SAINS TANAH – Journal of Soil Science and Agroclimatology

Journal homepage: http://jurnal.uns.ac.id/tanah

Metal Extractability Changes in Soils Under Thorny Amaranth

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ARTICLE INFO

Keywords:
Metal Analysis
Metal Extraction
Metal Forms
Tropical Soils

Article history
Submitted: 2022-09-19
Accepted: 2022-12-19
Available online: 2022-12-xx
Published regularly: Dec 2022

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ABSTRACT

The different forms of heavy metals may be significantly extracted from soils by plant roots. In a glasshouse experiment, the shifting of soil heavy metal forms under thorny amaranth was examined. To accomplish the research goal, thorny amaranth was planted for four weeks at field water content in soils with varying Cu and Zn contents. Copper and Zn levels in the soil were measured both before and after planting. High soil Cu and Zn levels reduced this plant's height and dry biomasses. Thorny amaranth considerably reduced the exchangeable and available Cu and Zn in the soil. The soil exchangeable and available Cu and Zn had a good correlation with the plant uptakes of these elements. Copper and Zn reductions by planting significantly lower than the available Cu and Zn. A significant portion of the soil exchangeable Cu and Zn shifted to stronger bonding during the incubation time. It was demonstrated that plants absorbed more Cu and Zn from forms different than the soil-exchangeable forms.

How to Cite: Salam, A K., Nopriansyah, H., Bucharie, H. (2022). Metal Extractability Changes in Soils Under Thorny Amaranth. Sains Tanah Journal of Soil Science and Agroclimatology, 19(2): 211-220. https://dx.doi.org/10.20961/stjssa.v19i2.65456

1. INTRODUCTION

Heavy metals in soils exist in various forms which determine their availability to plants (Abdu & Mohammed, 2016; Salam, 2017). The soluble metals that include free ions, complexes, and chelates are the most available to plants (Salam, 2017). The exchangeable forms of heavy metals are the soil solid-associated forms of heavy metal that are also available to plants after being released into the soil solution (El-Maghrabi & Mikhail, 2014; He et al., 2020; Salam, 2017). Other forms of heavy metals include the stronger adsorbed heavy metals, soil precipitates, or the secondary soil minerals and primary minerals that contain heavy metals with different solubility (Salam, 2017). These forms of heavy metals may release into the soil solution (soluble forms) and are available to plants regulated by the processes of adsorption-desorption and precipitation-dissolution depending on some determining factors like soil acidity which is controlled by plant root excretion (Chandra Shaha et al., 2012; El-Maghrabi & Mikhail, 2014; He et al., 2020; Salam, 2017; Salam & Helmke, 1998).

These various forms of heavy metals are related in an equilibrium system controlled by various soil chemical processes that include complexation-decomplexation, chelation-dechelation, adsorption-desorption, precipitation-dissolution, and also oxidation-reduction in soils affected by water saturation (Abdu & Mohammed, 2016; El-Maghrabi & Mikhail, 2014; He et al., 2020; Salam et al., 2022; Salam, 2017; Salam & Sriyani, 2019; Ugwu et al., 2020; Xiao et al., 2017; Zhang et al., 2021). The disturbance on any part of the system may change the size of each form and the affecting chemical reaction. For instance, the uptake of heavy metals by plants may reduce the concentrations of heavy metals in the solution, which may cause the heavy metal precipitates to dissolve under the control of the associated soil mineral solubility product (Salam & Sriyani, 2019). Dissolution could advance until it reaches the solubility constant (Salam, 2017); (Xiao et al., 2017).

The presence of plant roots may probably absorb the available heavy metals that include parts of the soluble form, the exchangeable form, the precipitates, and also the primary minerals depending on the properties of the soil environment affected by plant roots (Dietz et al., 2020). For example, plant roots that effectively lower the soil pH through their excretion may effectively solubilize the precipitates and the primary soil minerals and, therefore, increase the soil heavy soil metals beyond those supplied by the soluble and the exchangeable forms (Bray et al., 2015; More et al., 2020; Ohta & Hiura, 2016; Wu et al., 2018; Yang et al., 2019; Zhang et al., 2021). Therefore, different plants may shift the sizes of soil heavy metal forms, including soil exchangeable form and total available heavy metals

The shifting of the soil heavy metal extractability is suggested to be more significant in the presence of phytoremediator plants that may extract greater amounts of heavy metals (Chen et al., 2019; Guerra Sierra et al., 2021; Ishii et al., 2015; Salam, 2022; A. K. Salam, M. A. Hidayatullah, et al., 2021; Silva et al., 2021; Sumiahadi & Acar, 2018; Sun et al., 2019). These plants may include several weeds like napier grass and several vegetables like lettuce, spinach, amaranth, broccoli, chickpea, sunflowers, cabbage, caisim, water spinach, and willows (Guerra Sierra et al., 2021; Ishii et al., 2015; Matthews-Amune & Kakulu, 2012; Naser et al., 2017). For example, our earlier investigation demonstrated that the absorption of Cu or Zn by napier grass was higher with the soil concentrations of Cu or Zn resulted by amendment with heavy metal-containing waste (A. K. Salam, M. A. Hidayatullah, et al., 2021). Knowledge on this phenomenon is scarce due to limited research, particularly those conducted in tropical soils of Indonesia.

