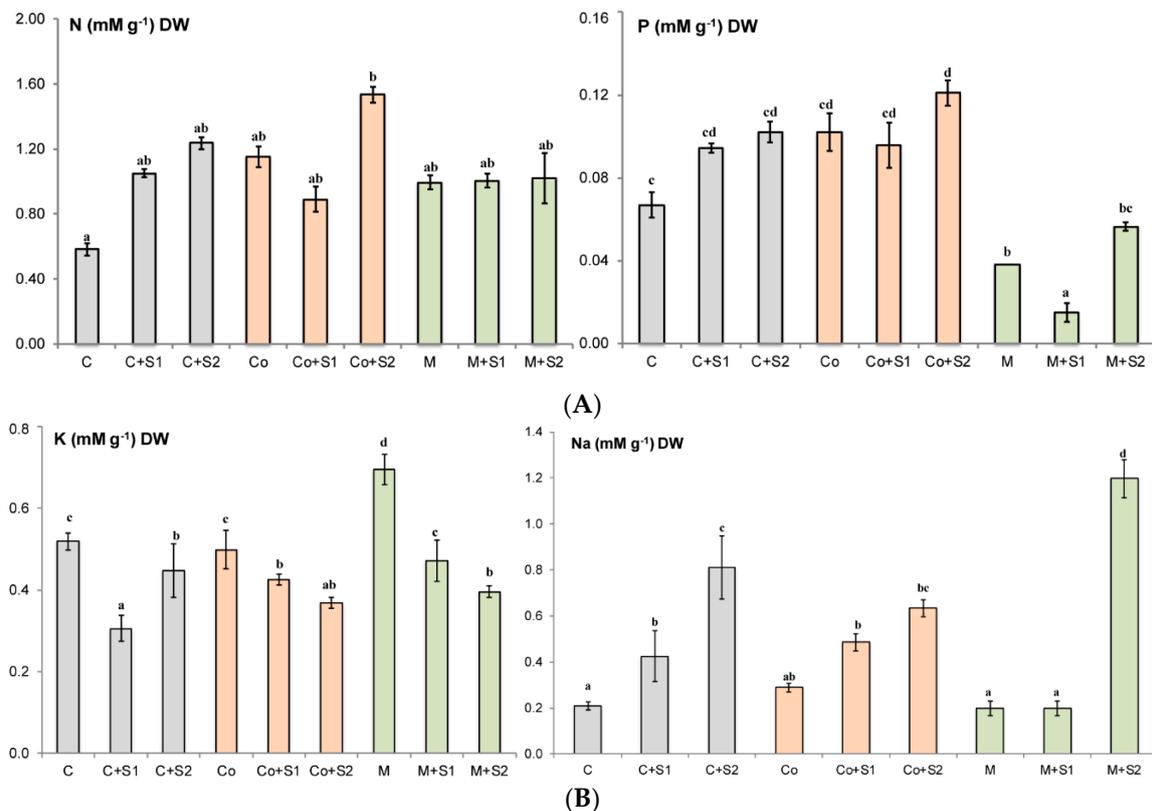


Figure 2. (A) Phosphorus (P), nitrogen (N) contents in above ground biomass of *Medicago sativa* plants cultivated for six months on clayey soils with or without MSW Compost (Co) or farmyard manure (M) and irrigated with 0 mM, 50 mM (S1), 100 mM (S2) NaCl water. Data are means of six repeats \pm SE. The different letters (abcd) represent a significant difference between treated samples. $p < 0.05$ by Duncan's multiple range test; (B) the concentration of potassium (K) and sodium (Na) in shoots of alfalfa grown for six months on clay soils amended with or without MSW Compost (Co) or farmyard manure (M) and irrigated water containing 0 mM, 50 mM (S1), 100 mM (S2) NaCl. Data are means of six repeats \pm SE. The different letters (abcd) represent a significant difference between treated samples. $p < 0.05$ by Duncan's multiple range test.

The compost contains also some other basic ions (Ca, Mg) in the form of bases, such as carbonates, hydroxides and oxides. Thus, the compost addition may prevent soil acidification, improving nutrient availability for plants [43]. As reported by Walker and Bernal [44], more Ca^{2+} in the exchange complex can be especially beneficial in saline-sodic soils, eliminating the contribution of Na^{+} in the exchange complex, with positive effects on the soil nutrient properties. Plant growth (dry weight of shoots and roots) increased in the presence of compost in tandem with salt water irrigation for both salt doses (S1 and S2). Analogous results were obtained for manure; moreover, a similar biomass production to the control was obtained. The highest biomass was obtained in variant S1 (Figure 1A,B).

Under salt stress, compost can raise the mineral nutrient status and growth of plants under salt stress by furnishing greater amounts of N and P [44,45]. However, plant K^{+} status did not improve by the addition of compost (Figure 2B), probably as a result of the already high K^{+} concentration of the soil used in this experiment (Table 1). Gradual mineralization followed the organic amendment providing

alfalfa plants a long-term supply of macronutrients overcoming salt stress that decreases compost decomposition [46]. The result is that organic amendments can be a significant input of trace elements. It leads also to the increase of Ca^{2+} in the rhizosphere, replacing Na^+ on the sites of adsorption. Thus, compost amendment under salt water irrigation is a good strategy for the remediation of sodic and saline-sodic soils.

