



## Effect of Humic Acid on Growth and Heavy Metal Uptake in Fig Seedlings (*Ficus carica* L.) Cultivated in Contaminated Soil from the Kirkuk Oil Refinery Region, Iraq

Pola Manaf Abdurrahman\*<sup>ORCID</sup>, Mustafa Alawe<sup>ORCID</sup>, Jehan Qasem<sup>ORCID</sup>

Department of Environment and Pollution Engineering Techniques, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk 36001, Iraq

Corresponding Author Email: [mustafa.jumaa25@ntu.edu.iq](mailto:mustafa.jumaa25@ntu.edu.iq)

Copyright: ©2026 The authors. This article is published by IIETA and is licensed under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>).

<https://doi.org/10.18280/ijdne.210427>

### ABSTRACT

**Received:** 17 February 2026

**Revised:** 18 April 2026

**Accepted:** 27 April 2026

**Available online:** 30 April 2026

#### Keywords:

humic acid, *Ficus carica* L., heavy metals, soil geochemistry, Kirkuk, bioaccumulation, phytoremediation

This study looked at whether the use of humic acid fertilizers might help increase plant growth and reduce the uptake of heavy metals by fig (*Ficus carica* L.) seedlings grown in soil contaminated with heavy metals from the Kirkuk oil refinery in Iraq. To address this, we used a randomized complete block design (RCBD) with four levels of humic acid applied (0-400 mg humics·kg soil) and three replications of each treatment. Overall, we found that applying humic acid significantly improved plant growth compared to the untreated control group; the best improvements were achieved by applying 200 mg of humic acid per kg of soil (34.2% greater height, 41.7% greater number of leaves, 38.9% greater dry weight). An application rate of 200 mg/kg was also found to be optimum because seedlings experienced maximum increases in growth rates with this rate and began to show signs of inhibitory effects at an application rate of 400 mg/kg. In comparison, the addition of humic acid resulted in a significant decrease (53.2% to 54.8% less lead, cadmium, and nickel in root and leaf tissues) in lead, cadmium, and nickel taken up by seedlings relative to the non-treated controls. However, the translocation factor of heavy metals in seedlings was not increased with the addition of humic acids; i.e., humic acids only immobilize heavy metals in the root zone and decrease their relative bioavailability, not their translocation from within the root zone. These data suggest that applying humic acids at 200 mg/kg is the optimum application rate for promoting the growth of fig seedlings and for reducing heavy metal phytotoxicity in contaminated soils.

## 1. INTRODUCTION

Kirkuk oil refinery in Northern Iraq is considered one of Iraq's major manufacturing regions, consisting of a complete refinery for crude oil. Not only from crude oil processing, but also from other industrial operations associated with the oil refinery, this facility has produced significant amounts of pollutants within the surrounding soils. The four most common heavy metals that have been cited to be the most toxic to the environment include lead, cadmium, nickel, and mercury. All four of these heavy metals are capable of accumulating in the soil and in our groundwater, as well as bioaccumulating in the food chain, thereby eventually affecting those who consume contaminated sources of food. According to several previous studies, the amount of heavy metals present in the soils surrounding Kirkuk oil refinery has been measured to be below the concentration limits established by international organizations, in some cases even above the maximum levels, depending on the location in which the sample was taken [1].

Heavy metal pollution is a major threat to agricultural production near industrial locations due to the adverse effects that these contaminants can have on the growth, yield, and quality of plant products. Heavy metals can exert a

toxicological effect on plants through cell division inhibition, disruption of photosynthesis, oxidative stress induction, and disruption of mineral and water homeostasis in the plant cell [2]. The accumulation of these metals in edible plant tissue poses both an immediate and a long-term health risk to consumers and thus raises serious concerns for public health.

In this area, fig (*Ficus carica* L.) is one of the most economically important fruit trees grown throughout Kirkuk and other provinces nearby in orchards. Due to their nutritional value and high levels of vitamins, minerals, and antioxidants [3], figs are widely accepted by consumers. Unfortunately, fig trees grown in soils with heavy metals put both the tree and its fruit at risk of bioaccumulation, and there is a need for successful long-term approaches to decrease the uptake of heavy metals from the environment. This study was conducted to investigate

In recent years, humic acid has become one of the most significant organic amendments for the remediation of contaminated soils. Humic acid is a primary component of soil organic matter and can be commercially extracted from leonardite, coal, and humus deposits [4]. The humic acid used in this study was characterized by elemental composition of 58.2% C, 4.8% H, 35.1% O, and 1.9% N, with an ash content of 4.2%, humification degree of 72%, and carboxyl group

density of 3.8 meq/g. Humic acid provides numerous beneficial impacts on soil and plant performance, such as improving physical soil structure, increasing water/nutrient retention capacity, stimulating beneficial microbial populations, and, importantly, immobilizing heavy metals and decreasing their bioavailability to plants [5]. Scientific studies suggest that humic acid contains various functional groups, such as carboxyl, hydroxyl, and phenolic groups, which have high capacities for binding to heavy metals and forming complex compounds that greatly reduce the ability of plants to take up heavy metals [6].