In this research, the shifting of Cu and Zn extractability was investigated by measuring the changes in the soil exchangeable (extracted by dilute salts) and available Cu and Zn (extracted by dilute acids) in heavy metal polluted soils shortly planted with thorny amaranth. The soil exchangeable Cu and Zn was measured by employing 1 *N* NH_4OAc pH 7.0 and the soil available Cu and Zn by 1 *N* HNO_3 (A. K. Salam, A. F. Pakpahan, et al., 2021). Knowledge related to the shifting in the various forms of heavy metals in soils is of more importance in the midst of heavy metal contamination and pollution all over the world (Adejoh, 2016; Aksu, 2015; Aprile & De Bellis, 2020; Arif et al., 2016; Arshad et al., 2015; Asati et al., 2016; Ayari et al., 2010; Chibuike & Obiora, 2014; Fang et al., 2016; Febriansyah et al., 2021; Gaza & Kugara, 2018; Jamal et al., 2013; Jankowski et al., 2019; Juel et al., 2018; Khodijah et al., 2019; Kočevar Glavač et al., 2017; Nachana'a Timothy, 2019; A. K. Salam, A. F. Pakpahan, et al., 2021; Sun et al., 2019; Wang & Zhang, 2018).

2. MATERIALS AND METHODS

2.1 The Samples of Soils Polluted with Metals

This research was executed from June to September 2021. The glasshouse experiment was conducted in the College of Al-Madani and all laboratory works were done in the Soil Science Laboratory the University of Lampung Bandar Lampung. Soil samples with different levels of heavy metals were employed to conduct this research. Composite soil samples were collected at an experimental field at 0-15 cm depth located at 5°20'14.1"S 105°14'39.2"E shown in Figure 1 (A. K. Salam, A. F. Pakpahan, et al., 2021). The experimental fields were set up in 1998 treated with industrial waste containing heavy metals at control level (0 Mg ha^{-1}), Low Heavy Metal (15 Mg ha^{-1}), and High Heavy Metal (60 Mg ha^{-1}) as reported by several researchers (Salam, 2000; A. K. Salam, A. F. Pakpahan, et al., 2021). For the glass-house experiment, soil was prepared as air-dried, ground to pass a 2-mm sieve, and thoroughly mixed sample. To establish oven-dry basis weighings, the water content of the soil sample was also determined. Table 1 contains a list of the soil samples' current properties. All of the soils were clay loam with a cation exchange capacity (CEC) of 9–11 cmol (+) kg^{-1}, a low organic C content, and a slightly low pH.

2.2 The Glass-House Test

As a growing medium, a 200 g of air-dry soil was used. Based on earlier studies, this amount of soil sample was deemed sufficient to support a 4-week growth and development of thorny amaranth. Before planting the thorny amaranth in the potting soil, the seed had been earlier prepared in a different medium and watered to 40%. (the related soil field-water capacity). For four weeks, thorny amaranth was grown in soil samples watered with capillary water provided by a water tank situated beneath the potting soil. Blank potted soil samples were made without any plants to assess the impact of thorny amaranth. Triplicates of each experimental unit were performed.

2.3 The Plant, Soil, and Data Analyses

Plant parts (shoots and roots) were analyzed for Cu and Zn uptakes. Therefore, plant parts were harvested and weighed for their wet-weight and oven-dry weight (after oven-drying at 60 °C for 3 x 24 hours) separately at the end of the planting period. The soil samples were also harvested for Cu and Zn determination by extraction using 1 *N* HNO_3. The iCE 3000 AAS was employed to measure the metal levels. The pH H_2O (1:2, pH electrode) of the soil, another significant aspect of the soil properties, was also measured. Analyses of the soil were performed both before and after planting. Soil analysis was also conducted on the blank soil without plants. Plant Cu and Zn were determined by the method as used by Silva et al. (2021) .