Chowdhury et al. [47] suggested that soil amendments with farmyard and poultry manure significantly increased the growth, grain and straw yields, K^+/Na^+ ratio and nutrient uptake of the cultivars of rice under saline conditions leading to the improvement of plant salt tolerance.

However, the potency of each organic amendment was different, partly due to their chemical composition, type, origin, and duration of mineralization [48].

Application of both compost and manure to the salinized soil in this study resulted in improved soil fertility, which, in turn, enhanced crop growth and yield and nutritional status. According to Meena et al. [49], the increased N, P and K content promotes various photochemical reactions in the surface affecting the number of the leaves, which leads to enhanced photosynthetic activity. MSW compost alleviated the harmful salinity effects on the growth of plants and the mineral status of soils was improved both in the presence or absence of salt.

An adequate amount of N and its bioavailability in the soil are different ways of promoting biomass allocation in plants. On account of Yadav et al. [50], a high level of nitrogen promotes shoot growth while phosphorus stimulates root growth. Organic amendments to the soil not only enhance the availability of micronutrients in the form of slow-release but also maximize dry shoot biomass. The root-to-shoot biomass ratio depends on the photosynthetic translocation between the above and below-ground parts and is directly proportional to soil fertility [51]. The high biomass of shoots compared to roots (Figure 1A,B) found in organic amended soil is explained by its potential to increase soil fertility. The ameliorating effect of compost at the same scale of farmyard manure in the presence of salt at low doses (50 mM NaCl) may be attributed to the significant impact of increased organic carbon and decreased EPS after the application of a combination of farmyard manure and vermicompost in acidic soil [52]. A report by Qadir et al. [53] demonstrated that a rise in the soil Ca^{2+} content resulted in the substitution of Na^+ by Ca^{2+} at the soil particle cation exchange sites. Li [54] showed ion homeostasis altered with salt tolerance, where an increase in K^+ , $\text{Ca}^{2+}/\text{Na}^+$, and K^+/Na^+ in plant tissues and a decline of Na^+ in the leaf for *B. alternifolia* was correlated with higher survival rates when compared to *W. florida* (Red Prince). In the presence of salt stress, compost decreased Na^+ uptake, while it increased K^+ uptake by plants (Figure 2B).

Organic amendments increased the salt tolerance of plants and reduced EPS, EC and increased SOC resulting in a significant increase in crop yield [55]. Tejada et al. [43] demonstrated that the enrichment of soil with organic amendments favoured the flocculation of clay minerals, thereby improving the soil structure. Fertilization with MSW Compost annulled the adverse effects of salinity caused by 50 mM NaCl and to some extent, at 100 mM NaCl. The foremost role of compost in salinity tolerance through promoting an efficient antioxidant system and key C, N and S assimilatory enzymes was suggested by Tartoura et al. [56].

3.2. Heavy Metal Bioaccumulation

Boosting nutrient levels with soil amendment is undoubtedly a beneficial practice. MSW composts are considered as the paramount source of metals' input in agricultural soils and are an environmental concern due to their toxicity to plants [57].

The presence of contaminants in MSW composts leads to the accumulation of heavy metal in soil and plant tissues, with negative effects on the environment and human health due to contamination of the ground water and the food chain [58]. The soil type, quality of the MSW compost and plant species determine the concentration of heavy metals that are introduced to the environment by the addition of compost [59].

Accumulation and distribution of heavy metals and its distribution is variable also within individual species. Therefore, selection of appropriate plant genotypes accumulating lower concentrations of heavy metals in consumed parts of plants produced in contaminated soil (Pb and Cd-safe cultivars) can be an efficient alternative strategy to decrease the contamination of the food chain [60].

In our experiment, the heavy metal concentration was significantly elevated in shoots under salt stress (Figure 3A,B).