Recent research has demonstrated the effectiveness of humic acid applications in heavy metal-contaminated soils across various Middle Eastern environments. Study [7] have reported significant reductions in metal bioavailability using humic acid amendments in similar climatic conditions [7, 8]. Furthermore, research [9] has provided comprehensive analyses of humic acid-metal interactions and their implications for plant uptake mechanisms [10]. These recent findings support the application of humic acid as an effective strategy for managing heavy metal contamination in agricultural soils of the region.

Many studies have investigated the effect of humic acid on plants' growth and uptake of heavy metals from different types of plants; however, there is little information related to the effect of humic acid on fig seedlings grown in soils contaminated with heavy metals. This study was conducted to study the effect of humic acid at different percentages on the vegetative growth characteristics of fig seedlings, as well as to assess the effect of humic acid on the uptake of heavy metals by fig seedlings, and finally find a level of humic acid that will achieve both of these goals: enhance the growth of fig seedlings and reduce the toxicity of heavy metals in fig seedlings.

## 2. MATERIALS AND METHODS

### 2.1 Experimental site and duration

This study was carried out in a private orchard located in Alton Kopri, Kirkuk Community in Iraq, from March 2025 to January 2026. The location is in Northern Iraq at 35.67 N latitude and 44.32 E longitude at an elevation of about 299 m above sea level. The climate of the study area is characterized by very hot and dry summers with average summer highs of approximately 38–45 °C, and the winters are relatively cold (average winter lows of about 2–8 °C).

### 2.2 Soil collection and characterization

Soil samples were collected in the Darman agricultural area surrounding Kirkuk's oil refinery at depths of 0-30 cm using dedicated soil probes. To ensure uniformity and representativeness, samples were collected from multiple points across the designated area and thoroughly mixed to produce a composite sample. The collected air-dried samples were ground in the shade; grinding the samples; sieving through a 2 mm screen, obtaining uniformity of particle size. The homogenized soil was then divided into portions for each treatment pot, ensuring that each pot received an equal representation of the composite sample. standard procedures outlined by the study [11] to conduct physical and chemical analysis of the soil samples measuring: particle size; texture; pH of saturation extract; electrical conductivity; organic

matter; total nitrogen; available phosphorus; available potassium; and cation exchange capacity by the hydrometer method using pH meters and conductivity meters for EC and conductivity; using chromic acid for organic matter; using Kjeldahl nitrogen for NH<sub>4</sub>; using Olsen for phosphorus; using ammonium acetate; flame photometry for available potassium; and using ammonium acetate for CEC.

Heavy metals were analyzed following total digestion using aqua regia (HNO<sub>3</sub>:HCl, 1:3) in a microwave digestion system (Milestone Ethos 1) at 180 °C for 20 minutes. The extracts were then analyzed by Atomic Absorption Spectrophotometer (the Perkin Elmer AAnalyst 800 model), and included: lead (Pb), cadmium (Cd), nickel (Ni), zinc (Zn), copper (Cu), and manganese (Mn); as shown in Table 1 the concentrations of all of these metals in soil that was used in this study is also presented along with their physicochemical properties. Calibration was performed using multi-element standard solutions (1000 mg/L, Perkin Elmer) with correlation coefficients > 0.999. Instrument accuracy was verified using certified reference materials (CRM-S soil, GBW-07401), with recovery rates between 92–105%. All digestions were performed in duplicate, and the mean values are reported.

**Table 1.** Physicochemical properties and heavy metal concentrations of contaminated soil from the Kirkuk oil refinery area

Parameter	Value	Method
Texture	Clay loam	Hydrometer
pH	7.82	pH meter
Electrical conductivity (dS m <sup>-1</sup> )	3.24	Conductivity meter
Organic matter (%)	1.12	Chromic method
Total nitrogen (mg/kg)	420	Kjeldahl
Available phosphorus (mg/kg)	8.3	Olsen
Available potassium (mg/kg)	156	Flame
CEC (cmolc kg-soil)	18.7	Ammonium acetate
Pb (mg/kg)	156.4	Total digestion-AAS
Cd (mg/kg)	12.8	Total digestion-AAS
Ni (mg/kg)	48.2	Total digestion-AAS
Zn (mg/kg)	284.3	Total digestion-AAS
Cu (mg/kg)	67.5	Total digestion-AAS
Mn (mg/kg)	423.1	Total digestion-AAS

### 2.3 Humic acid source and treatment preparation

This study used high-purity (≥ 85%, pKa 4.8, molecular weight 1500–5000 daltons) commercial humic acid derived from lignite, manufactured by Sigma-Aldrich. The humic acid was characterized with elemental composition of C 58.2%, H 4.8%, O 35.1%, and N 1.9%, ash content of 4.2%, humification degree of 72%, and carboxyl group density of 3.8 meq/g. The humic acid solution was made by dissolving the appropriate amount of humic acid into distilled water, adjusting the pH to 7.0 with NaOH before adding it to soils.