Figure 1. The location of the experimental field

Table 1. Selected soil properties[1,2]

Heavy Metal Levels	Soil Fractions			pH H_2O (1:2)	pH KCl (1:1)	CEC	Organic C
	Sand	Silt	Clay				
	……… % ………					cmol(+) kg^{-1}	… g kg^{-1} …
Control	33.35±2.46 a	34.54±0.33 a	31.10±2.79 a	5.99±0.06 a	4.76±0.08 b	8.59±1.40 a	15.86±7.01 a
Low	35.31±1.30 a	33.75±0.97 a	30.93±2.27 a	6.10±0.16 a	4.16±0.35 a	11.18±0.37 b	10.97±2.24 a
High	33.64±5.51 a	33.68±7.44 a	32.68±1.93 a	5.95±0.39 a	4.77±0.52 b	10.97±0.16 b	14.01±1.40 a

Remark: [1]Average of 3 replicates, [2]Different characters in one column denote significant difference

Table 2. The dry biomasses of thorny amaranth planted in soils polluted with metals[1]

Heavy Metal Level	Root	Shoot	Root + Shoot	Root/Shoot
	……… g ………			
Control	0.18 ± 0.16 ac	0.40 ± 0.26 ac	0.58 ± 0.41 ac	0.42 ± 0.09 b
Low	0.10 ± 0.04 bc	0.33 ± 0.06 bc	0.44 ± 0.09 bc	0.30 ± 0.07 ab
High	0.03 ± 0.01 a	0.13 ± 0.07 a	0.14 ± 0.07 a	0.23 ± 0.07 a

Remark: [1]Different characters in one column denote significant difference

The soil Cu and Zn analyses were conducted using two extractants i.e. 1 *N* NH_4OAc pH 7 to measure the soil exchangeable Cu and Zn and 1 *N* HNO_3 to measure the soil available Cu and Zn (A. Salam et al., 2021). The procedure was as followed, 10 g of oven-dry equivalent soil sample was weighed into an erlemeyer flask. After an addition of 20 ml 1 *N* NH_4OAc pH 7.0 (for measuring the soil exchangeable Cu and Zn) or 20 ml *N* HNO_3 (for measuring the soil available Cu and Zn), the mixture was then shaken for 2 hours. The Cu and Zn concentration was determined using flame AAS after filtration.

The difference between treatment was evaluated using their standard deviation. The change in the soil exchangeable or the soil available heavy metals (ΔHM) was used to evaluate the changes in the soil exchangeable and available heavy metals by the presence of thorny amaranth. Eq. 1 and Eq. 2 were used to calculate ΔHM.

$$\Delta \text{ Exch. HM} = \text{Exch. HM (Before Planting)} - \text{Exch. HM (After Planting)} \quad [1]$$

$$\Delta \text{ Avail. HM} = \text{Avail. HM (Before Planting)} - \text{Avail. HM (After Planting)} \quad [2]$$

Regression analysis was employed to evaluate the relationship between two important variables, particularly between plant uptakes of heavy metals with the heavy metal availability in soils and also the soil heavy metal relationship with the soil pH. The values of R^2 were used to determine the variable relationship and the value of “a” (in the equation y = ax + b) to determine sensitivity.

3. RESULT

3.1 The Growth Characteristics of Thorny Amaranth

High heavy metal level (HHM) significantly inhibited the thorny amaranth growth. Low heavy metal (LHM) also slightly affected the plant growth (Figure 2 and Table 2). For example, after 4 weeks, the plant height and dry-weight biomasses of root and shoots slightly decreased by 5.75 and 24.1 % at LHM and significantly decreased by 43.7 and 75.9% at HHM. The waste addition at 15-60 Mg ha^{-1} negatively affected the thorny amaranth growth currently planted after 23 years of waste amendment. A similar trend was observed for both shoot and roots.

3.2 The Uptakes of Cu and Zn

Plant uptake of Cu and Zn increased significantly with waste level over four weeks (Table 3). While HHM significantly increased Cu and Zn accumulation by 225 and 141%, LHM only slightly increased Cu and Zn accumulation by 31 and 71% compared to control treatment. Shown by Figure 3 that the Cu and Zn accumulation correlates well with the soil exchangeable and available Cu and Zn. The correlation coefficient of uptake Cu and available Cu or exchangeable Cu (0.707 and 0.626) was higher than those of Zn (0.343 and 0.294). Most of the absorbed Cu and Zn was accumulated in roots as indicated by TF for Cu and Zn < 1,00 (Table 3). The TF for Cu was 0.03-0.05 and for Zn was 0.03-0.06. Thorny amaranth was then classified as phyto-stabilizer.