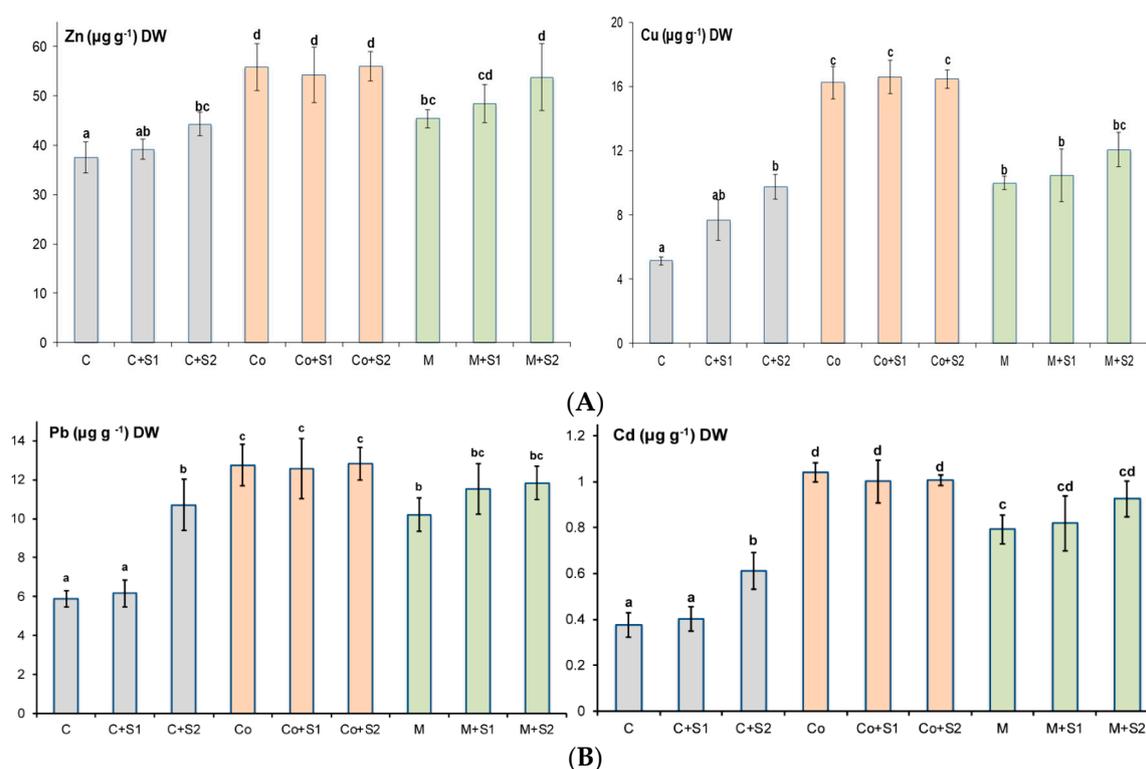


Figure 3. (A) Zinc (Zn) and copper (Cu) concentrations ($\mu\text{g g}^{-1}$ DW) in alfalfa shoots grown for six months on clay soils with or without MSW Compost (Co) or farmyard manure (M) application and irrigated water containing 0 mM, 50 mM (S1), 100 mM (S2) NaCl. Data are means of six repeats \pm SE. The different letters (abcd) represent a significant difference between treated samples. $p < 0.05$ by Duncan's multiple range test. (B) Lead (Pb) and cadmium (Cd) contents ($\mu\text{g g}^{-1}$ DW) in the shoots of alfalfa grown for six months on soil with or without the addition of MSW Compost (Co) or farmyard manure (M) and irrigated water with 0 mM, 50 mM (S1), 100 mM (S2) NaCl. Data are means of six repeats \pm SE. The different letters (abcd) represent a significant difference between treated samples. $p < 0.05$ by Duncan's multiple range test.

Mbarki et al. [40] reported that the heavy metal concentration increased in soil on application of MSW compost, resulting in higher amounts of heavy metal uptake by the plants. Although the compost increased the heavy metals accrual in the shoot parts, without showing any toxic effect, their concentrations were within the permissible limits (Figure 3A,B).

The heavy metal bioaccumulation not only depends on the amount of metal in the soil, but also the physicochemical properties of the soil, pH and EC, the strength, by which the element is bound in soil, and the regulation of the element uptake by the plant.

The order of heavy metal uptake by alfalfa was $\text{Zn} > \text{Cu} > \text{Pb} > \text{Cd}$, showing the relative lability of zinc, which is ready to transfer to plant tissues. This metal is often present in the soil enriched by the compost in higher concentrations in comparison with other heavy metals assessed in this study [61]. In turn, binding of Cu in soil is much stronger and its accumulation by plants is better regulated

compared to Zn [62]. On the other hand, some studies showed that the addition of MSW compost was a good approach to remediate the soils rich in labile elements as the adsorption processes eliminated the overall bioavailability of heavy metals [63].

The supply to the soil of MSW compost with the background concentration of heavy metals (Cu and Zn) reduced their extractability in comparison to an untreated control [64].

Plant availability of the lead (Pb) is very low in soil amended with the compost [64,65], and the risk of contamination to the food chain by this element is low, as it is blocked by the soil-plant barrier [66]. The order of heavy metal transfer depended on plant, soil and compost types, as Aylaj et al. [38] ascertained that regular compost use decreased heavy metal content in leaves.

Heavy metals accumulated mostly in leaves and roots and the transfer of metals to roots increased in the order: Cr (0.12–1.64) < Zn (0.87–1.21) < Mn (0.3–1.34) < Cu (0.28–2.28) < Co (0.53–4.10) < Fe (1.08–2.14) [67]. It was shown that Pb is preferentially bound in compost into stable forms, such as sulphide, having a low availability to the plants [67]. Gigliotti et al. [68] studied the mobility of Pb from calcareous soil (pH 8.3) to maize plants and found a decreased transfer of lead ions in variants amended for six years with a high dose (90 mg ha⁻¹) of a mechanically-segregated MSW-compost.

The interaction between the salt and compost treatments were well evident, being also significantly influenced by the heavy metal concentration (Figure 3A,B). Salt stress led to an increase in metal uptake in non-amended soil variants, whereas in compost-treated soil this trend was not observed.