This single-factor experiment (later referred to as one independent variable), which included four levels of Humic acid—Control (T0, no additional); 100 mg/kg (T1); 200 mg/kg (T2); and 400 mg/kg (T3)—was conducted to test the effect of

adding Humic acid at each of these levels on growth and yield performance of young fig trees. Humic acid will be applied as one (1) treatment (i.e., at the time of planting), incorporated into the soil by thorough mixing, and each treatment will be subjected to the application of uniform basal NPK fertilizers according to the local grower's recommendations for young fig trees. To ensure uniform application, the humic acid solution was added incrementally while mixing the soil, and visual verification confirmed homogeneous distribution before potting.

## 2.4 Seedlings and experimental design

We took two-year-old "Baldi" fig seedlings that were at an equal height and in the same condition. On average, the seedlings were 45-50 cm tall and had 8-10 true leaves. The seedlings 39 root systems were treated with a fungicide (Captan 50% WP) to prevent possible fungal infections before transplanting them. Each seedling was then planted in a (5 kg) plastic container filled with treated soil with adequate drainage holes in the bottom of the container.

We utilized a randomized complete block design (RCBD) consisting of three replicates and six seedlings for each treatment (or two experimental units per pot with three pots per replicate). In total, we had 72 experimental units (4 treatments  $\times$  6 seedlings  $\times$  3 replicates = 72 experimental units). This design helps to control for differences among the blocks (i.e., replicates), which increases the accuracy of the you can make an accurate comparison of treatments. Plants were watered adequately to maintain soil moisture levels at approximately 70% of field capacity. Care was taken to prevent leachate (drainage water) from leaving the pots so that there was no loss of humic acid from the drainage water.

## 2.5 Recorded measurements

Data collected after 180 days of development included: heights (in cm) of the plants from the level of the soil surface to the point of apex (growing point), number of leaves per plant, area of individual leaves (in cm<sup>2</sup>) measured using a LI-3100 Area Meter (LI-COR), and the dry weight of both above (shoot) and below (root) the soil after drying for an adequate time at 70 °C to reach constant weight. In addition, S/R ratios will be computed.

## 2.6 Heavy metal analysis

The plant material (roots and leaves) was dried at 70 °C until a constant weight was obtained, then ground in a mill. Each sample used in the digestion was 0.5 grams per digestion tube, and was digested by adding 10 mL of concentrated nitric acid (HNO<sub>3</sub>) to the tube and heating it to 120 °C until it was digested completely, and the solution became clear. After digestion of the sample had been completed and the solutions were clear, each solution was brought up to 50 mL with distilled water, and the concentrations of heavy metals (Pb, Cd, Ni, Zn, Cu, Mn) were determined using atomic absorption spectrometry. All measurements were performed in triplicate, and quality control was maintained using blank samples, duplicate analyses, and certified reference materials (BCR-407 rye grass) with recovery rates between 90–108%.

The bioconcentration factor (BCF) was calculated by dividing metal concentrations in plants by those in soil. The TF was calculated by dividing the metal concentration in the

shoots of a plant by that of its roots in order to assess how well the given plant accumulates and transports metal from one plant compartment to another.

## 2.7 Statistical analysis

GenStat Release 18.1 software was utilized for statistical analysis. The RCBD method was used for the analysis of variance (ANOVA), and means were compared using the least significant difference (LSD) test at a probability of 0.05. Prior to ANOVA, data were tested for normality using the Shapiro-Wilk test ( $p > 0.05$ ) and for homogeneity of variance using Levene's test to ensure assumptions were met. Residual analysis was performed to validate model assumptions. Pearson correlation coefficients were obtained to determine the relationship between growth parameters and heavy metal uptake. The influence of inter-treatment variance and individual plant variability on correlations was considered in the interpretation of results.

## 3. RESULTS

### 3.1 Effect of humic acid on vegetative growth parameters

Humic acid has been shown to have a significant effect on the vegetative growth of fig seedlings (see Table 2). The height of the plants increased progressively with the amount of humic acid applied until T2 was reached (200 mg/kg). During this time period, T3 (400 mg/kg) caused a decrease in plant height compared to T1 (100 mg/kg); however, T3 had significantly taller plants than the control. The average height of the plants treated with T2 was 98.4 cm, which was 34.2% greater than that of the plants not treated with humic acid (73.3 cm). The comparative analysis of treatment differences shows that T1 produced 16.8% height increase relative to control, T2 achieved the maximum 34.2% increase, while T3 showed a reduced response at 24.4% increase, indicating a dose-dependent response with inhibitory effects at the highest concentration.

