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Research Article

Influence of NaCl-Induced Salinity and Cd Toxicity on Respiration Activity and Cd Availability to Barley Plants in Farmyard Manure-Amended Soil

Adel R. A. Usman[1,2]

[1] *Department of Soils and Water, Faculty of Agriculture, Assiut University, Assiut 71526, Egypt*
[2] *Department of Soil Science, College of Food and Agriculture, King Saud University, P.O. Box 2460, Riyadh 114514, Saudi Arabia*

Correspondence should be addressed to Adel R. A. Usman; adelusman71@yahoo.com

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The objective of this study was to evaluate the Cd availability and toxicity as affected by NaCl-induced salinity and farmyard manure addition. The Cd availability and toxicity were investigated in greenhouse pot and incubation experiments were conducted on a calcareous loamy sand soil contaminated with Cd (0.5, 1.5, 3, 6, 12, and 24 mg kg^{-1} of soil) and amended with two rates of 0.0 and 30 g farmyard manure (FYM) kg^{-1}. Barley seeds (*Hordeum vulgare* L.) were sown in pots and irrigated with water containing different levels of salinity (0, 30, 60, and 120 mM NaCl). The results revealed that the DTPA-extractable Cd and its content in barley plant shoots tended to increase in line as Cd was applied and salt levels increased. Elevated decreases in the soil basal respiration with increased Cd applied and NaCl-induced salinity were found. However, applying FYM significantly reduced Cd availability and increased plant growth and soil respiration activity. The results clearly showed that adding farmyard manure as soil organic amendment decreased the availability of Cd to barley plants and mitigated the toxicity of both Cd and salinity to soil microbial activity.

1. Introduction

Cadmium (Cd) is one of the most dangerous heavy metals due to its high mobility and phytoavailability [1, 2]. Due to its high accumulation in the tissues of plants and animals, the Cd toxicity affects adversely human health. Moreover, Cd may have a negative effect on soil microbial activities altering soil nutrient cycle and subsequently resulting in changes in soil fertility [1, 3]. The bioavailability of heavy metals in soils depends on numerous factors such as pH, $CaCO_3$, clay content, organic matter nature and content, redox potential, and soil solution composition [2, 4, 5].

Soils and irrigation water of arid regions are characterized by high salinity levels, which may aggravate heavy metal pollution problems. In arid regions, irrigation water containing high levels of chloride ions might increase soil heavy metal mobilization through the formation of metal-chloride complexes [6, 7]. It has been reported that the consequences of soil salinity can increase or decrease heavy metal solubility and availability, mainly depending on the composition of soil solution and its dominant inorganic ligands [6–8].

Application of organic amendments to soil has been shown to improve soil fertility and alleviate environmental stresses in soils, resulting in enhancing plant growth. Specifically, the addition of organic amendments to soils can result in situ immobilization of heavy metals and subsequently reduce their bioavailability [8–10]. Ok et al. [9] reported that the addition of organic residues to heavy metal-contaminated soils increased soil organic matter content, improved the chemical and biological properties, and decreased the heavy metal phytoavailability. The effect of organic amendments on metal availability to plants corresponds to several factors including their influences on biochemical soil properties [9–11]. Recently, it has been reported that the application of organic manure to heavy metal-contaminated soil decreased the metal toxicity and subsequently increased soil microbial activities [12]. To our knowledge, however, there is no available information on the role of organic amendments in terms of their contribution to decrease metal phytotoxicity under saline conditions. Therefore, the objective of the present work was to study the influence of salinity and Cd toxicity on Cd availability to barley plants and soil respiration in farmyard manure-amended calcareous loamy sand soil.

2. Materials and Methods

2.1. Soil Samples and Characterization. The surface layer (0–30 cm) of agricultural loamy sand calcareous soils was collected from Assiut University Experimental Farm, Assiut, Egypt. All samples were air-dried and sieved by using a 2 mm mesh prior to soil characterization and experiments setup. The particle size distribution of soil samples was determined by the pipet method [13]. Soil chemical properties were measured according to standard methods [14]. Soil pH was measured using a digital pH meter in a saturation paste. The EC values were measured in paste extracts using a digital EC meter. Calcium carbonate content was determined using the calcimeter method. Soil organic matter (OM) was determined by a modified Walkley and Black method [15]. The particle size distribution was measured by the hydrometer method. The total Cd in the soil was determined using a GBC model 906 atomic absorption spectrophotometer (AAS) after conventional aqua regia digestion method [16]. The particle size distribution was 800 g sand kg^{-1}, 147 g silt kg^{-1}, and 53 g clay kg^{-1}, indicating a texture of loamy sand. The pH of the soil was 7.82 and the electrical conductivity was 3.64 dS m^{-1}. The organic C and $CaCO_3$ contents were 0.21% and 9.30%, respectively. The total soil content of Cd was 0.13 mg kg^{-1}. The pH and organic matter content of applied farmyard manure were 7.15 and 32.60%, respectively.