The risk from heavy metal load was assessed using the bioaccumulation factor (BAF) for individual metal elements assessed in shoots.

The BAF of Zn, Cu, and Pb was lower than 1, independent of treatments (Table 2). As noted in previous studies, salt stress augmented BAF for plants cultivated on soil without amendments (Table 2). Both the BAF and transfer factor (the ratio of concentration of heavy metal in plant related to the metal content in soil) for Cu and Zn in basil and Swiss chard cultivated in the pot experiments using sandy loam soil decreased in soil with the addition of the compost. This meant that the relative bioavailability of both Zn and Cu were lowered by the amendment of compost compared to the control without additions [64].

Table 2. Bioaccumulation Factor (BAF) calculated for metal contents (Zn, Cu, Pb and Cd) in alfalfa grown in clay soil (C) amended with or without MSW compost (Co) and Farmyard manure (M) on irrigation with water containing 0 mM, 50 mM (S1) and 100 mM (S2) NaCl.

| | C | C + S1 | C + S2 | Co | Co + S1 | Co + S2 | M | M + S1 | M + S2 |
|---------|------|--------|--------|------|---------|---------|------|--------|--------|
| Zinc | 0.32 | 0.32 | 0.41 | 0.45 | 0.40 | 0.48 | 0.56 | 0.52 | 0.52 |
| Copper | 0.10 | 0.14 | 0.19 | 0.26 | 0.28 | 0.32 | 0.42 | 0.48 | 0.58 |
| Lead | 0.13 | 0.15 | 0.24 | 0.23 | 0.28 | 0.31 | 0.41 | 0.45 | 0.45 |
| Cadmium | 0.10 | 0.13 | 0.18 | 0.26 | 0.29 | 0.35 | 0.45 | 0.48 | 0.52 |

Our results showed that MSW compost containing some heavy metals seemed to be useful as an organic fertilizer in agriculture with a low risk of phytotoxic effects due to excessive accumulation of Zn, Pb and Cu in plants even under salt irrigation [23,69]. However, the future consequences of regular amendment of the compost on soil texture and the bioavailability of the metals and its impact on plant performance need to be considered. Application of MSW compost may lower the metal availability by getting the soil pH higher [70], as the heavy metal availability mostly drops when the soil pH increases [71]. The addition of compost did not increase the BAFs with the effect of salt stress, whereas the manure addition showed an increase in the BAFs in the presence of high doses of NaCl, which is an important issue related to crop performance and quality for plant productivity and health safety.

However, the apparent relationship between the contents of Cu, Pb, Zn and Cd in plants and in compost can also be affected by other co-factors such as salinity that may influence the growth rate of the plants and the level of dilution of the concentration of heavy metal particles in plant tissues. On the other hand, the results of the plant transfer correspond to the data on DTPA extractable Cu

fraction [72]. However, many researchers questioned the use of organic manures as remediation agents in soil systems, claiming that manures could be a source of contamination as well as remediation [73]. Salt stress increased the uptake of heavy metals by plants grown without compost compared to the amended soils (Figure 3B and Table 2), leading to the remediation effect of compost in saline soils. For example, salt concentration and toxicity are more relevant compared to metal content in compost, especially in semi-arid and arid regions [74]. The applied dose of 40 mg ha⁻¹ of compost increased Pb, Cu, Cd and Zn levels (Table 2), but they remained within an acceptable range in plants [59]. On the other hand, the metal accumulation did not affect the obtained yields of alfalfa.

4. Conclusions

Mature MSW compost can be used successfully as a fertilizer for clay soil as its favoured nutrient content may improve the plant nutrition, development and growth as well as tissue metal content without overtaking admissible limits. Moreover, the use of this organic amendment under salt stress may represent an efficient way of increasing alfalfa biomass production.

The maximum effect on alfalfa growth was achieved by the utilization of MSW compost at a rate of 40 mg ha⁻¹ without any toxic effects on the plant. Using 40 mg ha⁻¹ of MSW compared to 40 mg ha⁻¹ farmyard manure with salt water irrigation can be an excellent strategy to enhance the heavy metal remediation of saline soils, and to allow the mitigation of the salt stress and heavy metal effects on alfalfa production.

Author Contributions: Conceptualization, S.M.; methodology, S.M. and C.A.; software, A.C. (Amrita Chakraborty) and M.S.; validation, M.Z. and S.M.; formal analysis, S.M. and M.S.; the investigation, M.S. and V.H.; resources, M.B. and O.T.; data curation, S.M.; writing—original draft preparation, S.M.; writing—review and editing, S.M., M.S., and M.Z.; English editing, M.S.; visualization, S.M. and A.C. (Artemi Cerda); supervision, C.A.; project administration, F.H.; funding acquisition, F.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the EU—Project “NutRisk Centre” grant number CZ.02.1.01/0.0/0.0/16_019/0000845.