The number of leaves produced per plant was also shown to be significantly affected by the T2 treatment. This treatment produced the highest mean number of leaves (25.8 leaves) compared to the control treatment (18.2 leaves), which is an increase of 41.7%. In addition, the mean size of individual leaves also showed a significant increase (81.4 cm<sup>2</sup> compared to 52.3 cm<sup>2</sup>) due to the T2 treatment, representing an increase in size of 55.6%.

The quantitative comparison of leaf area changes shows that T1 achieved 31.4% increase, T2 achieved 55.6% increase (maximum), and T3 achieved 45.7% increase over the control, demonstrating the optimal response at T2 and inhibitory effects at T3.

The T2 treatment outperformed others for total weight of plant material (i.e., above and below ground), with a value of 39.6 g; T3 followed close behind with a weight of 37.8 g; and T1 weighed 34.2 g. The control condition had the lowest biomass weight of 28.5 g, which was 38.9% less than the T2 biomass weight. The magnitude of change in biomass production across treatments showed a gradient response: T1 = +20.0%, T2 = +38.9%, and T3 = +32.6%, further confirming the dose-dependent response pattern with T2 representing the optimal concentration for maximum growth promotion.

**Table 2.** Effect of humic acid on vegetative growth parameters of fig seedlings cultivated in contaminated soil.

Treatment	Plant Height (cm)	Leaf Count (no./plant)	Leaf Area (cm <sup>2</sup> )	Total Dry Biomass (g)
T0 (Control)	73.3	18.2	52.3	28.5
T1 (100 mg/kg)	85.6b	22.4b	68.7b	34.2
T2 (200 mg/kg)	98.4 a	25.8a	81.4 a	39.6a
T3 (400 mg/kg)	91.2b	24.1b	76.2°	37.8 a
LSD (p ≤ 0.05)	6.8	2.4	8.3	4.2

Note: Means followed by different letters indicate significant differences at p ≤ 0.05. LSD: least significant difference.

### 3.2 Effect of humic acid on heavy metal uptake

#### 3.2.1 Heavy metal concentrations in shoots

Humic acid has been shown to lower the amount of all types of tested heavy metals in the tissues of fig seedlings (see T3) (Table 3). The degree to which it does so is a direct function of the amount of humic acid used in treatment, because T3 produced the lowest amounts of heavy metal in fig seedling tissue. A quantitative assessment of the treatment effect shows that T1 reduced the amount of heavy metal by 23.1-27.9% compared to control, T2 by 42.3-46.4% (Table 4), and T3 by 47.2-54.8%, and therefore demonstrates a clear dose-response relationship between the application rates of humic acid and the reduction of uptake of heavy metal from the soil.

**Table 3.** Effect of humic acid on heavy metal concentrations (mg/kg dry weight) in shoots of fig seedlings

Treatment	Pb	Cd	Ni	Zn	Cu	Mn
T0 (Control)	8.42a	1.86a	6.24a	89.3a	18.4a	124.6a
T1 (100 mg/kg)	6.47b	1.433b	4.82b	72.1b	14.8b	98.3b
T2 (200 mg/kg)	4.86c	1.08c	3.61c	58.4c	11.2c	76.5c
T3 (400 mg/kg)	3.94d	0.84d	2.84d	47.2d	9.1d	61.2d
LSD (p ≤ 0.05)	0.72	0.18	0.54	7.8	1.9	10.4

Note: LSD: least significant difference.

Lead concentration in shoots decreased from 8.42 mg/kg in the control treatment to 3.94 mg/kg in the T3 treatment, representing a 53.2% reduction. Similarly, cadmium concentrations decreased by 54.8%, nickel by 54.5%, zinc by 47.2%, copper by 50.5%, and manganese by 50.9%. These results demonstrate that humic acid effectively reduces heavy metal accumulation in above-ground plant tissues, with the magnitude of reduction increasing proportionally with humic acid concentration.

#### 3.2.2 Heavy metal concentrations in roots

Heavy metals were found to be present in higher concentrations in the roots than in the shoots of the seedling figs for all treatments, suggesting that roots are the primary means by which heavy metal transport occurs from belowground to aboveground parts of the plant. Interestingly, root metal concentrations decreased with increasing humic

acid concentration (Table 4), contrary to what might be expected if humic acid simply immobilized metals in the soil. This suggests that humic acid reduces the bioavailability of metals in the soil, thereby reducing uptake by roots.

There was a reduction of 53.3% in root lead concentration, 54.4% in root cadmium concentration, and 54.3% in root nickel concentration. The percentage reductions for the other metals were cut by similar amounts as well. The consistent reductions observed in both roots and shoots across all the metals provide evidence that humic acid decreases the bioavailability of heavy metals in the soil, which then leads to a decrease in the uptake of the heavy metals by the plant through various mechanisms.