2.2. Pot Experiment. A greenhouse pot experiment was carried out to investigate the interactive effects of NaCl-induced salinity and farmyard manure (FYM) on soil Cd availability and its uptake by barley plants (*Hordeum vulgare* L.) grown on sandy calcareous soils. A greenhouse experiment with six levels of Cd (0.5, 1.5, 3, 6, 12, and 24 mg kg^{-1} of soil, in the form of $CdCl_2$), two rates of farmyard manure (0.0 and 30 g FYM kg^{-1}), and four salinity levels was conducted. The four salinity levels were prepared by using deionized water with salinity of 0 (S0), 30 (S1), 60 (S2), and 120 (S3) mM NaCl. Plastic pots were filled with 3 kg of the artificially Cd-contaminated sandy calcareous soil samples treated and untreated with FYM. Ten seeds of barley plants were planted in each pot. The plants were thinned to five barley plants per pot after germination. The pots were irrigated with the water containing different salinity levels. Overall, in experiment period, all the pots were maintained at field capacity moisture content by weight. NPK basal fertilization was used with the first irrigation. The experiment was designed using a randomized complete block design with three replications.

2.3. Soil and Plant Analysis. At the end of the experiment, soil pH was measured using a digital pH meter in a saturation paste. Electrical conductivity (EC_e) and concentrations of Ca^{++}, Mg^{++}, Na^+, K^+, $SO_4{}^{-2}$, $HCO_3{}^-$, and Cl^- were measured in the paste extracts according to standard methods of Sparks [14]. The concentrations of Na and K were analyzed using a flame photometer. The concentrations of Ca^{++}, Mg^{++}, Cl^-, and $HCO_3{}^-$ were determined by titration. Sulfate ($SO_4{}^{-2}$) was determined using the turbidimetric method. In order to determine the available fraction of soil Cd, the soil samples were extracted by DTPA (diethylene triamine penta acetic acid) according to Norvell et al. [17]. The suspension was then shaken and centrifuged. The supernatant was filtered through Whatman No. 42 filter paper. Cd concentrations in the filtered solutions were analyzed by atomic absorption spectrophotometer (AAS).

Barley plants were harvested after 50 days of planting. To determine dry shoots weight, shoot samples of barley plants were oven-dried at 70°C. Dried shoots were ground and digested using a 2 : 1 $HNO_3 : HClO_4$ acid mixture. The shoot Cd concentrations were analyzed by AAS.

2.4. Incubation Experiment. At the end of the greenhouse pot experiment, the soil samples of each pot were collected and used to investigate the interactive effects of NaCl-induced salinity and Cd toxicity on soil basal respiration in farmyard manure-amended sandy calcareous soil. This experiment was conducted with the soil samples which were treated with two levels of Cd (0.5 and 24 mg kg^{-1} of soil) and amended with two rates of 0.0 and 30 g FYM kg^{-1} and different salinity levels of 0 (S0), 30 (S1), 60 (S2), and 120 (S3) mM NaCl.

The soil mixtures (100 g) were put in glass vessels (250 mL). Deionized water was added to each soil mixture to bring it to 70% of field capacity. Each treatment was replicated three times. Small vials with 10 mL of 1 M NaOH solution were placed in vessels to trap CO_2. After the addition of NaOH, the vessels were closed air tight and incubated for 28 days at 30°C. The NaOH solutions in the vials were changed after 1, 3, 7, 14, 21, and 28 days. CO_2 evolved during the incubation periods was trapped in 1 M NaOH and the excess NaOH was titrated with 0.1 M HCl following the $BaCl_2$ addition [18]. The soil respiration was calculated as CO_2-C rate (mg C g^{-1} soil day^{-1}).