Acknowledgments: We are grateful to independent reviewers for valuable comments on the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Smith, P.; House, J.I.; Bustamante, M.; Sobocká, J.; Harper, R.; Pan, G.; West, P.C.; Clark, J.M.; Adhya, T.; Rumpel, C. Global change pressures on soils from land use and management. *Glob. Chang. Biol.* **2016**, *22*, 1008–1028. [[CrossRef](#)]
2. Rodrigo-Comino, J.; Davis, J.; Keesstra, S.D.; Cerdà, A. Updated measurements in vineyards improves accuracy of soil erosion rates. *Agron. J.* **2018**, *110*, 411–417. [[CrossRef](#)]
3. Kirchhoff, M.; Rodrigo-Comino, J.; Seeger, M.; Ries, J.B. Soil erosion in sloping vineyards under conventional and organic land use managements (Saar-Mosel valley, Germany). *Cuad. Investig. Geogr.* **2017**, *43*, 119–140. [[CrossRef](#)]
4. Cerdà, A.; Rodrigo-Comino, J.; Giménez-Morera, A.; Keesstra, S.D. An economic, perception and biophysical approach to the use of oat straw as mulch in Mediterranean rainfed agriculture land. *Ecol. Eng.* **2017**, *108*, 162–171. [[CrossRef](#)]
5. Cerdà, A.; Rodrigo-Comino, J.; Giménez-Morera, A.; Keesstra, S.D. Hydrological and erosional impact and farmer’s perception on catch crops and weeds in citrus organic farming in Canyoles river watershed, Eastern Spain. *Agric. Ecosyst. Environ.* **2018**, *258*, 49–58. [[CrossRef](#)]
6. Ivits, E.; Cherlet, M.; Tóth, T.; Lewińska, K.; Tóth, G. Characterisation of productivity limitation of salt-affected lands in different climatic regions of Europe using remote sensing derived productivity indicators. *Land Degrad. Dev.* **2013**, *24*, 438–452. [[CrossRef](#)]

7. Keesstra, S.D.; Bouma, J.; Wallinga, J.; Tiftonell, P.; Smith, P.; Cerdà, A.; Montanarella, L.; Quinton, J.N.; Pachepsky, Y.; Van Der Putten, W.H. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. *Soil* **2016**, *2*, 111–128. [[CrossRef](#)]
8. Recha, C.; Mukopi, M.; Otieno, J. Socio-economic determinants of adoption of rainwater harvesting and conservation techniques in semi-arid Tharaka sub-county, Kenya. *Land Degrad. Dev.* **2015**, *26*, 765–773. [[CrossRef](#)]
9. Bekchanov, M.; Ringler, C.; Bhaduri, A. A water rights trading approach to increasing inflows to the Aral Sea. *Land Degrad. Dev.* **2018**, *29*, 952–961. [[CrossRef](#)]
10. Zalacáin, D.; Martínez-Pérez, S.; Bienes, R.; García-Díaz, A.; Sastre-Merlín, A. Salt accumulation in soils and plants under reclaimed water irrigation in urban parks of Madrid (Spain). *Agric. Water Manag.* **2019**, *213*, 468–476. [[CrossRef](#)]
11. Ghassemi, F.; Jakeman, A.J.; Nix, H.A. *Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies*; CAB International: Wallingford, UK, 1995.
12. Talaat, N.B.; Ghoniem, A.E.; Abdelhamid, M.T.; Shawky, B.T. Effective microorganisms improve growth performance, alter nutrients acquisition and induce compatible solutes accumulation in common bean (*Phaseolus vulgaris* L.) plants subjected to salinity stress. *Plant Growth Regul.* **2015**, *75*, 281–295. [[CrossRef](#)]
13. Saadi, S.; Todorovic, M.; Tanasijevic, L.; Pereira, L.S.; Pizzigalli, C.; Lionello, P. Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. *Agric. Water Manag.* **2015**, *147*, 103–115. [[CrossRef](#)]