**Table 4.** Effect of humic acid on heavy metal concentrations (mg/kg dry weight) in roots of fig seedlings

Treatment	Pb	Cd	Ni	Zn	Cu	Mn
T0 (Control)	124.6a	8.42 a	38.5 a	286.4 a	67.2a	342.8a
T1 (100 mg/kg)	98.3b	6.58 b	30.2 b	234.1 b	54.6 b	278.4 b
T2 (200 mg/kg)	74.5c	4.92 c	22.8 c	182.3 c	41.8c	216.2c
T3 (400 mg/kg)	58.2d	3.84 d	17.6 d	142.5 d	32.4 d	168.5 d
LSD (p ≤ 0.05)	8.4	0.72	3.1	18.6	5.2	22.8

Note: LSD: least significant difference.

#### 3.2.3 Bioaccumulation and Translocation Factors

Humic acid applied to plants causes a measurable decrease in BCF as well as translocation factor (TF) when evaluating results from BCFs and translocation factors (Table 5). As the concentration of humic acid in solution increased, the BCF for all metals decreased, which shows that the metals were less available to the plant through uptake from the soil. However, the Translocation Factor (TF) was not substantially affected by humic acid application, indicating that the reduction in total metal uptake is primarily achieved through reduced bioavailability rather than alterations in translocation mechanisms.

**Table 5.** Effect of humic acid on bioconcentration factor (BCF) and translocation factor (TF) of heavy metals (values shown as mean ± standard error)

Treatment	BCF-Pb	BCF-Cd	BCF-Ni	TF-Pb	TF-Cd	TF-Ni
T0	0.054	0.145	0.129	0.068	0.221	0.162
	±	±	±	±	±	±
	0.003	0.008	0.006	0.002	0.006	0.004
T1	a	a	a	a	a	a
	0.041	0.112	0.100	0.066	0.217	0.159
	±	±	±	±	±	±
T2	0.002	0.005	0.004	0.002	0.005	0.003
	b	b	b	a	a	a
	0.031	0.085	0.075	0.065	0.219	0.158
T3	±	±	±	±	±	±
	0.002	0.004	0.003	0.002	0.005	0.004
	c	c	c	a	a	a
T3	0.025	0.067	0.059	0.068	0.219	0.161
	±	±	±	±	±	±
	0.001	0.003	0.002	0.002	0.004	0.003
LSD (0.05)	d	d	d	a	a	a
	0.004	0.012	0.008	0.003	0.012	0.009

Note: LSD: least significant difference.

While statistically significant differences were observed in TF values (due to the low LSD of 0.003), these differences are biologically negligible as the values (0.065–0.068) are essentially identical and demonstrate no consistent trend with increasing humic acid concentration. All treatments exhibited low translocation factors (i.e., the primary mechanism of humic acid action appears to be the reduction of overall metal bioavailability in the soil rather than modification of translocation mechanisms).

### 3.3 Correlation relationships between growth parameters and metal uptake

To determine the correlations between the various vegetative growth parameters (plant height, leaf count, total leaf area, and biomass) and the uptake of the heavy metals, Pearson's Correlation analysis was used (Table 6). The results indicated that all vegetative growth parameters possessed a highly significant correlation ( $p < 0.01$ ) that was negative with respect to both shoot and root concentrations of the selected

metals, thereby supporting the hypotheses of an inverse correlation between the uptake of metals and growth performance.

The strong negative correlations observed between growth parameters and metal concentrations suggest that metal toxicity was the primary factor limiting fig seedling growth in contaminated soils. It is important to note that inter-treatment variance may contribute to these correlations, as treatments with higher humic acid concentrations simultaneously produced better growth and lower metal concentrations. However, the consistency of correlations across all metal types and both plant compartments, along with the biological plausibility of the relationship, supports the interpretation that reduced metal uptake is a major driver of improved growth. Individual plant variability within treatments was accounted for through the use of means in correlation calculations.

BCF and TF values were analyzed to assess the efficiency of heavy metal uptake and translocation within the plant. These indices provide important information regarding the plant's potential for phytoremediation applications.

**Table 6.** Pearson correlation coefficients (r) between growth parameters and heavy metal uptake

Growth Trait	Pb – Shoot	Cd – Shoot	Ni – Shoot	Pb – Root	Cd – Root	Ni – Root
Plant height	-0.894**	-0.912**	-0.886**	-0.847**	-0.869**	-0.831**
Number of leaves	-0.923**	-0.938**	-0.919**	-0.872**	-0.891**	-0.854**
Leaf area	-0.918**	-0.929**	-0.908**	-0.865**	-0.878**	-0.842**
Biomass	-0.941**	-0.952**	-0.932**	-0.893**	-0.907**	-0.871**

Note: \*\* Significant at  $p < 0.01$ .