2.5. Statistical Analysis. The mean values and standard deviation (±SD) of three replicates are calculated. The analysis of variance was performed using the statistical computer program of StatSoft [19].

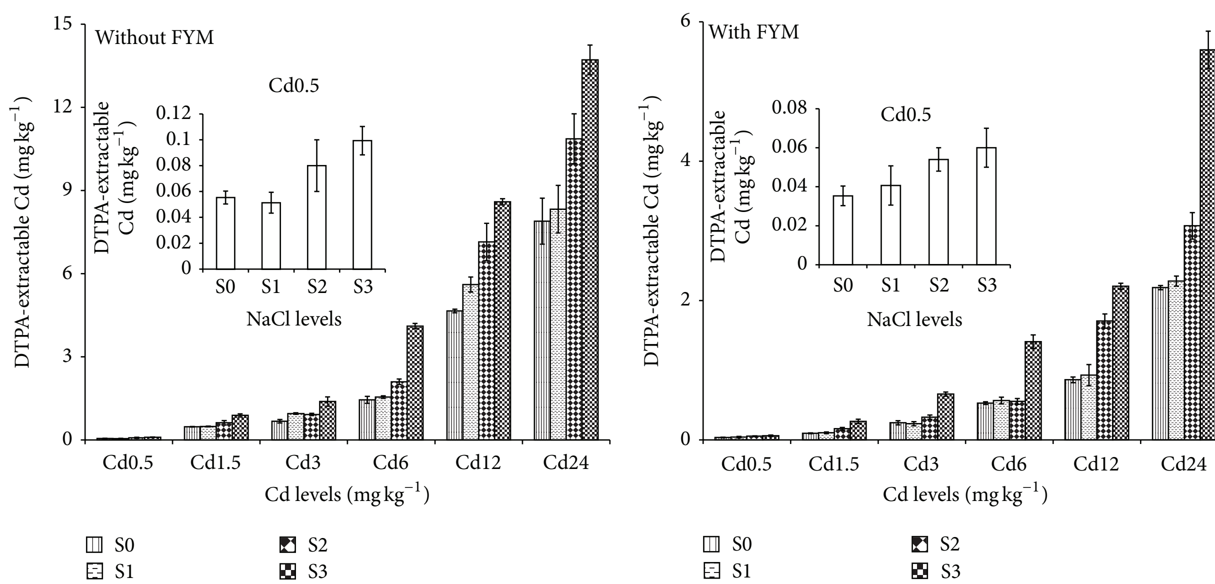
3. Results

3.1. Treatment Effects on Soil pH, EC, and Soluble Cations and Anions. Soil pH decreased slightly in the soils irrigated with saline water, especially with increasing NaCl salt levels (Table 1). As expected, the values of EC_e were significantly increased with increasing NaCl levels as well as in the presence of FYM. Na^+ and Cl^-concentrations increased in line as salt levels increased in NaCl-treated soils. It was generally observed that the irrigation with saline water caused significant increases in soluble K^+. The results clearly showed also that the addition of

Table 1: Treatment effects on pH, EC_e, and soluble cations and anions (±SD).

NaCl levels	pH	EC_e ($dS\,m^{-1}$)	Cations (mmol (+) L^{-1})				Anions (mmol (−) L^{-1})		
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	HCO_3^{-}
Without FYM									
S0	7.86 ± 0.05	3.69 ± 0.05	9.01 ± 0.72	4.02 ± 0.40	9.11 ± 1.18	0.39 ± 0.04	17.4 ± 0.83	8.66 ± 0.62	1.62 ± 0.10
S1	7.83 ± 0.04	4.19 ± 0.05	9.08 ± 0.64	4.01 ± 0.51	13.2 ± 1.10	0.36 ± 0.03	21.5 ± 1.08	8.59 ± 0.89	1.61 ± 0.08
S2	7.80 ± 0.03	4.95 ± 0.10	9.06 ± 0.84	4.19 ± 0.49	21.3 ± 1.42	0.44 ± 0.01	29.5 ± 1.94	8.92 ± 0.86	1.66 ± 0.06
S3	7.77 ± 0.05	6.29 ± 0.05	9.14 ± 0.70	4.36 ± 0.52	34.4 ± 1.55	0.52 ± 0.02	43.7 ± 2.35	9.10 ± 0.80	1.64 ± 0.07
LSD_S	0.04	0.06	NS	NS	1.07	0.03	1.34	NS	NS
With FYM									
S0	7.67 ± 0.03	3.84 ± 0.06	10.2 ± 0.71	4.74 ± 0.31	9.41 ± 1.00	0.62 ± 0.11	17.5 ± 1.52	8.90 ± 0.97	1.66 ± 0.07
S1	7.65 ± 0.04	4.33 ± 0.06	10.2 ± 0.66	4.90 ± 0.47	13.5 ± 1.51	0.63 ± 0.05	21.3 ± 1.76	8.93 ± 0.51	1.64 ± 0.07
S2	7.56 ± 0.05	5.16 ± 0.04	10.3 ± 0.76	5.21 ± 0.54	22.5 ± 1.13	0.68 ± 0.03	30.7 ± 1.60	9.01 ± 0.54	1.65 ± 0.06
S3	7.51 ± 0.04	6.42 ± 0.10	10.5 ± 0.65	5.01 ± 0.36	35.0 ± 1.88	0.78 ± 0.05	45.6 ± 1.73	9.23 ± 0.77	1.67 ± 0.06
LSD_S	0.03	0.06	NS	0.35	1.15	0.05	1.33	NS	NS
LSD_{SF}	0.02	NS	0.23	0.15	NS	0.03	NS	NS	0.02