3.3 The Changes in Soil Exchangeable and Available Cu and Zn

Thorny amaranth significantly lowered the soil exchangeable and available Cu and Zn. The soil exchangeable Cu and Zn decreased by 35.3 and 59.1% at Control, by 50.2 and 86.9 % at LHM, and by 56.1 and 44.5% at HHM (Table 4). Copper and Zn availability in the soil decreased by 40.7 and 51.2% at Control, 45.5 and 47.8% at LHM, and 30.1 and 28.4% at HHM, respectively (Table 5). These values exceeded the declines in soil by thorny amaranth (Table 4 and Table 5). As shown previously, the soil Cu and Zn after planting determine the plant Cu and Zn accumulations which correlated well with both the soil exchangeable and the soil available Cu and Zn (Figure 3). The soil exchangeable and available Cu and Zn negatively corelated with the soil pH, particularly for the soil available Cu and Zn (Figure 4 and Figure 5). The soil available Cu and Zn decreased with the increase in soil pH. The soil pH was shown to slightly decreased in the presence of thorny amaranth (Table 6). The correlation coefficients between the soil available Cu and the soil available Zn with the soil pH were 0.41 and 0.33, respectively. While those of the exchangeable Cu and exchangeable Zn were much lower, 0.03 and 0.09, respectively.

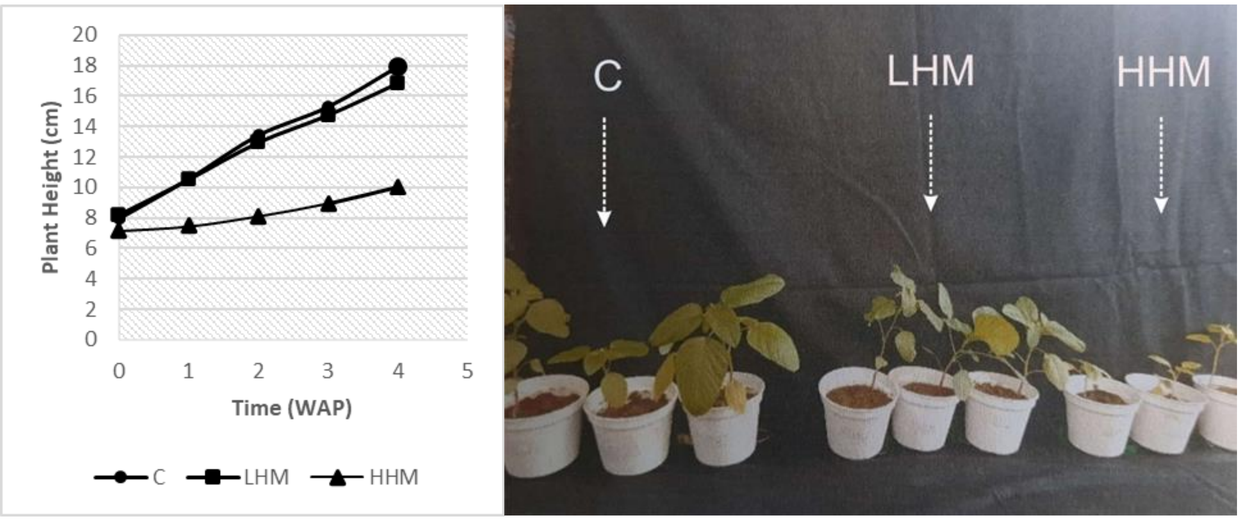

Figure 2. The thorny amaranth growth in the soils polluted with metals (C Control, LHM Low Heavy Metal, HHM High Heavy Metal)