14. Trujillo-González, J.; Mahecha-Pulido, J.; Torres-Mora, M.; Brevik, E.; Keesstra, S.; Jiménez-Ballesta, R. Impact of potentially contaminated river water on agricultural irrigated soils in an equatorial climate. *Agriculture* **2017**, *7*, 52. [[CrossRef](#)]
15. Trujillo-González, J.M.; Torres-Mora, M.A.; Keesstra, S.; Brevik, E.C.; Jiménez-Ballesta, R. Heavy metal accumulation related to population density in road dust samples taken from urban sites under different land uses. *Sci. Total Environ.* **2016**, *553*, 636–642. [[CrossRef](#)] [[PubMed](#)]
16. Leogrande, R.; Vitti, C. Use of organic amendments to reclaim saline and sodic soils: A review. *Arid Land Res. Manag.* **2019**, *33*, 1–21. [[CrossRef](#)]
17. Kanber, R.; Ünlü, M.; Kapur, B.; Özekici, B.; Donma, S. Adaptation of Contemporary Irrigation Systems to Face the Challenges of Future Climate Changes in the Mediterranean Region: A Case Study of the Lower Seyhan Irrigation System. In *Climate Change Impacts on Basin Agro-Ecosystems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 125–161.
18. Mbarki, S.; Labidi, N.; Talbi, O.; Jdidi, N.; Abdelly, C.; Pascual, J.A. Ameliorative effect of municipal solid waste compost on the biological quality of mediterranean salt lake soil. *Compost Sci. Util.* **2010**, *18*, 242–248. [[CrossRef](#)]
19. Chávez-García, E.; Siebe, C. Rehabilitation of a highly saline-sodic soil using a rubble barrier and organic amendments. *Soil Tillage Res.* **2019**, *189*, 176–188. [[CrossRef](#)]
20. Gamoun, M. Rain use efficiency, primary production and rainfall relationships in desert rangelands of Tunisia. *Land Degrad. Dev.* **2016**, *27*, 738–747. [[CrossRef](#)]
21. Ghrab, M.; Gargouri, K.; Ben Mimoun, M. Long-term effect of dry conditions and drought on fruit trees yield in dryland areas of Tunisia. *Options Mediterr. Ser. AN* **2008**, *80*, 107–112.
22. Shao, H.; Chu, L.; Lu, H.; Qi, W.; Chen, X.; Liu, J.; Kuang, S.; Tang, B.; Wong, V. Towards sustainable agriculture for the salt-affected soil. *Land Degrad. Dev.* **2019**, *30*, 574–579. [[CrossRef](#)]
23. Mbarki, S.; Cerdà, A.; Brestic, M.; Mahendra, R.; Abdelly, C.; Pascual, J.A. Vineyard compost supplemented with *Trichoderma harzianum* T78 improve saline soil quality. *Land Degrad. Dev.* **2017**, *28*, 1028–1037. [[CrossRef](#)]
24. Meena, M.; Yadav, R.; Narjary, B.; Yadav, G.; Jat, H.; Sheoran, P.; Meena, M.; Antil, R.; Meena, B.; Singh, H. Municipal solid waste (MSW): Strategies to improve salt affected soil sustainability: A review. *Waste Manag.* **2019**, *84*, 38–53. [[CrossRef](#)] [[PubMed](#)]
25. Cao, D.; Li, Y.; Liu, B.; Kong, F.; Tran, L.S.P. Adaptive mechanisms of soybean grown on salt-affected soils. *Land Degrad. Dev.* **2018**, *29*, 1054–1064. [[CrossRef](#)]
26. Abiala, M.A.; Abdelrahman, M.; Burritt, D.J.; Tran, L.S.P. Salt stress tolerance mechanisms and potential applications of legumes for sustainable reclamation of salt-degraded soils. *Land Degrad. Dev.* **2018**, *29*, 3812–3822. [[CrossRef](#)]