LSD_S ($P < 0.05$) = salt effect; LSD_{SF} ($P < 0.05$) = salt ∗ FYM effect, S0 (without NaCl), S1 (30 mM NaCl), S2 (60 mM NaCl), and S3 (120 mM NaCl); NS = not significant.



(a) (b)

Figure 1: Treatment effects on DTPA-extractable Cd (±SD).

organic manure caused a significant increase in soluble Ca^{++}, Mg^{++}, and K^{+}.

3.2. Treatment Effects on DTPA-Extractable Cd. The impact of treatments on the DTPA-extractable Cd is shown in Figure 1. The DTPA-extractable Cd was increased with increasing Cd and NaCl levels. In the soils nontreated with NaCl and FYM, the DTPA-extractable Cd concentrations were 0.06, 0.48, 0.68, 1.45, 4.65, and 7.89 $mg\,kg^{-1}$ for Cd0.5, Cd1.5, Cd3, Cd6, Cd12, and Cd24, respectively. Moreover, the DTPA-extractable Cd increased with increasing the levels of NaCl salinity and accounted for 0.05–8.33 $mg\,kg^{-1}$ for S1 and to 0.08–10.87 $mg\,kg^{-1}$ for S2 and 0.10–13.71 $mg\,kg^{-1}$ for S3.

The addition of FYM significantly decreased the extractability of soil Cd compared to untreated soils. In soil samples treated with FYM, the concentrations of DTPA-extractable Cd were 0.04–2.19 $mg\,kg^{-1}$ for S0, 0.04–2.28 $mg\,kg^{-1}$ for S1, 0.05–3.07 $mg\,kg^{-1}$ for S2, and 0.06–5.60 $mg\,kg^{-1}$ for S3.

3.3. Treatment Effects on Dry Matter and Shoot Cd Concentrations of Barley Plants. The impact of treatments on the shoot dry matter of barley plants is shown in Table 2. Increasing

Table 2: Treatment effects on shoot dry matter of barley plants (g pot^{-1}).

FYM treatments	NaCl levels	Cd levels ($mg\,kg^{-1}$) 0.5	1.5	3	6	12	24	LSD_{Cd}
Without FYM	S0	0.83	0.80	0.85	0.83	0.82	0.71	NS
	S1	0.82	0.82	0.80	0.81	0.80	0.70	NS
	S2	0.77	0.78	0.77	0.74	0.68	0.60	NS
	S3	0.69	0.66	0.68	0.64	0.53	0.39	0.17
LSD_S		NS	NS	NS	0.11	0.13	0.13	
With FYM	S0	1.10	1.12	1.08	1.15	1.10	1.11	NS
	S1	1.15	1.11	1.09	1.13	1.12	1.10	NS
	S2	1.10	1.07	1.08	1.07	1.05	0.98	NS
	S3	1.07	1.05	1.06	0.97	0.92	0.78	0.20
LSD_S		NS	NS	NS	NS	NS	0.21	
LSD_{SF}		0.08	0.07	0.09	0.08	0.10	0.12	

LSD_{Cd} ($P < 0.05$) = Cd effect; LSD_S ($P < 0.05$) = salt effect; LSD_{SF} ($P < 0.05$) = salt ∗ FYM effect, S0 (without NaCl), S1 (30 mM NaCl), S2 (60 mM NaCl), and S3 (120 mM NaCl); NS = not significant.

