Journal of Soil Science and Plant Nutrition (2022) 22:177–185
https://doi.org/10.1007/s42729-021-00642-6

ORIGINAL PAPER

Nitrogen and Compost Enhanced the Phytoextraction Potential of Cd and Pb from Contaminated Soils by Quail Bush [*Atriplex lentiformis* (Torr.) S.Wats]

Mamdouh A. Eissa[1] · Hatim M. Al-Yasi[2] · Adel M. Ghoneim[3] · Esmat F. Ali[2] · Rania El Shal[4]

Received: 16 July 2021 / Accepted: 29 September 2021 / Published online: 12 October 2021

Abstract

Cleaning of pollutants from contaminated soils is a public matter to prevent their access to the food chain. There are many technological methods that are used in the remediation of contaminated soils, but phytoremediation technology is the new trend in the world because it does not cause damage on soil quality and it is an environmentally friendly method. This study aims to use one of the halophytic plants [*Atriplex lentiformis* (Torr.) S.Wats] to clean a soil contaminated with cadmium (Cd) and lead (Pb). Furthermore, the study aims to explore the mechanism of compost and nitrogen fertilization in the phytoremediation capacity of quail bush plants. A pot experiment was conducted for a year to evaluate the effect of compost and nitrogen fertilization on the efficiency of quail bush [*Atriplex lentiformis* (Torr.) S.Wats] in removing Cd and Pb from the contaminated soil. The experiment contained four treatments including control without any fertilization (C), compost (COM) at a rate of 10 g kg^{-1} soil, nitrogen fertilization (N) at a rate of 150 mg N kg^{-1} soil, and combined application of compost and nitrogen (COM + N). The application of N, COM, and COM + N significantly ($P < 0.05$) enhanced the growth of quail bush plants. The growth of quail bush plants as affected by N and COM treatments can be arranged in the descending order: COM + N > N > COM > C. N, COM, and COM + N increased the Cd in shoots by 40, 33, and 60%, respectively, compared to C, and increased Pb by 17, 7, and 23%. Quail bush plants removed 6.6–14.1% of the total soil Cd and 1.0–1.7% of the total soil Pb. Quail bush removed 11, 10, and 14% of the total soil Cd when the soil was amended with N, COM, and COM + N, respectively, while it removed 1.48, 1.28, and 1.74% of the total Pb as results of the same treatments. The addition of COM and N led to an increase in the synthesis of chlorophyll and a decrease in the synthesis of proline and oxalate which are used to control the osmosis of plant cells. The single addition of N and COM led to significant improvement in alleviating the toxicity stress, while adding them together significantly outperformed the individual additions. The ability of quail bush plants in cleaning the polluted soil increased as a result of nitrogen and compost application due to the increase in the metal concentration in the shoot and the increase in the total plant biomass. The studied quail bush plants have a high ability to withstand Cd and Pb in polluted soil, but their ability to remove Pb from the contaminated soils is weak, while they remove large amounts of Cd. Quail bush plants grown on metal-contaminated soils removed 14% of the total soil Cd during a year when amended with both compost and nitrogen.

Keywords Cadmium · Lead · Contaminated soils · Quail bush · Proline · Oxalate · Phytoremediation

1 Introduction

The contamination of soil with toxic elements is an important issue to maintain the health of living organisms and to ensure sustainable development (Zeng et al. 2020; Khalilzadeh et al. 2020). The accumulation of these elements in the soil or reaching them to the ground water may be harmful to people, animals, plants, and other organisms (Eissa and Negim, 2018; Sharma et al. 2021). These elements reach the soil through some human and industrial activities such as mining and heavy industries, adding organic and mineral fertilizers, and using untreated wastewaters to irrigate agriculture lands (Seleiman and Kheir 2018; Wu et al. 2021). The metal-contaminated soils must be remediated and pollutants must be removed to ensure food

✉ Mamdouh A. Eissa
mamdouh.eisa@aun.edu.eg

Extended author information available on the last page of the article

safety (Almaroai and Eissa 2020; Wu et al. 2021; Sharma et al. 2021).

Remediation methods of metal-contaminated soils, e.g., washing, vitrification, and solidification, are not effective in agriculture lands, and they are expensive and cause soil disturbances (Martin and Ruby 2004; Khan et al. 2021). Phytoremediation and more specifically phytoextraction, which was based on the removing of metals from soil into plant shoot tissues, has been posed as a cost-effective, environment-friendly alternative restoration strategy for the remediation of contaminated soils (Kumar et al. 2021). Halophytic plants occur naturally in saline environments and can also be cultivated on saline soils or irrigated by saline water (Li et al. 2021). Halophytic plants have different physiological mechanisms that allow them to tolerate high levels of salts in soils and water such as the secretion of substances that help to restore the osmotic pressure of cells, e.g., proline and oxalates, as it raises the content of cells of antioxidants when exposed to salt stress or toxicity of elements (Lutts et al. 2004; Eissa and Roshdy 2018; Li et al. 2021). *Atriplex* is a genus of the halophytic plants and contains more than 100 species and may be of importance for phytoremediation because of its high yield production and good root system able to cope with the poor structure and xeric characteristics of several polluted materials (Ding et al. 2021a, 2021b). Shoot tissues of these species contain high concentrations of substances regulating the osmotic pressure of plant cells, which may assume positive functions in tolerance mechanisms to metal stress (Eissa 2017; Eissa and Roshdy 2018; Eissa and Abeed 2019). Use of some halophytic plants in phytoremediation was reported by Manousaki and Kalogerakis (2009) and Eissa (2017). *Atriplex* is one of the most important halophytic plants and is known by the common names of saltbush. The genus is widely distributed in the different world deserts. A few numbers of these species were studied for phytoremediation. *A. lentiformis* plants accumulate high levels of Cd and Pb in their root and shoot tissues and have been used as a hyperaccumulator in several studies (Lutts et al. 2004; Manousaki and Kalogerakis 2009; Eissa 2017).