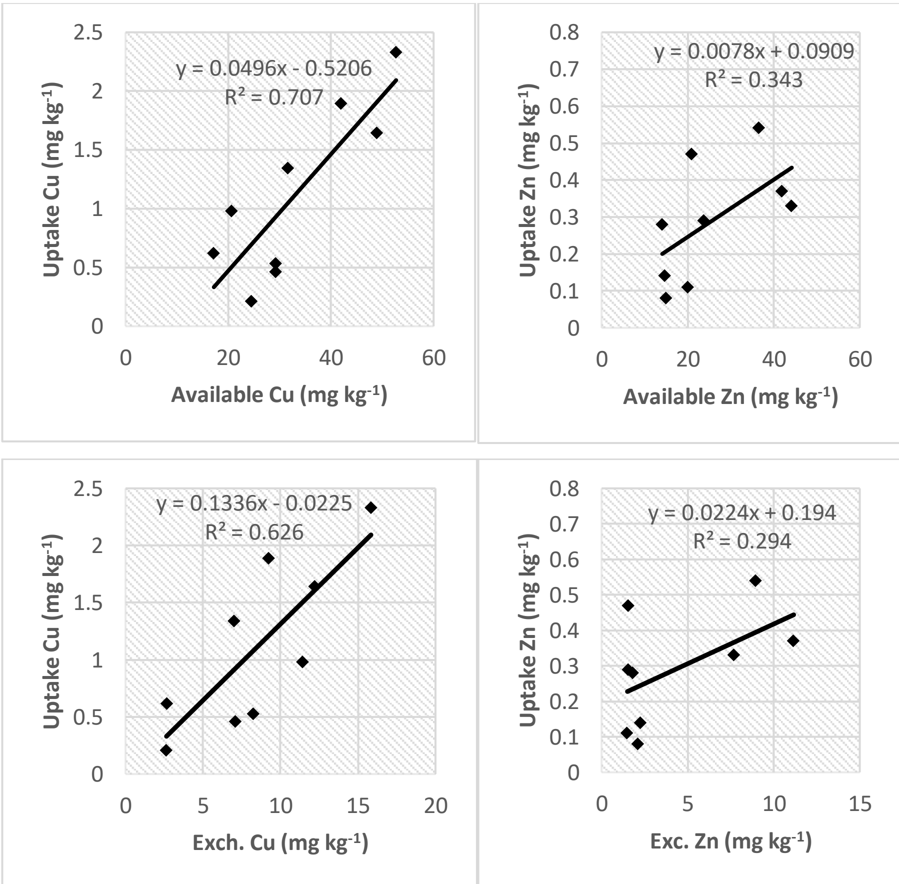

Figure 3. The plant uptake relationship with the soil Cu and Zn

Table 3. The Cu and Zn uptakes by thorny amaranth planted in soils polluted with metals[1]

Heavy Metal Level	Cu				Zn			
	Root	Shoot	Root+Shoot	TF	Root	Shoot	Root+Shoot	TF
	……….……..……mg kg^{-1} …………………………				………………………. mg kg^{-1} ……….…………….			
Control	0.58 ± 0.38 a	0.03 ± 0.01 a	0.60 ± 0.39 a	0.05	0.16 ± 0.10 a	0.01 ± 0.00 a	0.17 ± 0.10a	0.06
Low	0.75 ± 0.48 a	0.03 ± 0.01 a	0.78 ± 0.49 a	0.04	0.28 ± 0.17ab	0.01 ± 0.00 a	0.29 ± 0.18 ab	0.04
High	1.90 ± 0.34 b	0.05 ± 0.02 a	1.95 ± 0.35 b	0.03	0.40 ± 0.11b	0.01 ± 0.00 a	0.41 ± 0.11 b	0.03

Remark: [1]Different characters in one column denote significant difference

3.4 The Shifting of Cu and Zn Extractability

In the presence of thorny amaranth, the decrease in the soil available Cu was significantly higher than that in the absence of plant, ranging from 14.30-25.08 mg kg^{-1} compared to 1.43-4.88 mg kg^{-1}. On the other hand, the decrease in the soil exchangeable Cu was lower, 3.05-7.53 mg kg^{-1} in the presence of thorny amaranth compared to 2.73-6.27 mg kg^{-1} in the absence of plant (Table 7). These findings demonstrate that the soil exchangeable Cu decreased more noticeably than the soil available Cu in the presence of thorny amaranth. In contrast, the decline in the amount of available and exchangeable Cu in the absence of plant was noticeably less pronounced than it was in the presence of thorny amaranth. In the absence of thorny amaranth, the decrease in soil exchangeable and soil available Cu was roughly the same.

A similar phenomenon was demonstrated by soil Zn (Table 8). The decrease in the soil available Zn in soil without plant ranged from 3.79-4.50 mg kg^{-1}, about similar to soil exchangeable Zn ranging from 2.08-6.80 mg kg^{-1}. While the decreases in the soil available Zn in the presence of thorny amaranth ranged from 15.32-19.78 mg kg^{-1} while that for the soil exchangeable Zn ranged lower from 3.21-10.15 mg kg^{-1}. This data show that in the presence of thorny amaranth, the soil available Zn decreased more significantly than the soil exchangeable Zn. Conversely, the decrease in the soil available Zn in soils without plant were relatively small, comparable to those of the soil exchangeable Zn.