Table 3: Treatment effects on shoot Cd content ($mg\,kg^{-1}$) of barley plants.

FYM treatments	NaCl levels	Cd levels ($mg\,kg^{-1}$) 0.5	1.5	3	6	12	24	LSD_{Cd}
Without FYM	S0	0.49	0.63	0.90	1.67	2.03	2.97	0.44
	S1	0.42	0.67	0.93	1.83	2.10	2.93	0.47
	S2	0.74	1.06	1.29	2.25	2.70	4.17	0.77
	S3	0.99	1.73	2.30	2.92	3.25	5.74	0.95
LSD_S		0.31	0.52	0.66	0.75	0.93	0.99	
With FYM	S0	0.33	0.34	0.70	1.13	1.57	1.90	0.42
	S1	0.35	0.26	0.67	1.47	1.53	2.05	0.45
	S2	0.52	0.64	0.91	1.48	2.04	2.38	0.54
	S3	0.47	1.03	1.17	1.89	2.17	3.08	0.66
LSD_S		NS	0.10	0.20	0.55	NS	0.95	
LSD_{SF}		0.18	0.36	0.41	0.43	0.50	0.85	

LSD_{Cd} ($P < 0.05$) = Cd effect; LSD_S ($P < 0.05$) = salt effect; LSD_{SF} ($P < 0.05$) = salt ∗ FYM effect, S0 (without NaCl), S1 (30 mM NaCl), S2 (60 mM NaCl), and S3 (120 mM NaCl); NS = not significant.

irrigation water salinity combined with increasing levels of Cd decreased significantly the shoot dry matter of barley plants (Table 2). Through the applied salinity levels without FYM, the shoot dry matter accounted for 0.71–0.85 g pot^{-1} in S0, for 0.70–0.82 g pot^{-1} in S1, for 0.60–0.78 g pot^{-1} in S2, and for 0.39–0.69 g pot^{-1} in S3. On the contrary, applying FYM significantly stimulated the biomass production of barley plants compared to the unamended soil. Through the applied salinity levels with FYM, the shoot dry matter accounted for 1.08–1.15 g pot^{-1} in S0, for 1.09–1.15 g pot^{-1} in S1, for 0.98–1.10 g pot^{-1} in S2, and for 0.78–1.07 g pot^{-1} in S3. These results clearly showed that NaCl-induced salinity significantly reduced the growth and shoot dry matter yield of barley plants, especially when the highest salt level (120 mM) was in conjunction with the highest Cd content (24 mg kg^{-1}).

The shoot Cd concentrations were increased with increasing applied Cd and NaCl levels (Table 3). In soil treated and nontreated with FYM, the addition of NaCl resulted in a significant increase in Cd concentrations in the shoot of barley plants. Through the applied Cd levels without FYM, the shoot Cd concentrations accounted for 0.49–2.97 mg kg^{-1} in S0, for 0.42–2.93 mg kg^{-1} in S1, for 0.74–4.17 mg kg^{-1} in S2, and for 0.99–5.74 mg kg^{-1} in S3. In soil treated with FYM, meanwhile, the shoot Cd concentrations were 0.33–1.90 mg kg^{-1} for S0, 0.26–2.05 mg kg^{-1} for S1, 0.52–2.38 mg kg^{-1} for S2, and 0.47–3.08 mg kg^{-1} for S3. These results indicated that applying FYM significantly reduced the Cd availability to barley plants.

The results also indicated that the increases in the shoot Cd concentration were correlated positively ($P < 0.05$) with the DTPA-extractable Cd (r^2 = 0.82–0.87), as shown in Figure 2.

3.4. Treatment Effects on Soil Respiration in Incubation Experiment. The CO_2-C evolution rates are presented in Table 4. The Cd and NaCl treatments in this study significantly reduced soil respiration. On the contrary, the FYM significantly enhanced soil respiration. In soil without FYM, the CO_2-C evolution rates were 0.0027–0.0276 mg C g^{-1} soil

Table 4: Treatment effects on CO_2-C evolution rate (mg C g^{-1} soil day^{-1}) during incubation time.