In contaminated soils, humic substances in the organic fertilizers form soluble complexes with heavy metals, and the degree of solubility and plant uptake of these elements is determined by the type of organic matter and the nature of its interaction with the soil (Conte et al. 2005; Eissa 2017; Yildirim et al. 2021). Soil environment factors such as soil pH and the ionic composition of other soil solutions affect the direction of these interactions (Conte et al. 2005; Eissa 2017). Compost has been widely used as soil conditioners and soil fertilizers (Ding et al. 2020; Li et al. 2021; Ding et al. 2021a, 2021b). This practice has been recommended, since soil fertility needs to be sustained (Li et al. 2021; Yildirim et al. 2021). Compost has several beneficial effects as a nutrient source for plant production and does not have deleterious impacts on soil and plant (Hua et al. 2008; Scotti et al. 2016). Compost contains many enzymes and hormones that can promote plant growth (Liu et al. 2021). Several studies have documented the beneficial effects of the application of compost on several types of soil with proper amendment rate (Singh and Agrawal 2007; Ding et al. 2020; Liu et al., 2021; Ding et al., 2021a, 2021b). The role of compost in increasing the phytoextraction of metal-contaminated soils by using halophytic plants needs to be evaluated. Nitrogen is a plant nutrient and is required by plants in larger amounts than other elements (Marschner 1997). Nitrogen is an essential component of many vital compounds in plant, such as chlorophyll, nucleotides, proteins, alkaloids, enzymes, hormones, and vitamins; besides, N plays an important role in plant photosynthesis by improving leaf area index (Marschner 1997). Nitrogen increases the ability of plants to withstand heavy metal toxicity and improves the plant growth, and therefore, supplying plants with N can contribute to the removal of a greater amount of toxic elements from polluted soils (Noaman 2004; Weia et al. 2010; Eissa and Roshdy 2018). Plant nutrition plays an important role in heavy metal uptake, but there is little information about the effect of N nutrition on the phytoextraction of Cd and Pb by quail bush plants.

The use of plants to remove toxic elements from the contaminated soil is one of the modern technological means that preserve the environment ecosystems (Ali et al. 2021; Chen et al. 2021). There is not much information available on the use of quail bush [*Atriplex lentiformis* (Torr.) S.Wats] on the removal of Cd and Pb from polluted soils; therefore, this study was conducted to fill this gap. There is a little information about the response of quail bush plants to nitrogen and compost fertilization under metal-contaminated soils. The current research paper aims to study the following hypotheses: quail bush plants which are halophytic plants will tolerate the high concentrations of heavy metals as it resists the high concentrations of salts in soil and in irrigation water. The other investigated hypothesis is that the ability to resist metal toxicity can be improved through mineral and organic nutrition. Therefore, this study aims to evaluate the accumulation of Cd and Pb by quail bush plants as affected by nitrogen and compost.

2 Material and Methods

2.1 Soil and Compost Characterization

The soil in this trial was collected from Illwan, Assiut, Egypt (27° 12′ 01.9″ N, 31° 05′ 46.5″ E), and Table 1 shows the basic properties. The soil in the experimental site contains high levels of Cd and Pb due to the irrigation with untreated

Table 1 Basic chemical and physical properties for the studied soil

Soil properties	Value
Clay (g kg^{-1})	43 ± 4
Silt (g kg^{-1})	157 ± 15
Sand (g kg^{-1})	800 ± 25
Texture	Sandy loam
$CaCO_3$ (g kg^{-1})	50 ± 6
CEC (cmol kg^{-1})	17 ± 3
pH (1:2)	7.92 ± 0.08
EC (1:2) (dS m^{-1})	2.11 ± 0.15
Organic carbon (g kg^{-1})	3.50 ± 0.2
Total nitrogen (mg kg^{-1})	100 ± 7
Total Pb	850 ± 28
Available Pb	4.8 ± 0.2
Total Cd	40 ± 5
Available Cd	2.4 ± 0.09

Each value represents the means of four replicates (± SD)

CEC cation exchange capacity, *EC* electric conductivity of soil solution

sewage wastewater for more than 60 years. The soil sample was air dried and sieved to pass through a 2-mm sieve. After preparation of soil, it was filled into the pots, while keeping a sample to estimate the physical and chemical properties.

The soil texture was determined by pipette method (Carter and Gregorich 2007). The soil pH was measured in a 1:2 (soil to water) suspension, while the soil salinity was measured by salt bridge method in 1:2 (soil to water) extract (Carter and Gregorich 2007). Dichromate oxidation method was used in the determining soil organic matter (Carter and Gregorich 2007). Soil total carbonates were measured by using a Collins calcimeter and expressed as $CaCO_3$ (Carter and Gregorich 2007). Total nitrogen was estimated by micro-Kjeldahl distillation method (Carter and Gregorich 2007). The available form of Cd and Pb was extracted by DTPA method and then measured by atomic absorption spectrophotometer (AAS) (Lindsay and Norvell 1969). The soil sample was subjected to acid digestion ($HF-HNO_3-HClO_4$ (1:1:1, v/v)) to extract the total Cd and Pb (Burt, 2004).

Compost used in this study is a commercial product and was prepared from maize residues and cow farm wastes at a ratio of 3:1 (w/w). The chemical properties of the compost were determined according to Burt (2004) before using it in the study, and they are presented in Table 2. Compost sample (2 g) was used to measure the total organic carbon by combustion method at 650 °C for 5 h (Burt 2004). The sample of compost was digested by a mixture of H_2SO_4 and $HClO_4$ (1:1 v/v) acids to determine the nitrogen (N), phosphorus (P), potassium (K), cadmium (Cd), and lead (Pb). The pH of compost was determined by using a digital pH meter in a 1:10 suspension, while the salt content was determined in 1:10 compost:water extract by the salt bridge method (Burt 2004).