4. DISCUSSION

As predicted based on some previous reports (Asati et al., 2016; Chibuike & Obiora, 2014; Gill, 2014; Jamal et al., 2013; A. K. Salam, M. A. Hidayatullah, et al., 2021), the growth of thorny amaranth was significantly inhibited by the presence of high concentrations of heavy metals in soils. Similar data were also obtained in earlier studies using the same soil samples on caisim, lettuce, land spinach, napier grass, water spinach, and corn (Salam, 2022; A. K. Salam, M. A. Hidayatullah, et al., 2021; Silva et al., 2021). The high soil Cu and Zn concentrations are correlated with this. The Ni concentration in the waste-amended soils used in this study was quite high, according to our most recent analysis. At least these 3 heavy metals might have significantly lowered the plant height and biomasses including plant roots and shoots (Figure 2 and Table 2). Copper and Zn are actually micronutrients for plants but needed at low quantities. However, due to their high concentrations in soils, higher than the allowable concentrations, their presence was detrimental to this plant. Nickel was found at relatively high concentrations, which may have also inhibited plant growth, despite the fact that it is a trace element that is not a nutrient and is not harmful to plants at low concentrations. These 3 heavy metals were originated from the metal wares industrial waste amended in 1998 or 23 years ago. Heavy metals analysis before waste treatment into the experimented soils in 1998 revealed that the industrial waste was high in Cu and Zn, about 754 and 44.6 mg kg^{-1}, respectively (A. K. Salam, A. F. Pakpahan, et al., 2021). Current analysis of the control, low heavy metal (LHM) and high heavy metal (HHM) field plots show that the concentration of soil Ni were 46.3, 49.1, and 80.6 mg kg^{-1}, respectively. Nickel was relatively high in HHM, similar to Cu and Zn. In order to give plants the right concentrations of heavy metals and prevent significant disruptions to plant growth, this level must be chemically lowered.

Although there are many different forms of heavy metals in soils, it is suggested that the most vulnerable forms to plant uptake are the soluble forms, the weakly held heavy metals on the soil solid surfaces, and the most soluble precipitates. Therefore, the soil exchangeable form of heavy metals (extracted by 1*N* NH_4OAc pH 7.00) and the available forms that include all soluble forms (free cations, chelates and complexes), the exchangeable form, and the soluble precipitates (extracted by 1*N* HNO_3) may greatly affect plant roots. Linear regression analysis with high correlation coefficients were found between the soil available Cu and Zn with the related plant uptake (R^2= 0.707 for available Cu and R^2=0.343 for available Zn). High correlations were also found for the soil exchangeable Cu and Zn with their uptakes (R^2=0.626 for Cu and 0.294 for Zn) (Figure 3). This data show that the soil exchangeable and the soil available Cu and Zn both determine heavy metal effects on plant growth. The negative effects of heavy metals on plants were, therefore, governed by the amounts of metals absorbed by plant roots and shoots, which are determined by the soil available and the soil exchangeable forms.

The values of gradients ("a" in the linear regression of y = ax + b) which were higher for Cu than for Zn indicate that this plant was more responsive to Cu than to Zn, meaning that Cu was more detrimental to plants. As shown by Figure 3, the "a" values for Cu are 0.0496 and 0.1336 for the available and exchangeable form, respectively. These values are greater than those for Zn, which are 0.0078 and 0.0294 for the available and exchangeable form. According to some reports, Cu was more toxic than Zn. The values of TF << 1.00 indicate that the greater part of Cu and Zn were accumulated in roots rather than in shoots (Table 3). Therefore, these heavy metals could have destroyed roots more severely.

The absorption of Cu and Zn lowered the soil exchangeable and available Cu and Zn (Table 4 and Table 5). Their concentrations also decreased in the absence of plant, probably due to the shifting of adsorbed heavy metal cations to high energy retainment that make heavy metals more difficult to extract. However, these tables show that the decrease in Cu and Zn were much higher in soils also planted with thorny amaranth. Thorny amaranth definitely absorbed the soil Cu and Zn causing the lowering exchangeable and available Cu and Zn. This plant most probably also excretes some organic acid and soil enzymes causing the decrease in soil pH as shown in Table 6 (Bowles et al., 2014; Dietz et al., 2020; Meena & Rao, 2021; Wu et al., 2018). As suggested by some researchers the decrease in soil pH may solubilize the soil structural Cu and Zn and may increase their absorption. The negative relationship with soil pH, particularly of the soil available Cu and exchangeable Cu (Figure 4 and Figure 5) were in accordance with this suggestion (Salam & Helmke, 1998). These relationships may have caused the greater plant absorption and the decreases in the available and exchangeable Cu and Zn in soils planted with thorny amaranth.