Cd levels	NaCl levels	Day 1	Day 3	Day 7	Day 14	Day 21	Day 28	LSD_T
		Incubation time						
		Without FYM						
0.5 ppm Cd	S0	0.0276	0.0140	0.0065	0.0035	0.0033	0.0033	0.0018
	S1	0.0263	0.0134	0.0062	0.0035	0.0033	0.0034	0.0036
	S2	0.0222	0.0109	0.0056	0.0029	0.0031	0.0031	0.0023
	S3	0.0164	0.0090	0.0049	0.0026	0.0025	0.0027	0.0024
LSD_S		0.0057	0.0025	0.0013	0.0016	0.0013	0.0017	—
24 ppm Cd	S0	0.0197	0.0105	0.0051	0.0029	0.0025	0.0025	0.0016
	S1	0.0181	0.0097	0.0046	0.0028	0.0023	0.0024	0.0020
	S2	0.0094	0.0055	0.0028	0.0017	0.0015	0.0015	0.0040
	S3	0.0069	0.0034	0.0017	0.0010	0.0009	0.0009	0.0013
LSD_S		0.0026	0.0044	0.0025	0.0011	0.0016	0.0008	—
LSD_{CdS}		0.0040	0.0033	0.0018	0.0013	0.0013	0.0012	
Cd levels	NaCl levels	With FYM						
0.5 ppm Cd	S0	0.1145	0.0653	0.0377	0.0226	0.0196	0.0177	0.0034
	S1	0.1125	0.0643	0.0373	0.0229	0.0197	0.0180	0.0025
	S2	0.1108	0.0631	0.0361	0.0225	0.0195	0.0178	0.0030
	S3	0.1013	0.0569	0.0324	0.0196	0.0175	0.0157	0.0027
LSD_S		0.0055	0.0046	0.0018	0.0012	0.0006	0.0009	—
24 ppm Cd	S0	0.1154	0.0658	0.0373	0.0221	0.0194	0.0175	0.0029
	S1	0.1137	0.0647	0.0367	0.0218	0.0193	0.0177	0.0021
	S2	0.0942	0.0544	0.0318	0.0191	0.0171	0.0153	0.0036
	S3	0.0769	0.0457	0.0275	0.0167	0.0144	0.0130	0.0036
LSD_S		0.0071	0.0040	0.0024	0.0010	0.0009	0.0011	
LSD_{CdS}		0.0058	0.0039	0.0019	0.0010	0.0007	0.0009	
LSD_{CdSF}		0.0047	0.0035	0.0018	0.0011	0.0010	0.0010	

LSD_T ($P < 0.05$): time effect; LSD_S ($P < 0.05$): salt effect; LSD_{CdS} ($P < 0.05$): Cd ∗ salt effect; LSD_{CdSF} ($P < 0.05$) = Cd ∗ salt ∗ FYM effect, S0 (without NaCl), S1 (30 mM NaCl), S2 (60 mM NaCl), and S3 (120 mM NaCl); NS = not significant.

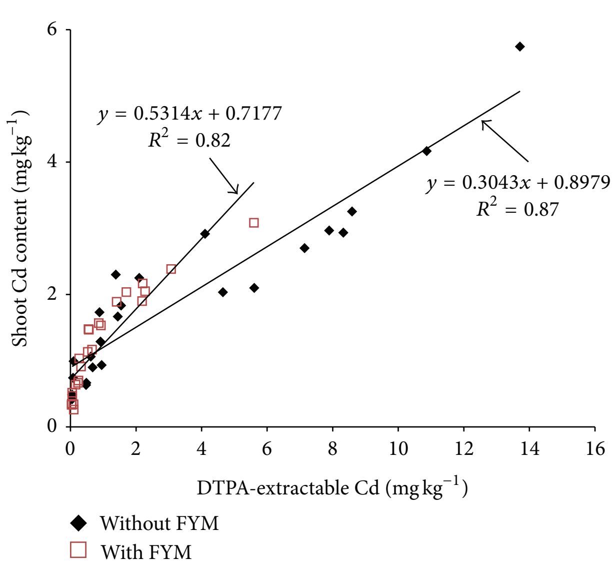


Figure 2: Relationship between shoot Cd concentrations and soil DTPA-extractable Cd.