2.2 Pot Experiment

Quail bush [*Atriplex lentiformis* (Torr.) S.Wats] seeds were brought from the Desert Cultivation Center at Assiut University, Egypt, and then planted in pots filled with sandy soil and compost (2:1). After 2 months, the seedlings (15 cm length with four leaves) were transferred to the pots in which the experiment was conducted. A pot experiment in a greenhouse (25 °C and 12-h light) was conducted to study the ability of quail bush plants to accumulate Cd and Pb as affected by nitrogen and compost treatment. The experiment contained four treatments including control without any fertilization (C), compost (COM) at a rate of 10 g kg^{-1} soil, nitrogen fertilization (N) at a rate of 150 mg N kg^{-1} soil, and combined application of compost and nitrogen (COM + N). The experiment includes 16 total pots with four pots for each treatment. The experiment was laid out in a completely random design (CRD) with four replicates. Plastic pots (15 cm in diameter and 20 cm in depth) were filled with 5 kg of the studied contaminated soil. One seedling of quail bush was cultivated in each pot. Pots were carefully watered to near field capacity. Compost was added to the pots during the preparation of soil and before cultivation. Nitrogen was added to the pots of each treatment in the form of NH_4NO_3 (33% N). A solution containing nitrogen rate was prepared and added in three equal doses during the plant growth period: the first was after 2 weeks of seedling cultivation, the second was 3 months later, and the last one was 3 months later of the second addition. After 1 year of seedling cultivation, the roots and shoots were removed from the pots.

2.3 Plant Analysis

Plants were left in pots for 1 year of transplanting. At the end of the experiment, the plant samples were collected and washed by tap water twice. Inorganic wastes were removed

Table 2 Some chemical properties of compost

pH 1:10	Salts (dS m^{-1})	Organic C (g kg^{-1})	N (%)	P (%)	K (%)	Pb (g kg^{-1})	Cd (g kg^{-1})
8.02 ± 0.08	3.8 ± 0.2	350 ± 16	1.5 ± 0.13	0.43 ± 0.08	0.72 ± 0.10	0.08 ± 0.03	0.02 ± 0.00

Each value represents the means of four replicates (± SD) from the plant samples by washing in 0.1 HCl and Tween 80. The plant samples then were washed with distilled water. After air drying, the plant samples were oven-dried (70 °C), ground, and then submitted to acid digestion using a mixture of 2:1 HNO_3:$HClO_4$. Cd and Pb concentrations were determined by atomic absorption spectrophotometer (PerkinElmer Analyst 200 AA, USA) with detection limits of 0.01 and 0.001 mg L^{-1} for Pb and Cd, respectively. Proline in the fresh leaves was extracted by sulfosalicylic acid and then determined by the method of Bates et al. (1973). Chlorophyll was extracted from the fresh leaves by acetone and then measured by Arnon (1949) method. The leaf content of oxalic acid was extracted by 0.25 N HCl and then titrated by 0.02 N $KMnO_4$ (Naik et al. 2014).

2.4 Statistical Analysis

The obtained results were checked for normality by the Shapiro–Wilk test and then the data were subjected to one-way ANOVA to test the significance. Means were compared by Duncan. All the statistical tests were run by SPSS 17.0 software package (SPSS, Chicago, IL, USA).

3 Results

3.1 Effect of Compost and Nitrogen Fertilization on the Growth of Quail Bush Plants

The application of COM and N fertilization had significant ($P < 0.05$) effects on the growth of quail bush plants (Table 3). The root dry weight (RDW), shoot dry weight (SDW), leaf number (LN), leaf area (LA), and plant height (PH) of quail bush plants were increased when the soil was fertilized with the organic or inorganic amendments. Both N and COM led to significant increases in the growth characteristics, while adding them together (COM + N) significantly outperformed the individual additions. N increased RDW, SDW, LN, LA, and PH by 40, 20, 17, 43, and 72%, respectively, compared to C, while these increases were 37, 13, 7, 33, and 56% in the case of compost. Addition of COM + N increased RDW, SDW, LN, LA, and PH by 51, 33, 28, 60, and 95%, respectively, compared to C. In general, the maximum growth of quail bush was found in the soil amended with COM + N, while the lowest value was in C. The growth of quail bush plants as affected by N and COM treatments can be arranged in the descending order: COM + N > N > COM.

3.2 Effect of Compost and Nitrogen on the Uptake of Cd and Pb

Cd concentrations ranged between 350 and 500 mg kg^{-1} in the roots and between 88 and 141 mg kg^{-1} in the shoots, while these values were 700–820 and 300–370 mg kg^{-1}, respectively, in the case of Pb concentrations. Roots contained higher concentrations of Cd and Pb than shoots (Fig. 1). The concentrations of Cd and Pb in the roots and shoots of quail bush plants were affected significantly ($P < 0.05$) by COM and N treatments. Single additions or combined application of COM and N increased the concentrations of Cd and Pb in the roots and shoots of quail bush plants. The single application of N increased Cd in the roots and shoots by 29 and 40% and increased Pb in the root and shoot by 14 and 17%, respectively, compared to the control (C). COM increased Cd in the roots and shoots by 14 and 33% and increased Pb in the root and shoot by 7%, respectively, compared to C. The combined addition of COM + N increased Cd in the roots and shoots by 43 and 60% and increased Pb in the root and shoot by 17 and 23%, respectively, compared to C.

The ability of quail bush in removing Cd and Pb from the metal-contaminated soil was increased significantly ($P < 0.05$) as a result of COM and N addition (Fig. 2). Quail bush plants removed 6.6–14.1% of the total soil Cd and 1.0–1.7% of the total soil Pb. The studied plants were able to remove remarkable and large amounts of Cd from the polluted soils, while the removed quantities were very small in the case of Pb. N and COM increased the ability of quail bush plants to remove Cd and Pb, and the double addition of the two amendments was more effective in raising the efficiency of the tested plants in cleaning the soil from that toxic

Table 3 Effect of nitrogen (N) and compost (COM) on growth of *A. lentiformis*

Treatments	RDW	SDW	PH	Leaves number plant^{-1}	Leaves area plant^{-1} (cm^2)
C	75 ± 1.55^c	150 ± 5.40^d	128 ± 5.50^d	98 ± 2.22^c	150 ± 5.28^d
COM	103 ± 1.56^b	170 ± 5.66^c	200 ± 5.20^c	105 ± 2.44^b	200 ± 6.25^c
N	105 ± 1.33^b	180 ± 6.44^b	220 ± 5.10^b	115 ± 3.33^a	215 ± 5.11^b
COM + N	113 ± 1.55^a	200 ± 5.53^a	250 ± 5.40^a	125 ± 3.45^a	240 ± 5.66^a

Means (± standard deviation, $n = 4$) denoted by different letters are significantly different at $P < 0.05$

C control without amendments, *RDW* root dry weight (g pot^{-1}), *SDW* shoot dry weight (g pot^{-1}), *PH* plant height (cm)