Table 4. The changes in the soil exchangeable Cu and Zn by thorny amaranth[1]

Time of Analysis	Level of Heavy Metal					
	Control		LHM[2]		HHM[3]	
	No Plant	With Plant	No Plant	With plant	No Plant	With Plant
	……… mg kg^{-1} ………					
Cu						
Before Planting	8.64 ±0.00 b	8.64 ± 0.00 a	14.95 ± 0.00 b	14.95 ± 0.00 b	28.36 ± 0.00 b	28.36 ± 0.00 b
After Planting	5.91 ± 0.81 a	5.59 ± 5.07 a	8.68 ± 1.97 a	7.45 ± 0.70 a	16.27 ± 2.91 a	12.43± 3.31 a
Zn						
Before Planting	5.26 ± 0.00 b	5.26 ± 0.00 b	11.69 ± 0.00 b	11.69 ± 0.00 b	16.47 ± 0.00 b	16.47 ± 0.00 b
After Planting	3.18 ± 0.04 a	2.05 ± 0.23 a	6.76 ± 1.52 a	1.54 ± 0.03 a	9.67 ± 2.05 a	9.14 ± 1.94 a

Remark:[1]Different characters in one column for each element denote significant difference, [2]LHM Low Heavy Metals, [3]HHM High Heavy Metal

Table 5. The changes in the soil available Cu and Zn by thorny amaranth[1]

Time of Analysis	Level of Heavy Metal					
	Control		LHM[2]		HHM[3]	
	No Plant	With Plant	No Plant	With Plant	No Plant	With Plant
	……… mg kg^{-1} ………					
Cu						
Before Planting	35.10 ± 0.00 b	35.10 ± 0.00 b	55.15 ± 0.00 b	55.15 ± 0.00 b	68.50 ± 0.00 b	68.50 ± 0.00 b
After Planting	33.67 ± 0.76 a	20.80 ± 3.65 a	50.27 ± 2.25 a	30.07 ± 1.33 a	64.90 ± 1.75 a	47.86 ± 5.42 a
Zn						
Before Planting	29.92 ± 0.00 b	29.92 ± 0.00 b	41.35± 0.00 b	41.35 ± 0.00 b	57.13± 0.00 b	57.13 ± 0.00 b
After Planting	26.13 ± 1.82a	14.60 ± 0.46 a	36.73 ± 0.67 a	21.57 ± 1.99 a	52.43 ± 3.23 a	40.90 ± 3.90 a

Remark: [1]Different characters in one column for each element denote significant difference, [2]LHM Low Heavy Metals, [3]HHM High Heavy Metal

Table 6. The changes in soil pH by thorny amaranth

Level of Heavy Metal	Planting Treatment	Before Planting	After Planting	ΔpH[1]
Control	No Plant	5.61	5.52	-0.09
	With Plant	5.61	5.59	- 0.02
Low	No Plant	5.66	5.55	-0.11
	With Plant	5.66	5.62	-0.04
High	No Plant	5.67	5.52	-0.15
	With Plant	5.67	5.57	-0.10

Remark: [1]ΔpH = Soil pH (After Planting) – Soil pH (Before Planting)

Table 7. The changes in the soil Cu extractability by thorny amaranth[1]

Level of Heavy Metal	Plant Treatment	ΔCu[2]			
		Available		Exchangeable	
		….. mg kg^{-1} …..	… % …	….. mg kg^{-1} ….	…. % ….
Control	No Plant	1.43 ± 0.74 a	4.1	2.73 ± 0.81 a	31.1
	With Plant	14.30 ± 3.69 c	40.7	3.05 ± 5.07 a	35.3
Low	No plant	4.88 ± 2.22 b	8.8	6.27 ± 1.98 b	41.9
	With Plant	25.08 ± 1.33 d	45.5	7.50 ± 0.70 b	50.2
High	No Plant	3.60 ± 2.91 ab	5.3	3.69 ± 2.91 a	18.5
	With Plant	20.64 ± 5.46 cd	30.1	7.53 ± 3.32 b	37.7

Remark: [1]Different characters in one column denote significant difference, [2]ΔCu = Cu (Before Planting) – Cu (After Planting

Table 8. The changes in the soil Zn extractability by thorny amaranth[1]

Level of Heavy Metal	Plant Treatment	ΔZn[2]			
		Available		Exchangeable	
		….. mg kg^{-1} …..	… % …	….. mg kg^{-1} …..	… % …
Control	No Plant	3.79 ± 1.82 a	12.7	2.08 ± 0.04 a	39.5
	With Plant	15.32 ± 0.44 b	51.2	3.21 ± 0.21 b	61.0
Low	No plant	4.62 ± 0.66 a	11.2	4.90 ± 1.52 bc	42.2
	With Plant	19.78 ± 1.95 c	47.8	10.15 ± 0.03 d	86.8
High	No Plant	4.70 ± 3.24 a	8.23	6.80 ± 2.05 c	41.3
	With Plant	16.23 ± 3.89 bc	28.4	7.33 ± 1.94 c	44.5

Remark: [1]Different characters in one column denote significant difference, [2]ΔZn = Zn (Before Planting) – Zn (After Planting)