day^{-1} at Cd0.5 and 0.0009–0.0197 mg C g^{-1} soil day^{-1} at Cd24. Meanwhile, in soil treated with FYM, the CO_2-C evolution rates were 0.0157–0.1145 mg C g^{-1} soil day^{-1} at Cd0.5 and 0.0130–0.1154 mg C g^{-1} soil day^{-1} at Cd24. Overall, the highest values of CO_2-C evolution rates were recorded at day 1 but tended to decrease sharply when incubation time increased. The results of this study also indicated that the salt stress and Cd affect adversely the microbial activity, as indicated by lower values of CO_2-C evolution rate. The lowest values of CO_2-C evolution rates were found in soil treated with the highest levels of NaCl (120 mM) and Cd (24 mg Cd kg^{-1}). It was observed that these decreases in CO_2-C evolution rate were higher in soil without FYM than those in FYM-treated soil. In the absence of FYM, compared to the soil nontreated with NaCl (S_0), S_1, S_2, and S_3 with Cd0.5 reduced the CO_2-evolution rate by 1.76–4.50%, 7.06–22.2%, and 19.4–40.5%, respectively. Additionally, S1, S2, and S3 with Cd24 reduced the CO_2-evolution rate by 4.69–8.40%, 38.4–52.5, and 62.4–67.1%, respectively. In the presence of FYM, compared to the soil nontreated with NaCl (S_0), S_1, S2, and S3 with Cd0.5 reduced the CO_2-evolution rate by 1.10–1.80%, 0.6–4.39%, and 10.8–14.3%, respectively. However, S1, S2, and S3 with Cd24 reduced the CO_2-evolution rate by 0.61–1.66%, 12.51–18.30, and 25.7–33.4%, respectively.

4. Discussion

The results of the present study showed that soil pH tended to be decreased slightly with increasing salt levels, mainly due to proton displacement by Na^+ of saline irrigation water. As expected, the values of EC_e, Na^+, and Cl^- were significantly increased with increasing NaCl levels. Additionally, the concentration of soluble K^+ tended to increase significantly with increasing NaCl levels. This may be linked with the exchange of this ion by Na^+ on soil surface sites. Overall, the addition of FYM lowered the soil pH as compared to unamended soil (Table 1), mainly due to releasing H^+ ions that were associated with mineralized organic anions or by nitrification [9]. The results showed also that the addition of organic manure caused a significant increase in soluble Ca^{++}, Mg^{++}, and K^+, perhaps due to the release of nutrients through the decomposition of organic amendments [20].

The concentration of DTPA-extractable Cd was increased with increasing Cd levels (Figure 1). Additionally, increasing levels of NaCl caused a significant increase in DTPA-extractable Cd. The highest increase in soil available Cd was pronounced when the soils treated with the highest Cd level (24 mg g^{-1}) were irrigated with the highest NaCl level (120 mM) (Figure 1). This observation confirms the earlier findings that chloride ligands can form particularly strong complexes with heavy metals such that they affect their adsorption reactions with the soil surface [6, 7, 17, 21, 22]. In this context, Ghallab and Usman [6] suggested that the increases in soil chloride ions by NaCl-induced salinity can form strong complexes with Cd, resulting in decreasing the positive charge of Cd and conveying it from the solid to the solution phase. Thus, this leads to enhancing solubility and availability of Cd. Another possible explanation is that Na^+ ions may also contribute to enhancing Cd solubility through the ion exchange of Na^+ for Cd on soil exchange sites. In a study conducted by Smolders et al. [22], to investigate the effect of NaCl and $NaNO_3$ on soil Cd availability, increasing the levels of NaCl addition to soil increased Cd availability and treatments with $NaNO_3$ did not significantly affect soil Cd availability. Therefore, the increases in soil Cd availability could be attributed to the formation of $CdCl_n^{2-n}$ complexes but not to Na^+ exchange with Cd onto soil surfaces. These results are in accordance with those of several other researchers [6, 23, 24].