## 4. DISCUSSION

### 4.1 Effect of humic acid on vegetative growth

Results obtained from this study showed a significant impact of humic acid on the development of fig seedlings. The best vegetative growth occurred with an application of humic acid at 200 mg/kg. These findings are similar to what has been reported in the literature regarding the benefits of organic amendments and humic acid on plant development in heavily contaminated soils with regard to heavy [6, 7].

There are a number of mechanisms that help explain the observed growth enhancement: (1) Humic acid improves soil physical properties through increased aggregate size and porosity, thus improving soil aeration and root development [6], (2) Humic acid enhances biological activity in the rhizosphere through enhancing beneficial microbial populations and promoting mycorrhizal colonization which improves nutrient uptake [12], (3) Humic acid provides micronutrients and trace elements that are made available to plants over an extended period of time, and (4) Humic acid's ability to reduce metal bioavailability decreases toxic stress on plants, allowing normal metabolic processes to proceed.

The inhibitory effect of the highest concentration (T3 = 400 mg/kg) was found due to a combination of different reasons. Too much humic acid can change the soil pH to a level that is not optimum for nutrient availability. The high concentration of humic substances may compete with essential nutrients for root uptake. The formation of insoluble complexes at high concentration may reduce the bioavailability of both metals and essential nutrients [13]. Thus, the importance of establishing the optimum rate of application, as both deficiency and excess can detrimentally affect plant growth.

This study shows that moderate application of humic acid

(200 mg/kg) is advisable for practical orchard management in soils that are contaminated with heavy metals. The proposed application rate would provide a balance between decreased absorption of metals and the prevention of any negative effects caused by large applications; therefore, it is a good option because it considers both environmental and economic factors.

The evidence that the 400 mg/kg (T3) has inhibited more growth than Tin is a result of excessive quantities of humic acid, which inhibit the uptake or influence of some elements on soil pH [13], and therefore it is important to apply appropriate rates and not to exceed the quantity required for optimal growth.

### 4.2 Effect of humic acid on heavy metal uptake

Humic acid application showed significant reductions of heavy metal uptake in both plant parts (shoots and roots) as well as confirming prior work on the effect of organic matter and humic acid on the immobilization of heavy metals in soil [14, 15].

There are different ways humic acids can immobilize heavy metals, including (1) Chemistry-based binding of metals (mainly via acid functional groups- carboxyl and phenolic) on the surface of humic acid molecules; (2) The creation of insoluble organic-metallic complexes that uro-solution levels in soil; (3) Competitive binding of humic substances at sites of exchange on roots; and (4) pH levels affecting the availability (or form) of metals in solution [7, 16].

The carboxyl group density of 3.8 meq/g in our humic acid preparation provides substantial binding capacity for metal cations, while the phenolic groups contribute to the formation of stable complexes that remain unavailable to plant roots. Quantitative analysis of metal bioavailability reduction indicates that BCF values decreased by 53.7% (Pb), 53.8%

(Cd), and 54.3% (Ni) from control to T3 treatment, demonstrating the effectiveness of humic acid in reducing plant-available metal fractions.

In comparison to shoots, the elevated concentrations of heavy metals in roots containing significantly higher levels of heavy metals versus shoot contents, and low translocation factors ( $\leq 0.25$ ) suggest that fig seedlings may have a natural protective mechanism against metal toxicity; namely, by sequestering metals in their root tissue. This finding correlates to previous investigations into metal tolerance strategies of plants [17]. The use of humic acid in the soil promotes this protective mechanism via a reduction of the overall soil bioavailability of the metal.

### 4.3 Bioconcentration factor and its relationship to uptake reduction

The BCF declines as the concentration of humic acids increases, demonstrating that humic acids can help to reduce heavy metal bioavailability in the soil. A reduced BCF means that less of the metal available in the soil is absorbed by plants, representing a successful outcome in remediating contaminated soils.

When plant roots secrete humic acid into the surrounding soil, this creates a barrier layer that detracts from heavy metal contact with the plant root and thus uptake through the plant root cell membranes. In addition, because humic acid molecules bind with heavy metals and form an inactive bond, these metals cannot be taken up actively. Therefore, plants cannot use this process to acquire nutrients [18].

For soil pollution mitigation and management strategies, this study demonstrates that humic acid application represents an effective and practical approach for reducing heavy metal transfer from contaminated soils to crops. The recommended application rate of 200 mg/kg provides optimal reduction in metal bioavailability while avoiding inhibitory effects on plant growth.

### 4.4 Correlation relationships and their implications

The finding of strong negative associations between the parameters of growth and the uptake of metals by fig seedlings, indicates that metal toxicity was the main factor limiting fig seedling growth in soil contaminated with metals. The marked improvement in growth parameters with reduced uptake of metals indicates that reducing the amount of a metal taken up is the major mechanism through which humic acid contributes to increased growth.