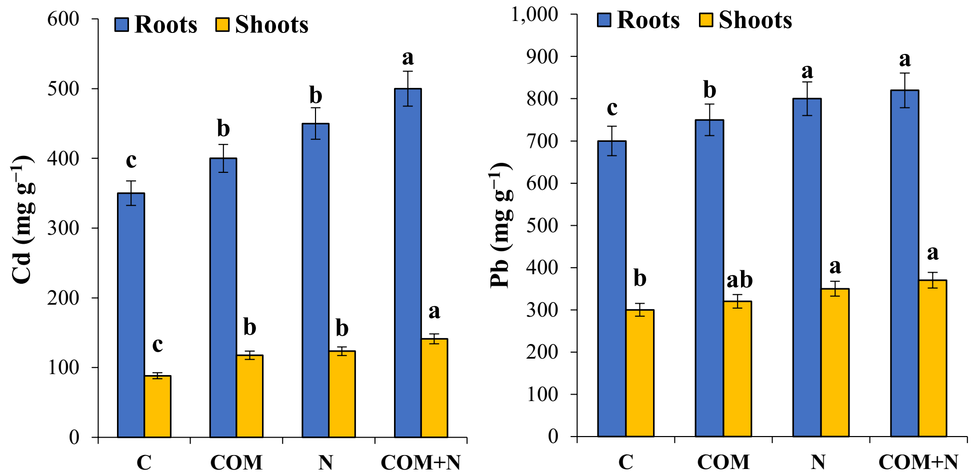

Fig. 1 Cd and Pb concentrations in the roots and shoots of quail bush plants as affected by nitrogen (N) and compost (COM). C, control without amendments. Means (± standard deviation, $n = 4$) denoted by different letters are significantly different at $P < 0.05$

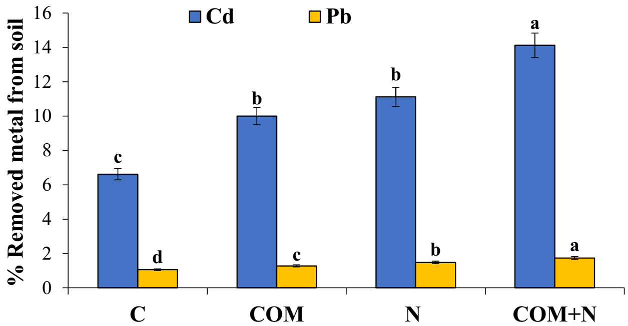

Fig. 2 Effect of nitrogen (N) and compost (COM) on the ability of quail bush plants in removing Cd and Pb from polluted soil. C, control without amendments. Means (± standard deviation, $n = 4$) denoted by different letters are significantly different at $P < 0.0$. % Removed element = (Metal in shoot (mg kg^{-1}) × Shoot dry weight (g pot^{-1}) × 100)/(Total metal in soil (mg kg^{-1}) × Soil weight in pot (g))

elements. Addition of N increased the removed Cd and Pb by 68 and 40%, respectively, compared to the control, while compost increased these values by 51 and 21%. Addition of COM + N increased the removed Cd and Pb by 113 and 64%. Quail bush plants grown on the contaminated soils and amended with COM + N removed 14 and 1.7% of the total soil Cd and Pb, respectively.

3.3 Effect of Compost and Nitrogen Fertilization on Soil Characteristics and Availability of Cd and Pb

The studied soil properties were affected significantly by the addition of nitrogen fertilizer N and COM (Table 4). The sole application of N increased the organic C and cation exchange capacity by 13 and 6%, respectively, compared to C, while COM increased these values by 34 and 18%. The combined addition of COM + N increased the organic C and cation exchange by 37 and 18%. The sole application of N reduced Cd and Pb availability by 22 and 13%, respectively, compared to C, while COM minimized these values by 18 and 7%, respectively. Addition of COM + N reduced Cd and Pb availability by 40 and 18% compared to the non-amended soil. The addition of COM and N fertilization significantly ($P < 0.05$) reduced the soil pH in comparison to C. The soil pH was reduced from 7.88 to 7.80, 7.73, and 7.62 when the soil was amended with COM, N, and COM + N, respectively. Adding COM + N was more effective in reducing the soil pH compared to the single additions.

Table 4 Effect of nitrogen (N) and compost (COM) on soil characteristics and availability of Cd and Pb

Treatments	Organic-C (g kg^{-1})	Cation exchange capacity (cmol kg^{-1})	EC (dS m^{-1})	pH 1:2	DTPA-Cd (mg kg^{-1})	DTPA-Pb (mg kg^{-1})
C	3.8 ± 0.26^{c}	17 ± 1.20^{b}	2.50 ± 0.06^{b}	7.88 ± 0.06^{d}	2.22 ± 0.05^{a}	4.40 ± 0.24^{a}
COM	5.1 ± 0.23^{a}	20 ± 1.31^{a}	3.40 ± 0.07^{a}	7.80 ± 0.03^{c}	1.82 ± 0.05^{b}	4.10 ± 0.35^{b}
N	4.3 ± 0.12^{b}	18 ± 1.12^{b}	3.50 ± 0.08^{a}	7.73 ± 0.02^{b}	1.73 ± 0.08^{c}	3.85 ± 0.25^{c}
COM + N	5.2 ± 0.15^{a}	20 ± 1.52^{a}	3.60 ± 0.09^{a}	7.62 ± 0.05^{a}	1.33 ± 0.06^{d}	3.63 ± 0.37^{d}

Means (± standard deviation, $n = 4$) denoted by different letters are significantly different at $P < 0.05$

C control without amendments, *EC* electric conductivity of soil solution

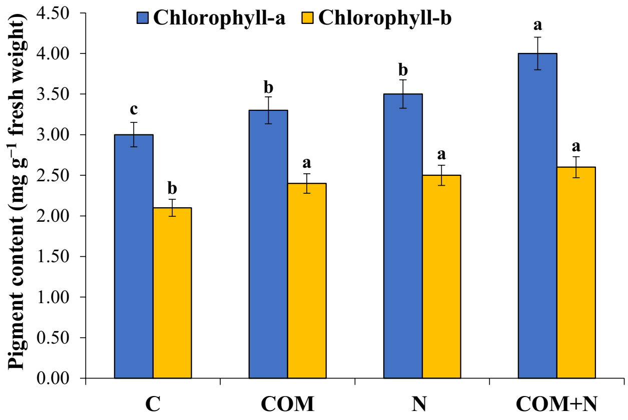

Fig. 3 Chlorophyll content in the leaves of quail bush as affected by nitrogen (N) and compost (COM). C, control without amendments. Means (± standard deviation, $n=4$) denoted by different letters are significantly different at $P<0.05$