27. Hu, G.; Liu, H.; Yin, Y.; Song, Z. The role of legumes in plant community succession of degraded grasslands in northern China. *Land Degrad. Dev.* **2016**, *27*, 366–372. [[CrossRef](#)]
28. Pansu, M.; Gautheyrou, J. *Handbook of Soil Analysis: Mineralogical, Organic and Inorganic Methods*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2007.
29. Baize, D. *Guide des Analyses en Pédologie: 3e Édition Revue et Augmentée*; Editions Quae: Versailles, France, 2018.
30. Fleury, P. La méthode nitro-vanado-molybdique de Misson pour le dosage colorimétrique du phosphore. Son intérêt en biochimie. *Bull. Soc. Chem. Biol.* **1943**, *25*, 201–205.
31. Li, M.; Luo, Y.; Su, Z. Heavy metal concentrations in soils and plant accumulation in a restored manganese mineland in Guangxi, South China. *Environ. Pollut.* **2007**, *147*, 168–175. [[CrossRef](#)]
32. Keesstra, S.; Nunes, J.; Novara, A.; Finger, D.; Avelar, D.; Kalantari, Z.; Cerdà, A. The superior effect of nature based solutions in land management for enhancing ecosystem services. *Sci. Total Environ.* **2018**, *610*, 997–1009. [[CrossRef](#)]
33. Pan, Y.Q.; Guo, H.; Wang, S.M.; Zhao, B.; Zhang, J.L.; Ma, Q.; Yin, H.J.; Bao, A.K. The photosynthesis, Na⁺/K⁺ homeostasis and osmotic adjustment of *Atriplex canescens* in response to salinity. *Front. Plant Sci.* **2016**, *7*, 848. [[CrossRef](#)]
34. Rahman, M.M.; Mostofa, M.G.; Rahman, M.A.; Miah, M.G.; Saha, S.R.; Karim, M.A.; Keya, S.S.; Akter, M.; Islam, M.; Tran, L.S.P. Insight into salt tolerance mechanisms of the halophyte *Achras sapota*: An important fruit tree for agriculture in coastal areas. *Protoplasma* **2019**, *256*, 181–191. [[CrossRef](#)]
35. Eghball, B.; Wienhold, B.; Gilley, J.; Eigenberg, R. *Mineralization of Manure Nutrients. Biological Systems Engineering*; University of Nebraska: Lincoln, NE, USA, 2002.
36. Kusmiyati, F.; Purbajanti, E. The Effects of Manure at Saline Soil on Growth, Dry Matter Production and Crude Protein of *Sesbania grandiflora*. In Proceedings of the IOP Conference Series: Earth and Environmental Science, Banda Aceh, Indonesia, 26–27 September 2018; p. 012023.
37. Weber, J.; Kocowicz, A.; Bekier, J.; Jamroz, E.; Tyszkla, R.; Debicka, M.; Parylak, D.; Kordas, L. The effect of a sandy soil amendment with municipal solid waste (MSW) compost on nitrogen uptake efficiency by plants. *Eur. J. Agron.* **2014**, *54*, 54–60. [[CrossRef](#)]
38. Aylaj, M.; Lhadi, E.K.; Adani, F. Municipal waste and poultry manure compost affect biomass production, nitrate reductase activity and heavy metals in tomato plants. *Compost Sci. Util.* **2019**, *27*, 11–23. [[CrossRef](#)]
39. Kaya, M.D.; Okçu, G.; Atak, M.; Cıkılı, Y.; Kolsarıcı, Ö. Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). *Eur. J. Agron.* **2006**, *24*, 291–295. [[CrossRef](#)]
40. Mbarki, S.; Labidi, N.; Mahmoudi, H.; Jedidi, N.; Abdelly, C. Contrasting effects of municipal compost on alfalfa growth in clay and in sandy soils: N, P, K, content and heavy metal toxicity. *Bioresour. Technol.* **2008**, *99*, 6745–6750. [[CrossRef](#)]
41. Massa, D.; Mattson, N.S.; Lieth, H.J. Effects of saline root environment (NaCl) on nitrate and potassium uptake kinetics for rose plants: A Michaelis–Menten modelling approach. *Plant Soil* **2009**, *318*, 101. [[CrossRef](#)]
42. Parida, A.K.; Das, A.B. Salt tolerance and salinity effects on plants: A review. *Ecotoxicol. Environ. Saf.* **2005**, *60*, 324–349. [[CrossRef](#)]
43. Tejada, M.; Garcia, C.; Gonzalez, J.; Hernandez, M. Use of organic amendment as a strategy for saline soil remediation: Influence on the physical, chemical and biological properties of soil. *Soil Biol. Biochem.* **2006**, *38*, 1413–1421. [[CrossRef](#)]
44. Walker, D.J.; Bernal, M.P. The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil. *Bioresour. Technol.* **2008**, *99*, 396–403. [[CrossRef](#)]
45. Walker, D.J.; Bernal, M.P. Plant mineral nutrition and growth in a saline Mediterranean soil amended with organic wastes. *Commun. Soil Sci. Plant Anal.* **2005**, *35*, 2495–2514. [[CrossRef](#)]
46. Muhammad, S.; Müller, T.; Joergensen, R.G. Compost and P amendments for stimulating microorganisms and maize growth in a saline soil from Pakistan in comparison with a nonsaline soil from Germany. *J. Plant Nutr. Soil Sci.* **2007**, *170*, 745–752. [[CrossRef](#)]
47. Chowdhury, S.; Bhusan, D.; Hashem, M.A.; Hoque, M.A. Organic amendments for mitigating soil salinity in rice. *Res. Agric. Livest. Fish.* **2019**, *6*, 11–17. [[CrossRef](#)]
48. Ansari, R.A.; Sumbul, A.; Rizvi, R.; Mahmood, I. Organic Soil Amendments: Potential Tool for Soil and Plant Health Management. In *Plant Health under Biotic Stress*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 1–35.