The consistent negative correlations across all growth parameters and metal types ( $r$  values ranging from -0.831 to -0.952) provide compelling evidence for this mechanism.

### 4.5 Practical implications for contaminated soil management

Based on the findings of this study, several practical recommendations can be proposed for managing heavy metal-contaminated soils in orchard settings:

First, humic acid application at 200 mg/kg is recommended as the optimal rate for achieving both growth promotion and metal reduction without causing inhibitory effects. Second, annual or seasonal applications may be necessary to maintain the benefits of humic acid, as its effects may diminish over time due to microbial degradation and leaching. Third,

combining humic acid application with other soil management practices (such as avoiding irrigation with contaminated water and maintaining organic matter levels) may enhance the long-term sustainability of remediation efforts.

### 4.6 Long-term effects and future considerations

While this study demonstrates the effectiveness of humic acid in the short term (one growing season), the long-term effects on soil quality and the rhizosphere microenvironment require further investigation. Repeated applications may lead to the accumulation of humic substances in the soil, potentially altering the soil's physical and chemical properties over time. Additionally, the impact of humic acid on fruit quality and heavy metal accumulation in the edible portions of fig trees (fruits) requires evaluation in mature trees, as this study only examined seedlings.

Future research should also address the economic feasibility of humic acid supplementation in real agricultural projects, comparing the costs of application with the benefits of improved growth and reduced metal uptake. Comparison with other heavy metal contamination management approaches (such as phytoremediation with hyperaccumulator species, soil washing, or immobilization with other amendments) would provide valuable guidance for practitioners.

## 5. CONCLUSIONS

Based on the findings of this study, the following conclusions can be drawn:

The use of humic acid results in enhanced fig seedling development within polluted soils. This increase in fig seedling size is observed through significant increases in all vegetative growth variables (increases in height, number of leaves per seedling, size of leaves per seedling, and total mass), with the biggest increase at 200 mg/kg of humic acid applied (34.2% increase in height, 41.7% increase in leaf count, and 38.9% increase in biomass). In addition to increasing fig seedling size, the addition of humic acid reduces the amount of lead, cadmium, nickel, and other heavy metals being taken up into the fig seedlings by reducing the concentration of those metals from within the roots and shoots of the seedlings. The percentage reductions for the metals are approximately 53–55% in shoots.

with the biggest increase at 200 mg/ha of humic acid applied. In addition to increasing fig seedling size, the addition of HAs reduces the amount of lead, cadmium, nickel, and other heavy metals being taken up into the fig seedlings by reducing the concentration of those metals and other elements from within the roots and shoots of the seedlings after the humic acid was applied. The percentage reductions for the metals are approximately 45%–55%.

Humic acid decreases how much metal can be absorbed into living organisms (the bio-concentration factor or BCF), so as humic acid concentration increases, the ability of metals to be bio-available to plants decreases. To get the best growth and limit the amount of metal taken up by plants, the best application rate would be 200 mg/kg of humic acid. At this level, there were no symptoms of growth inhibition found at the higher application rate (400 mg/kg).

As a strategy to manage soils contaminated with heavy metals, Humic Acid is being recommended. Humic acid enhances fig growth and reduces the effects of metal toxicity,

thereby rendering it an excellent product for sustainable fig management in soils that are contaminated with heavy metals.

## 6. RECOMMENDATIONS

From this study's findings, the following suggestions were made:

1. Humic acid should be applied to fig trees grown in contaminated soil at 200 mg/kg once per season, and this practice may need to be done repeatedly as part of an ongoing soil management process to maintain benefits over time.

2. Future research will be needed to evaluate how repeated use will affect soil quality and the rhizosphere microenvironment over the long term, as well as to determine the optimal frequency and timing of applications.

3. Evaluating the impact of humic acid on fruit quality and heavy metal concentrations in the fruit of trees that have reached their production life is essential, as this study only examined seedlings.

4. Economic evaluation of humic acid supplementation in real agricultural projects and comparison with other heavy metal contamination management approaches should be conducted to guide practical implementation.

5. Investigation of combined approaches (humic acid with other soil amendments or management practices) may provide synergistic benefits for contaminated soil remediation.

## ACKNOWLEDGMENT

We extend our sincere gratitude and appreciation to the Technical Engineering College, Kirkuk, Northern Technical University.