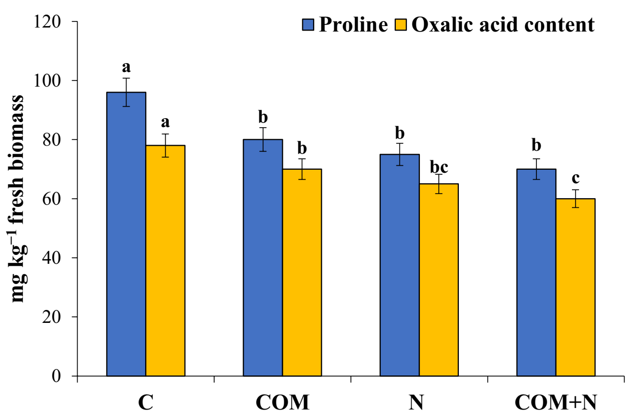

Fig. 4 Proline and oxalic acid content in the leaves of quail bush as affected by nitrogen (N) and compost (COM). C, control without amendments. Means (± standard deviation, $n=4$) denoted by different letters are significantly different at $P<0.05$

3.4 Effect of Compost and Nitrogen Fertilization on Some Biochemical Compounds in the Leaves of Quail Bush Plants

COM and N significantly ($P<0.01$) reduced the proline and oxalic acid content in the leaves of quail bush plants grown on the contaminated soil (Fig. 3); on the other hand, the mentioned amendments caused significant increases ($P<0.002$) in the chlorophyll content (Fig. 4). The addition of N to the contaminated soil reduced the proline and oxalic acid content in quail bush leaves by 22 and 17%, respectively, compared to C, while compost minimized these values by 17 and 10%. N addition increased chlorophyll *a* and chlorophyll *b* by 17 and 19%, while these increases were 10 and 14% in the case of COM. Addition of COM + N reduced the proline and oxalic acid by 27 and 23%, respectively; on the other hand, this treatment increased the chlorophyll *a* and chlorophyll *b* by 33 and 24%, respectively, compared to C.

4 Discussion

Long-term use of untreated wastewaters in the irrigation of agriculture soils increases the levels of toxic metals; moreover, it may also lead to the access of these elements to the food chain, which poses a threat to the health of living organisms and the environmental ecosystem (Khalilzadeh et al. 2020; Kheir et al. 2021; Ding et al. 2021a, 2021b). The levels of total Cd and Pb in the soil used in this study were 40 and 850 mg kg^{-1}, while the available forms were 2.4 and 4.8 mg kg^{-1} (Table 1). The soil of the current study contains levels of Cd and Pb above the permissible limits of European Union Standards (EU 2002) and United States Environmental Protection Agency (USEPA 1997). The two mentioned agencies confirm that soil containing more than 3 and 300 mg kg^{-1} of total Cd and Pb, respectively, is considered a metal-contaminated soil. The main reason for raising the limits of Cd and Pb in the current studied soil is the addition of untreated sewage wastewater for more than 60 years. Therefore, remediation of metal-contaminated soil is important in order to preserve the non-renewable resources in order to achieve sustainable development (Ding et al. 2021a, 2021b; Almaroai and Eissa 2020).

Plants that are used in the phytoremediation of polluted soils must be characterized by their high ability to grow under the metal stress conditions (Eissa and Abeed 2019). Quail bush plants, in the current study, were able to grow under the high levels of Cd and Pb toxicity without showing any symptoms of being affected by these high concentrations. The high toxicity of metals in the contaminated soils is the first problem facing the plant growth. The presence of these toxic elements in plant growth media leads to physiological damage to the plant cells, which may lead to the plant's inability to complete its life cycle, and this depends primarily on the presence of the plant's defense systems to counter this type of stress (Zheng et al. 2021; Rai et al. 2021).

The growth of quail bush plants in the contaminated soil was improved significantly by the addition of nitrogen and compost. Both nitrogen and compost led to remarkable increases in the growth characteristics, while adding the two mentioned amendments together significantly outperformed the individual additions. Compost and nitrogen are valuable soil conditioners and source of plant nutrients and their positive effects on the plant growth have been reported in several studies (Ding et al. 2020; Pampuro et al. 2020; Liu et al. 2021). The increase in the quail bush plants planted on the metal-contaminated soil is due to increasing the nutrient availability and chlorophyll synthesis and alleviating the metal toxicity stress (Al-Sayed et al. 2020; Liu et al., 2021; Rai et al. 2021). Compost addition increases nutrient availability, improves soil structure and water holding capacity, and enhances the soil microbial activities and enzymes (Liu et al. 2021). Providing quail bush planted on the contaminated soil with adequate amount of N improves the growth by increasing the photosynthesis and the total leaf area, thus lead to increase in the total plant biomass (Noaman 2004; Qi et al. 2019; Chen et al. 2020). Adequate amounts of essential nutrient, e.g., nitrogen, not only affect the plant growth, but also alleviate the metal toxicity (An et al. 2002; Eissa and Roshdy 2018). In the current study, the addition of compost and nitrogen alleviated the metal toxicity and reduced the accumulation of proline and oxalic acid in the leaves of quail bush plants. Plants exposed to metal stress direct their energy to form some compounds that help them regulate the osmosis of plant cells, but in the end, this comes at the expense of plant growth (Eissa and Roshdy 2018; Eissa and Abeed 2019; Ma et al. 2021). The combined addition of compost and nitrogen increased the uptake of Cd and Pb by quail bush plants. The high ability of quail bush in absorbing Cd and Pb under the compost and nitrogen fertilization is due to the improving of root growth. The addition of N enhanced the root biomass, root surface area, and root length (Chen et al. 2020). In the current study, the combined application of compost and nitrogen increased the root biomass of quail bush plants by 55% compared to the untreated soil. Increasing the growth of roots enables to explore more area of soil (Qi et al. 2019; Chen et al. 2020). Moreover, the application of compost and nitrogen reduces the soil pH from 7.88 to 7.62. Lowering the pH of the alaknie soil decreases the metal adsorption by clay minerals and organic soil collides and this may increase the availability of soil Cd and Pb (Zeng et al. 2011; Wei et al. 2020).