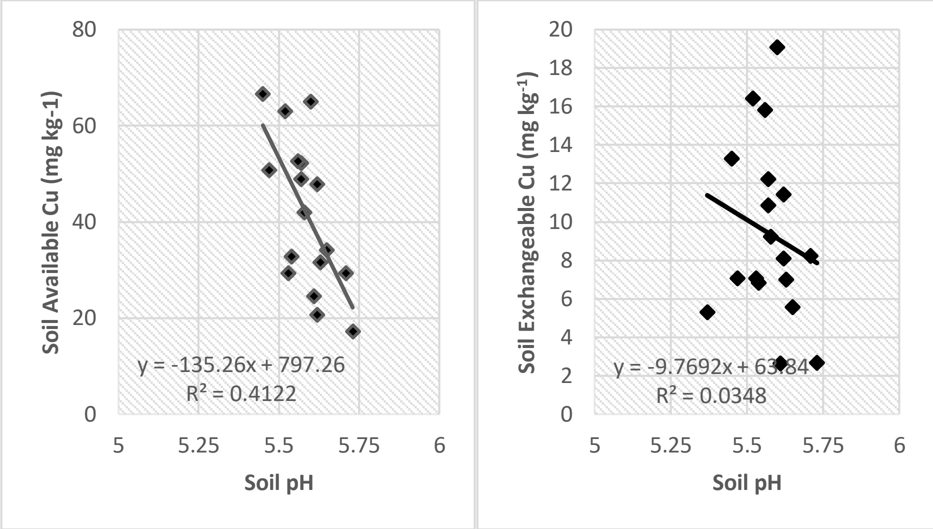

Figure 4. The soil Cu relationship with pH

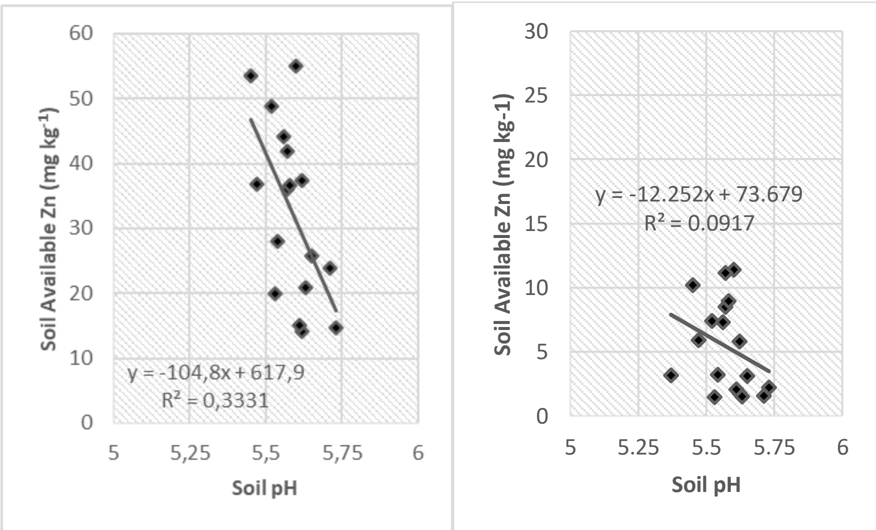

Figure 5. The soil Zn relationship with pH

The accumulated Cu and Zn in plant biomasses may have come from the soil exchangeable Cu and Zn or the soil available Cu and Zn which include the soluble forms, the exchangeable form, and soil precipitates. However, Tables 7 and 8 show that the decrease in soil available and exchangeable Cu and Zn in soils with plants was relatively comparable, whereas the decrease in soil available and exchangeable Cu and Zn in soils without plants was more pronounced. These observations indicate that the available heavy metal predominantly determines plant absorption. Heavy metals were absorbed by plant roots mostly from forms other that the soil exchangeable form. Part of the soil heavy metal precipitates most probably supplied the soil available form for plant absorption.

Therefore, in measuring the availability and also the mobility and toxicity of Cu and Zn and also other heavy metals, the use of dilute acids may give more accurate prediction than the use of dilute salt that measure the soil exchangeable heavy metals. Further research must be conducted to devise the suitable acid concentrations that may give better correlation with particular plant accumulation of heavy metals through correlation studies.

5. CONCLUSION

The growth of all plants as indicated by plant height and dry-biomasses was depressed by the presence of higher soil exchangeable and available Cu and Zn. Thorny amaranth considerably reduced the exchangeable and available Cu and Zn in the soil. The plant Cu and Zn uptakes correlate well with the soil exchangeable and available Cu and Zn. However, a significant part of the soil exchangeable Cu and Zn probably shifted to stronger bonding during the incubation time. It was demonstrated that plants absorbed more Cu and Zn from forms different than the soil-exchangeable forms.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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