49. Meena, B.; Marimuthu, T.; Vidhyasekaran, P.; Velazhahan, R. Biological control of root rot of groundnut with antagonistic *Pseudomonas fluorescens* strains. *Z. Pflanzenkrankh. Pflanzenschutz* **2001**, *108*, 369–381.
50. Yadav, S.K.; Singh, G.; Jain, V.K.; Tiwari, A. Response of Potato (*Solanum tuberosum* L.) Cultivars to Different Levels of Nitrogen. *Int. J. Curr. Microbiol. Appl. Sci.* **2017**, *6*, 2734–2739. [[CrossRef](#)]
51. Fageria, N.; Moreira, A. The role of mineral nutrition on root growth of crop plants. In *Advances in Agronomy*; Elsevier: Amsterdam, The Netherlands, 2011; Volume 110, pp. 251–331.
52. Singh, A.; Singh, K.; wasnik, K.; Singh, R. Vermicompost and farmyard manure increase fertility of sodic soil and the productivity of green vegetables. *Int. J. Adv. Res.* **2017**, *5*, 2623–2632. [[CrossRef](#)]
53. Qadir, M.; Oster, J. Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Sci. Total Environ.* **2004**, *323*, 1–19. [[CrossRef](#)]
54. Li, X. Ion Concentration Changes in Plants of Varying Tolerance under Saline Environment. *Agron. J.* **2019**, *111*, 1666–1674. [[CrossRef](#)]
55. Tejada, M.; Benítez, C. Effects of crushed maize straw residues on soil biological properties and soil restoration. *Land Degrad. Dev.* **2014**, *25*, 501–509. [[CrossRef](#)]
56. Tartoura, K.A.; Youssef, S.A.; Tartoura, E.S.A. Compost alleviates the negative effects of salinity via up-regulation of antioxidants in *Solanum lycopersicum* L. plants. *Plant Growth Regul.* **2014**, *74*, 299–310. [[CrossRef](#)]
57. Smith, S.R. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environ. Int.* **2009**, *35*, 142–156. [[CrossRef](#)]
58. Shah, G.M.; Tufail, N.; Bakhat, H.F.; Ahmad, I.; Shahid, M.; Hammad, H.M.; Nasim, W.; Waqar, A.; Rizwan, M.; Dong, R. Composting of municipal solid waste by different methods improved the growth of vegetables and reduced the health risks of cadmium and lead. *Environ. Sci. Pollut. Res.* **2019**, *26*, 5463–5474. [[CrossRef](#)]
59. Pinamonti, F.; Stringari, G.; Gasperi, F.; Zorzi, G. The use of compost: Its effects on heavy metal levels in soil and plants. *Resour. Conserv. Recycl.* **1997**, *21*, 129–143. [[CrossRef](#)]
60. Wang, P.; Chen, H.; Kopittke, P.M.; Zhao, F.J. Cadmium contamination in agricultural soils of China and the impact on food safety. *Environ. Pollut.* **2019**, *249*, 1038–1048. [[CrossRef](#)] [[PubMed](#)]
61. Speir, T.; Horswell, J.; Van Schaik, A.; McLaren, R.; Fietje, G. Composted biosolids enhance fertility of a sandy loam soil under dairy pasture. *Biol. Fertil. Soils* **2004**, *40*, 349–358. [[CrossRef](#)]
62. Kabata-Pendias, A.; Pendias, H. *Trace elements in soils and plants*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2001.
63. Brown, S.; Chaney, R.; Hallfrisch, J.; Ryan, J.A.; Berti, W.R. In situ soil treatments to reduce the phyto- and bioavailability of lead, zinc, and cadmium. *J. Environ. Qual.* **2004**, *33*, 522–531. [[CrossRef](#)] [[PubMed](#)]
64. Zheljzkov, V.D.; Warman, P.R. Phytoavailability and fractionation of copper, manganese, and zinc in soil following application of two composts to four crops. *Environ. Pollut.* **2004**, *131*, 187–195. [[CrossRef](#)] [[PubMed](#)]
65. Planquart, P.; Bonin, G.; Prone, A.; Massiani, C. Distribution, movement and plant availability of trace metals in soils amended with sewage sludge composts: Application to low metal loadings. *Sci. Total Environ.* **1999**, *241*, 161–179. [[CrossRef](#)]
66. Keeney, D.R. Proceedings of the workshop on utilization of municipal wastewater and sludge on land. *J. Environ. Qual.* **1984**, *13*, 656. [[CrossRef](#)]
67. Zheng, G.; Chen, T.; Gao, D.; Luo, W. Dynamic of lead speciation in sewage sludge composting. *Water Sci. Technol.* **2004**, *50*, 75–82. [[CrossRef](#)]
68. Gigliotti, G.; Businelli, D.; Giusquiani, P.L. Trace metals uptake and distribution in corn plants grown on a 6-year urban waste compost amended soil. *Agric. Ecosys. Environ.* **1996**, *58*, 199–206. [[CrossRef](#)]
69. Lakhdar, A.; Hafsi, C.; Rabhi, M.; Debez, A.; Montemurro, F.; Abdelly, C.; Jedidi, N.; Ouerghi, Z. Application of municipal solid waste compost reduces the negative effects of saline water in *Hordeum maritimum* L. *Biores. Technol.* **2008**, *99*, 7160–7167. [[CrossRef](#)]
70. Jordao, C.; Nascentes, C.; Cecon, P.; Fontes, R.; Pereira, J. Heavy metal availability in soil amended with composted urban solid wastes. *Environ. Monit. Assess.* **2006**, *112*, 309–326. [[CrossRef](#)] [[PubMed](#)]
71. De Haan, S. Results of municipal waste compost research over more than fifty years at the Institute for Soil Fertility at Haren/Groningen, the Netherlands. *Neth. J. Agric.* **1981**, *29*, 49–61.

72. Baldwin, K.R.; Shelton, J.E. Availability of heavy metals in compost-amended soil. *Biores. Technol.* **1999**, *69*, 1–14. [[CrossRef](#)]
73. Irfan Sohail, M.; Arif, M.; Rauf, A.; Rizwan, M.; Ali, S.; Saqib, M.; Zia-ur-Rehman, M. Organic Manures for Cadmium Tolerance and Remediation. In *Cadmium Tolerance in Plants*; Elsevier, Academic Press: London, UK, 2019; pp. 19–67.
74. Maftoun, M.; Moshiri, F.; Karimian, N.; Ronaghi, A. Effects of two organic wastes in combination with phosphorus on growth and chemical composition of spinach and soil properties. *J. Plant Nutr.* **2005**, *27*, 1635–1651. [[CrossRef](#)]



© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).