The roots of quail bush plants in the current study contained 350–500 mg kg^{-1} of Cd and 700–820 mg kg^{-1} of Pb (dry weight basis), while the aboveground parts contained 88–141 and 300–370 mg kg^{-1} of Cd and Pb, respectively. The toxicity limits in plant tissues are 5–30 (Cd) and 30–300 (Pb) mg kg^{-1} (dry weight basis) (Kabata-Pendias 2001). The studied quail bush plants were able to withstand concentrations of Cd and Pb much higher than the toxicity limits in traditional plants, which qualifies them for use in the phytoremediation of soil contaminated with toxic metals. The plants that used in phytoremediation of metal-contaminated soils must have strong tolerance to metal toxicity without showing symptoms of toxicity (Baker et al. 2000). The studied soil contains 850 and 40 mg kg^{-1} of Pb and Cd which are above the permissible limits (Inglezakis et al. 2014). Although the studied soil and plant tissues contain concentrations higher than the toxicity limits of Cd and Pb, no symptoms of toxicity of elements appeared on the tested plants, which make them eligible for use in the remediation of polluted soils. The quail bush plants are able to protect themselves against toxicity stress through vacuolar sequestration of toxic elements, by linking these metals to some organic acids, e. g., malate, citrate, or oxalate, or by phytochelating by glutathione (Lutts et al. 2004; Ali et al. 2013; Eissa 2017; Eissa and Abeed 2019).

Quail bush plants removed 6.1–14.1% of the total soil Cd and only 1.0–1.7% of the total soil Pb. The studied plants were able to remove large amounts of Cd from the polluted soils, while the removed quantities were very small in the case of Pb. Phytoextraction is the use of plant in removing toxic elements from contaminated soils, water, and sludge, and the plants used for that technique are able to absorb toxic element by their roots and then transfer to the aboveground parts (Chaney et al. 1997). The removed amount of element depends on the concentration of the element in the shoot multiplied by the total dry weight of the aboveground parts (Chaney et al. 1997). The combined addition of compost and nitrogen increased the growth of roots and shoots of quail bush plants. Increasing the growth of the root system of quail bush plants encouraged the plants to reach a larger volume of contaminated soil and thus increased the plant's ability to remove Cd and Pb from the soil. On the other hand, the addition of nitrogen fertilizer with compost led to a significant improvement in the vegetative growth and thus increased the total biomass of the plant. Addition of compost and nitrogen to quail bush plants grown on the metal-contaminated soils is an effective tool to increase the root and shoot growth (Eissa and Ahmed 2016; Eissa and Roshdy 2018; Feng et al. 2020).

5 Conclusion

Phytoextraction which is a technique of using plants in removing toxic elements from contaminated soils has become one of the most effective and widespread means because it is safe for environmental ecosystems. In this research paper, quail bush plants were used in the phytoextraction of cadmium (Cd) and lead (Pb) from a metal-contaminated soil. Quail bush plants removed 6.1–14.1% of the total soil Cd, while in the case of Pb, they only removed 1.0–1.7% of the total soil Pb. The addition of compost and nitrogen increased the ability of quail bush plants in removing Cd and Pb from the contaminated soil. The addition of compost and nitrogen alleviates the metal toxicity stress and increases the removed metal at the end of the experiment. Quail bush plants planted in polluted soils and amended with both compost and nitrogen can remove 14% of the total soil Cd during a year. The finding of the current study confirms that the studied quail bush plants can remove large amount of soil Cd and negligible amount of Pb from the contaminated soils. More studies are required on the use of soil conditioners and nutrients to stimulate the ability of these plants to remove larger amount of polluting elements. Field studies are required to evaluate various rates and types of organic amendments. In addition, the fractions of heavy metals should be studied to explore the mechanism of transformation of heavy metals in the contaminated soils as a result of the addition of soil amendments.

Funding The authors extend their appreciation to the deanship of scientific research for funding this article by Taif University Researchers Supporting Project (number (TURS-2020/199), Taif University, Saudi Arabia.

Declarations

Conflict of Interest The authors declare no competing interests.

References

Ali B, Huang CR, Qi ZY, Ali S, Daud MK, Geng XX, Liu HB, Zhou WJ (2013) 5-Aminolevulinic acid ameliorates cadmium-induced morphological, biochemical and ultra structural changes in seedlings of oilseed rape. Environ Sci Pollut Res 20:7256–7267

Ali AM, Awad MYM, Hegab SA, Abd El Gawad AM, Eissa MA (2021) Effect of potassium solubilizing bacteria (*Bacillus cereus*) on growth and yield of potato. Journal of Plant Nutrition 44(3):411–420. https://doi.org/10.1080/01904167.2020.1822399

Al-Sayed HM, Hegab SA, Youssef MA, Khalafalla MY, Almaroai YA, Ding Z, Eissa MA (2020) Evaluation of quality and growth of roselle (*Hibiscus sabdariffa* L.) as affected by bio-fertilizers. Journal of Plant Nutrition 43(7):1025–1035. https://doi.org/10.1080/01904167.2020.1711938

Almaroai YA, Eissa MA (2020) Effect of biochar on yield and quality of tomato grown on a metal-contaminated soil. Scie Hort 265:109210. https://doi.org/10.1016/j.scienta.2020.109210

An ZZ, Wang XC, Shi WM, Yan WD, Cao ZH (2002) Plant physiological responses to the interactions between heavy metal and nutrients. Soil Environ Sci 11:392–396

Arnon DI (1949) Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta vulgaris*. Plant Phys 24:1–15

Baker AM, McGrath SP, Reeves RD, Smith JC (2000) Metal hyperaccumulator plants: a review of the ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In: Terry N, Banuelos G, Vangronsveld J (eds) Phytoremediation of contaminated soil and water. Lewis Publisher, Boca Raton, FL, USA, pp 85–107