Results showed also that increasing levels of Cd and NaCl caused increases in the phytoavailability of Cd, as indicated by a significant increase in the shoot Cd concentration (Table 3). However, the addition of FYM significantly decreased DTPA-extractable Cd compared to unamended soils (Figure 1). Furthermore, addition of FYM caused a significant decrease in shoot Cd content of barley plants. These results are in accordance with those of Ahmad et al. [25], who observed that farm manure amendment significantly decreased AB-DTPA-extractable Cd and Pb concentrations and their content in wheat grains. Decreased bioavailability of Cd with organic amendments has also been reported by several other researchers [9, 26–30]. The lower Cd availability in the FYM amended soils could be mainly related to the Cd immobilization through sorption, chelation, and sequestration by the solid and soluble organic matter. Indeed, soil metal availability can be reduced following the addition of organic materials through metal transformation from more readily available forms to less available forms such as fractions associated with organic materials, carbonates, or metal oxides, causing a reduction in metal uptake by plants [9, 30]. Organic matter contains reactive functional groups of hydroxyl, phenoxyl, and carboxyl, which may be responsible for governing the adsorption and complex of heavy metals with soil and subsequently their effect on metal bioavailability [26, 28, 31]. Narwal and Singh [26] found that the DTPA-extractable Cd, Cu, Ni, and Zn in soils were decreased with increasing application rates of cow and pig manure and peat except one case of pig manure where the DTPA-extractable Zn increased. They also found that the concentration of metals was lower in plants grown in the cow manure-amended soil as compared to those grown in the soil amended with either pig manure or peat soil. Our results also clearly showed that the increases in the shoot Cd concentration were correlated positively with the DTPA-extractable Cd (Figure 2). This result suggests that the availability of Cd to plants is dependent not only on its total content but also on its soil available fraction. Therefore, chemical extractants such as DTPA should be taken into account for evaluating the availability of Cd to plants.

Soil respiration can be considered as a main process as a result of organic matter turnover. The individual effects of salinity and metal toxicity on microbial activity are well known but less is known about their interactive effects. Our results indicated that CO_2-C evolution rates were rapid initially and then tended to decrease sharply with incubation time (Table 4). It is possible that this is mainly due to the high readily available organic C to soil microorganisms at the beginning, which can easily be exhausted with time [12, 32, 33]. Adding FYM led to a significant increase in soil respiration compared to unmanured soil, as indicated by the higher CO_2-C evolution rate. This might be caused by the unstable organic fraction in FYM [9, 12].

Salt stress affects adversely the soil respiration and organic C mineralization, as indicated by lower values of CO_2-C evolution rate with increasing NaCl levels. Overall, the lowest values of CO_2-evolution rates were found in soil samples treated with the highest levels of NaCl treatments. This result suggests that a portion of soil microorganisms might be not able to tolerate high osmotic stress. A lower osmotic potential by a higher salinity in the soil can result in lowering microbial activity and organic matter transformation [34]. The toxicities of specific ions may also be a reason for inhibiting microbial activity under saline conditions [35]. The obtained findings can explain the lowered CO_2-C evolution rates in saline soils by the reduced size and activity of the microbial community [36]. In terms of heavy metal toxicity, it is also clear that the higher content of Cd caused significant decreases in the values of CO_2-evolution rate. The highest depressed impact on soil respiration was found when the soil was treated with the highest Cd level (24 mg kg^{-1}) in conjunction with the highest NaCl level (120 mM). The increases in soil Cd availability in soils with increasing NaCl levels could enhance metal toxicity to soil microorganisms, resulting in the lowest microbial activity. It has been reported that Cd has a toxic effect on soil microbial activity [1, 37].

On the other hand, the CO_2-efflux rate was affected by FYM application. Applying FYM to Cd-contaminated soil irrigated with NaCl showed higher CO_2-evolution rates compared to NaCl treatment in the absence of FYM. This suggests that organic amendment can significantly stimulate the microbial activity, even under metal contamination and saline conditions. Generally, organic amendment can increase microbial activity and diversity and microbial tolerance to stress conditions can be detected over time [1, 38]. On the other hand, soil organic matter may contribute to adsorption and immobilization of Cd and thus restrict its solubility and bioavailability. Therefore, organic amendments such as FYM may have an important role to improve quality and minimize metal toxicity of contaminated soils under heavy metals and salinity stress. More recently, it has been speculated that the application of organic manure to metal-contaminated soil may create good environmental condition for mitigating the toxicity induced by high metal concentrations [12].

5. Conclusion

This study suggests that Cd-contaminated soil irrigated with NaCl increased the inhibitory toxic effect on plant growth and soil respiration activity. However, Cd bioavailability in calcareous loamy sand soil reduced following the application of farmyard manure. Further researches are needed to fully understand the effects of FYM on the availability and transformation of heavy metal in different metal-contaminated soils of arid conditions.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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