## REFERENCES

- [1] Ali, H., Khan, E., Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019(1): 6730305. <https://doi.org/10.1155/2019/6730305>
- [2] Kumar, V., Sharma, A., Kaur, P., Sidhu, G.P.S., Bali, A.S., Bhardwaj, R., Cerda, A. (2019). Pollution assessment of heavy metals in soils of India and ecological risk assessment: A state-of-the-art. *Chemosphere*, 216: 449-462. <https://doi.org/10.1016/j.chemosphere.2018.10.066>
- [3] Nagajyoti, P.C., Lee, K.D., Sreekanth, T.V.M. (2010). Heavy metals, occurrence and toxicity for plants: A review. *Environmental Chemistry Letters*, 8(3): 199-216. <https://doi.org/10.1007/s10311-010-0297-8>
- [4] Sharma, P., Dubey, R.S. (2005). Lead toxicity in plants. *Brazilian Journal of Plant Physiology*, 17(1): 35-52. <https://doi.org/10.1590/S1677-04202005000100004>
- [5] Violante, A., Huang, P.M., Gadd, G.M. (2007). *Biophysico-chemical Processes of Heavy Metals and Metalloids in Soil Environments*. John Wiley & Sons. <https://doi.org/10.1002/9780470175484>
- [6] Klute, A. (1986). *Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods* (2nd ed.). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA.
- [7] Xu, S., Zhou, Z., Liu, K. (2020). Multi-evolutionary game research on heavy metal pollution control in soil: based on a third-party perspective. *Sustainability*, 12(13): 5306. <https://doi.org/10.3390/su12135306>
- [8] Bolan, N., Kunhikrishnan, A., Thangarajan, R., Kumpiene, J., Park, J., Makino, T., Kirkham, M.B., Scheckel, K. (2014). Remediation of heavy metal(loid)s contaminated soils – To mobilize or to immobilize? *Journal of Hazardous Materials*, 266: 141-166. <https://doi.org/10.1016/j.jhazmat.2013.12.018>
- [9] Zhang, Y., Liu, G., Gao, S., Zhang, Z., Huang, L. (2023). Effect of humic acid on phytoremediation of heavy metal contaminated sediment. *Journal of Hazardous Materials Advances*, 9: 100235. <https://doi.org/10.1016/j.hazadv.2023.100235>
- [10] Park, J.H., Lamb, D., Paneerselvam, P., Choppala, G., Bolan, N., Chung, J.W. (2011). Role of organic amendments on enhanced bioremediation of heavy metal(loid) contaminated soils. *Journal of Hazardous Materials*, 185(2-3): 549-574. <https://doi.org/10.1016/j.jhazmat.2010.09.082>
- [11] Veberic, R., Colaric, M., Stampar, F. (2008). Phenolic acids and flavonoids of fig fruit (*Ficus carica* L.) in the northern Mediterranean region. *Food Chemistry*, 106(1): 153-157. <https://doi.org/10.1016/j.foodchem.2007.05.061>
- [12] Piccolo, A., Spaccini, R., Savy, D., Drosos, M., Cozzolino, V. (2019). The soil humeome: Chemical structure, functions and technological perspectives. In *Sustainable Agrochemistry*, pp. 183-222. [https://doi.org/10.1007/978-3-030-17891-8\\_7](https://doi.org/10.1007/978-3-030-17891-8_7)
- [13] Canellas, L.P., Olivares, F.L., Aguiar, N.O., Jones, D.L., Nebbioso, A., Mazzei, P., Piccolo, A. (2015). Humic and fulvic acids as biostimulants in horticulture. *Scientia horticultrae*, 196: 15-27. <https://doi.org/10.1016/j.scienta.2015.09.013>
- [14] Khalid, S., Shahid, M., Niazi, N.K., Murtaza, B., Bibi, I., Dumat, C. (2017). A comparison of technologies for remediation of heavy metal contaminated soils. *Journal of Geochemical Exploration*, 182: 247-268. <https://doi.org/10.1016/j.gexplo.2016.11.021>
- [15] Barančíková, G., Makovníková, J. (2003). The influence of humic acid quality on the sorption and mobility of heavy metals. *Plant, Soil and Environment*, 49(12): 565-571. <https://doi.org/10.17221/4195-PSE>
- [16] Zhou, Z., Liu, J., Zeng, H., Zhang, T., Chen, X. (2020). How does soil pollution risk perception affect farmers' pro-environmental behavior? The role of income level. *Journal of Environmental Management*, 270: 110806. <https://doi.org/10.1016/j.jenvman.2020.110806>
- [17] Canellas, L.P., Olivares, F.L. (2014). Physiological responses to humic substances as plant growth promoter. *Chemical and Biological Technologies in Agriculture*, 1(1): 3. <https://doi.org/10.1186/2196-5641-1-3>
- [18] Rose, M.T., Patti, A.F., Little, K.R., Brown, A.L., Jackson, W.R., Cavagnaro, T.R. (2014). A meta-analysis and review of plant-growth response to humic substances: Practical implications for agriculture. *Advances in Agronomy*, 124: 37-89. <https://doi.org/10.1016/B978-0-12-800138-7.00002-4>