Bates LS, Walden RP, Teare ID (1973) Rapid determination of free proline for water stress studies. Plant Soil 39:205–207

Burt R (2004) Soil survey laboratory methods manual. Soil Survey Investigations Report No. 42, Version 4.0, Natural Resources Conservation Service, United States Department of Agriculture

Carter MR, Gregorich EG (2007) Soil sampling and methods of analysis. 2nd (Ed), CRC Press, Boca Raton. FL, ISBN: 0849335868:427–444

Chaney RL, Malik M, Li YM, Brown SL, Brewer EP, Angle JS, Baker AJ (1997) Phytoremediation of soil metals. Curr Opin Biotechnol 8:279–328

Chen J, Liu L, Wang Z, Zhang Y, Sun H, Song S, Bai Z, Lu Z, Li C (2020) Nitrogen fertilization increases root growth and coordinates the root–shoot relationship in cotton. Front Plant Sci 11:880. https://doi.org/10.3389/fpls.2020.00880

Chen L, Liu J, Zhang W, Zhou J, Luo D Li Z (2021) Uranium (U) source, speciation, uptake, toxicity and bioremediation strategies in soil-plant system: a review. J HazardMater 125319. https://doi.org/10.1016/j.jhazmat.2021.125319

Conte P, Agretto A, Spaccini R, Piccolo A (2005) Soil remediation: humic acids as natural surfactants in the washings of highly contaminated soils. Environ Pollu 135:515–522. https://doi.org/10.1016/j.envpol.2004.10.006

Ding Z, Alharbi S, Almaroai YA, Eissa MA (2021a) Improving quality of metal-contaminated soils by some halophyte and non-halophyte forage plants. Sci Total Environ 764:142885. https://doi.org/10.1016/j.scitotenv.2020.142885

Ding Z, Zhou Z, Lin X, Zhao F, Wang B, Lin F, Ge Y, Eissa MA (2020) Biochar impacts on NH3-volatilization kinetics and growth of sweet basil (Ocimum basilicum L) under saline conditions. Ind Crops Products 157:112903. https://doi.org/10.1016/j.indcrop.2020.112903

Ding Z, Ali EF, Elmahdy AM, Ragab KE, Seleiman MF, Kheir AM (2021b) Modeling the combined impacts of deficit irrigation, rising temperature and compost application on wheat yield and water productivity. Agric Water Manag 244:106626. https://doi.org/10.1016/j.agwat.2020.106626

Eissa MA, Ahmed EM (2016) Nitrogen and Phosphorus Fertilization for some *Atriplex* Plants Grown on Metal-contaminated Soils. Soil and Sediment Contamination: An International Journal 25(4):431–442. https://doi.org/10.1080/15320383.2016.1158693

Eissa MA, Negim OE (2018) Heavy metals uptake and translocation by lettuce and spinach grown on a metal-contaminated soil. J Soil Sci Plant Nutr 18:1097–1107. https://doi.org/10.4067/S0718-95162018005003101

Eissa MA (2017) Phytoextraction mechanism of Cd by Atriplex lentiformis using some mobilizing agents. Ecol Eng 108:220–226

Eissa MA, Abeed AH (2019) Growth and biochemical changes in quail bush (*Atriplex lentiformis* (Torr.) S.Wats) under Cd stress. Environ Sci Pollut Res 26:628–635

Eissa MA, Ahmed E, Reichman SM (2016) Production of the forage halophyte *Atriplex amnicola* in metal-contaminated soils. Soil Use Manage 32:350–356

Eissa MA, Roshdy NMK (2018) Nitrogen fertilization: effect on Cd-phytoextraction by the halophytic plant quail bush [*Atriplex lentiformis* (Torr.) S. Wats]. Safr J Bot 115:126–131

European Union (EU) (2002) Heavy metals in wastes, European commission on environment (http://ec.europa.eu/environment/waste/studies/pdf/heavy metals report.pdf)

Feng H, Li Y, Yan YX, Wei YY, Long Zhang L, Lin Ma L, Wu Li W, Xiangru Tang X, Zhaowen Mo Z (2020) Nitrogen regulates the grain yield, antioxidant attributes, and nitrogen metabolism in fragrant rice grown under lead-contaminated soil. J Soil Sci Plant Nutr 20:2099–2111. https://doi.org/10.1007/s42729-020-00278-y

Hua L, Wang Y, Wu W, McBride MB, Chen Y (2008) Biomass and Cu and Zn uptake of two turfgrass species grown in sludge compost-soil mixtures. Water Air Soil Pollut 188:225–234

Inglezakis VJ, Zorpas AA, Karagiannidis A, Samaras P, Voukkali I, Sklari S (2014) European Union legislation on sewage sludge management. Fresenius Environ Bull 23:635–639

Kabata-Pendias A (2001) Trace elements in soils and plants, 3rd edn. CRC, Boca Raton

Khalilzadeh R, Pirzad A, Sepehr E, Khan S, Anwar S (2020) Long-term effect of heavy metal–polluted wastewater irrigation on physiological and ecological parameters of *Salicornia europaea L*. J Soil Sci Plant Nutr 20:1574–1587. https://doi.org/10.1007/s42729-020-00299-7

Khan AHA, Kiyani A, Mirza CR, Butt TA, Barros R, Ali B, Iqbal M, Yousaf S (2021) Ornamental plants for the phytoremediation of heavy metals: present knowledge and future perspectives. Environ Res 195:110780. https://doi.org/10.1016/j.envres.2021.110780

Kheir AMS, Ali EF, Ahmed M, Eissa MA, Majrashi A, Ali AM (2021) Biochar blended humate and vermicompost enhanced immobilization of heavy metals, improved wheat productivity, and minimized human health risks in different contaminated environments. J Environ Chemical Eng 9:105700

Kumar V, Ferreira LFR, Sonkar M, Singh J (2021) Phytoextraction of heavy metals and ultrastructural changes of Ricinus communis L. grown on complex organometallic sludge discharged from alcohol distillery. Environ Technol Innov 22:101382. https://doi.org/10.1016/j.eti.2021.101382

Li J, Ali EF, Majrashi A, Eissa MA, Ibrahim OH (2021) Compost enhances forage yield and quality of river saltbush in arid conditions. Agriculture 11:595. https://doi.org/10.3390/agriculture11070595

Lindsay WL, Norvell WA (1969) Equilibrium relationship of Zn^{+2}, Fe^{+3}, Ca^{+2} and H^{+} with EDTA and DTPA in soils. Soil Sci Soc Am Proc 33:62–68

Liu D, Ding Z, Ali EF, Kheir AM, Eissa MA, Ibrahim OH (2021) Biochar and compost enhance soil quality and growth of roselle (Hibiscus sabdariffa L.) under saline conditions. Sci Rep 11:8739. https://doi.org/10.1038/s41598-021-88293-6

Lutts S, Lefe I, Delpe C, Kivits S (2004) Heavy metal accumulation by halophyte species. J Environ Qual 33:1271–1279

Ma L, Huang Z, Li S, Ashraf U, Yang W, Liu H, Xu D, Li Wu, Zhaowen W, Mo Z (2021) Melatonin and nitrogen applications modulate early growth and related physio-biochemical attributes in maize under cd stress. J Soil Sci Plant Nutr 21:978–990. https://doi.org/10.1007/s42729-021-00415-1

Manousaki E, Kalogerakis N (2009) Phytoextraction of Pb and Cd by the Mediterranean saltbush (*Atriplex halimus* L.): metal uptake in relation to salinity. Environ Sci Pollut Res 16:884–854

Marschner H (1997) Mineral nutrition of higher plants. Academic press, N.Y.

Martin TA, Ruby MV (2004) Review of in situ remediation technologies for lead, zinc and cadmium in soil. Remed J 14:35–53

Naik VV, Patil NS, Aparadh VT, Karadge BA (2014) Methodology in determination of oxalic acid in plant tissue: a comparative approach. J Glob Trends Pharm Sci 5:1662–1672

Noaman MN (2004) Effect of potassium and nitrogen fertilizers on the growth and biomass production of some halophytes under high levels of salinity. J Agron 3:25–30

Pampuro N, Caffaro F, Cavallo E (2020) Farmers attitudes toward on-farm adoption of soil organic matter in Piedmont Region. Italy Agriculture 10:14

Qi D, Hu T, Song X, Zhang M (2019) Effect of nitrogen supply method on root growth and grain yield of maize under alternate partial root-zone irrigation. Sci Rep 9:1–10. https://doi.org/10.1038/s41598-019-44759-2

Rai KK, Pandey N, Meena RP, Rai SP (2021) Biotechnological strategies for enhancing heavy metal tolerance in neglected and underutilized legume crops: a comprehensive review. Ecotoxicol Enviro Saf 208:111750. https://doi.org/10.1016/j.ecoenv.2020.111750

Scotti R, Pane C, Spaccini R, Palese AM, Piccolo A, Celano G, Zaccardelli M (2016) On-farm compost: a useful tool to improve soil quality under intensive farming systems. Applied Soil Ecol 107:13–23. https://doi.org/10.1016/j.apsoil.2016.05.004

Seleiman MF, Kheir AM (2018) Maize productivity, heavy metals uptake and their availability in contaminated clay and sandy alkaline soils as affected by inorganic and organic amendments. Chemosphere 204:514–522

Sharma P, Pandey AK, Udayan A, Kumar S (2021) Role of microbial community and metal-binding proteins in phytoremediation of heavy metals from industrial wastewater. Bioresour Technol:124750

Singh R, Agrawal M (2007) Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of *Beta vulgaris* plants. Chemosphere 67:2229–2240

USEPA (United State Environmental Protection Agency). 1997. Exposure factors handbook. Volume II—food ingestion factors. EPA/600//P-95/002Fa.Office of Research and Development. Washington, DC, USA

Wei B, Yu J, Cao Z, Meng M, Yang L, Chen Q (2020) The availability and accumulation of heavy metals in greenhouse soils associated with intensive fertilizer application. Int J Environ Res Public Health 17:5359

Weia S, Li Y, Zhou Q, Srivastava M, Chiu S, Zhane J, Wu Z, Sun T (2010) Effect of fertilizer amendments on phytoremediation of Cd-contaminated soil by a newly discovered hyperaccumulator *Solanum nigrum* L. J Hazard Mater 176:269–273

Wu B, Peng H, Sheng M, Luo H, Wang X, Zhang R, Xu F, Xu H (2021) Evaluation of phytoremediation potential of native dominant plants and spatial distribution of heavy metals in abandoned mining area in Southwest China. Ecotoxicol Environ Saf 220:112368

Yildirim E, Ekinci M, Turan M, Ağar G, Dursun A, Kul R, Alim Z, Argin S (2021) Humic^{+} fulvic acid mitigated Cd adverse effects on plant growth, physiology and biochemical properties of garden cress. Sci Rep 11:1–8. https://doi.org/10.1038/s41598-021-86991-9

Zeng F, Ali S, Zhang H, Ouyang Y, Qiu B, Wu F, Zhang G (2011) The influence of pH and organic matter content in paddy soil on heavy metal availability and their uptake by rice plants. Environ Pollut 159:84–91

Zeng J, Han G, Yang K (2020) Assessment and sources of heavy metals in suspended particulate matter in a tropical catchment, northeast Thailand. J Clean Prod 265:121898. https://doi.org/10.1016/j.jclepro.2020.121898

Zheng S, Liu S, Feng J, Wang W, Wang Y, Yu Q, Liao Y, Mo Y, Xu Z, Li L, Gao X (2021) Overexpression of a stress response membrane protein gene OsSMP1 enhances rice tolerance to salt, cold and heavy metal stress. Environ Exp Bot 182:104327. https://doi.org/10.1016/j.envexpbot.2020.104327

Authors and Affiliations

Mamdouh A. Eissa[1] · Hatim M. Al-Yasi[2] · Adel M. Ghoneim[3] · Esmat F. Ali[2] · Rania El Shal[4]

[1] Department of Soils and Water, Faculty of Agriculture, Assiut University, Assiut 71526, Egypt

[2] Department of Biology, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia

[3] Field Crops Research Institute, Agricultural Research Center, Giza 12112, Egypt

[4] Department of Soil and Water Science, Faculty of Agriculture, Tanta University, P.O. Box 31527, Tanta, Egypt