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Remediation Potentials of *Amaranthus spinosus* L. and Compost Amendments on Copper-contaminated soil from Mankayan, Benguet, Philippines

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ABSTRACT
Pot experiment was conducted to test the potentials of Amaranthus spinosus and compost amendment in remediating copper-contaminated soil from abandoned mine tailing pond in Mankayan, Benguet, Philippines. Treatments replicated three times and completely randomized were: T1-plant +normal soil, 0 compost; T2A& T2B – plant + normal soil+ compost A or B; T3– plant + contaminated soil, 0 compost; T4 A & T4 B– plant +contaminated soil + compost A or B; T5 A &T5 B – 0 plant, contaminated soil + compost A or B. pH of potting media was monitored and extractable soil Cu was analyzed before and after the experiment. Total Cu was analyzed in plant tissues. Compost was characterized before use. A. spinosus showed copper tolerance. Mean plant height, stem diameter and biomass in T1 and T3were not statistically differential though T3 plants exhibited extensive chlorosis and delayed flowering. It was classified as a metal excluder and a phytostabilizer based on its ability to accumulate copper in roots and reduce soil Cu by 30%. Compost A & B had similar effects in hastening plant's growth shown in T4A, T4B, T2Aand T2B. Compost alone in T5 reduced Cu by 27% by immobilization and through increased pH of medium lowering Cu bioavailability. Compost low plant nutritional value may be responsible for its inability to significantly improve plant's growth in T4 that did not enhance its Cu extracting ability. Compost and A. spinosus can be used as remediating agents in rehabilitating Cu contaminated soil however mineral fertilizers should also be added.
Key words: remediation, copper toxicity, compost amendment, *Amaranthus spinosus*, copper tolerant

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INTRODUCTION

One of the many highlighted issues in pollution biology is soil contamination by heavy metals that comes from the accumulation of toxic heavy metals and metalloids. It is considered as one of the most serious threats to soil and water resources as well as to human health (1). Unlike organic contaminants, heavy metals are non-biodegradable. They are not affected by microbial action nor are chemically degraded and can proceed to bioaccumulation and in turn to biomagnification process. This problem is common among countries with greatly exploited mineral resources which readily present routes for soil heavy metal contamination. The Philippines, privileged by its geologic history, is the site of many mineral extraction corporations that may have contributed to the country's economic growth through the years (2). In contrast to the progressive opportunities that the mining industry has provided, data from the United Nations Environmental Program (UNEP) show that the country holds the record of being one of the worst in the world when it comes to mine-tailing dam failures that lead to inundation of water systems, commonly rivers, and nearby lands with toxic wastes including heavy metals (3). This clearly identifies the Philippines for many cases of soil heavy metal contamination. Various efforts to address this issue have been developed however phytoremediation and heavy-metal bioavailability manipulation using compost amendments are among the widely used and well-known remediation methods (1, 2, 4, 13).

Mankayan, Benguet is one area in the Philippines that suffers from soil heavy metal contamination. It is the host municipality of Lepanto Consolidated Mine Co. (LCMCo) operating since 1937, whose tailing pond no. 3 ruptured in 1986 releasing huge amounts of mine wastes, particularly copper (Cu) to the environment. According to Cuevas et al. (2) the current level of copper in the contaminated agricultural soil is greater than 220 μg g^{-1}. This value is much higher than the normal level of soil copper at 30 μg g^{-1}.Fontanilla and Cuevas(4), Cuevas et al., (2). The threshold level for normal soil may extend up to 50 μg g^{-1}, the upper limit of the common range of soil copper (5).High soil copper content is taken for granted by the local people because of the normal appearance of the fields undergoing natural regeneration with presence of grasses as common pioneer species.

This present study devised a bipartite soil remediation setup with a phytoremediation component, *Amaranthus spinosus* L., and a heavy metal bioavailability manipulation component – compost amendment. The primary purpose is to evaluate their remediation potentials, both separately and cooperatively, on Cu-contaminated soil from Mankayan, Benguet. *A. spinosus* is among the dominant species growing in some surveyed mine sites in the Philippines indicating its possible tolerance to high soil copper. It is also fast growing and canbe easily cultivated, attributes of a good phytoremediating species (6). Cuevas et al. (2) and Fontanilla and Cuevas (4) have demonstrated that compost is an effective remediating agent of mine waste contaminated soil. In the present study, two types of compost with different substrate sources that resulted to their different levels of organic matter and humic acid contents were used. Humic acid is known to affect the mobility and availability of heavy metal contaminants present in the soil (7).

MATERIALS AND METHODS

Two soil types were used – normal soil with 50 ug $g^{-1}$and high Cu-containing soil or contaminated soil with 102 ug g^{-1} extractable Cu contents. Both soil samples were taken from Mankayan, Benguet. Two different types of compost were used. Compost A has 17% OM content and was chicken-manure based while compost B has 28% OM content and was purely plant materials-based. Two percent (2%) compost was added on a dry weight basis to every soil setup assigned to have amendment following the recommendation of Cuevas et al (2).pH of the potting media was monitored and extractable soil Cu was analyzed before and after the experiment. Soil samples were analyzed for% organic matter(OM) and while composts were analyzed for % OM, % total Nitrogen, %P_20_5, and % K_20 before use.

Seeds previously tested for high viability and taken from only one individual plant collected from a locality 200 km away from mining site were used in the study. The experimental layout was a completely randomized design of 8 treatments with three replicates each. The treatments made were: T1- plant + normal soil, 0 compost; T2 A – plant + normal soil + compost A; T2B -– plant + normal soil + compost B; T3 – plant + contaminated soil, 0 compost; T4 A– plant + contaminated soil + compost A; T4 B-plant + contaminated soil + compost B; T5 A – 0 plant, contaminated soil + compost A; T5 B 0 plant + contaminated soil + compost B. The potting medium for each treatment was placed in plastic pots with dimensions 10.16 cm x 17.78 in x 10.16 cm. Each bag contained 500 g of specified treatment medium all measured and proportioned on a dry weight basis. The pots were maintained at the Institute's experimental station for 105 days from mid October 2014- January 2015. The pots were arranged in a 6 cm x 4 grid cm with each pot occupying randomly selected position. Ten dried *A. spinosus* seeds were placed in each pot for all treatments except in T5 A &T5 B. Seed germination was monitored two weeks after seed sowing. Only one seedling was maintained per pot from seedling stage until seed production. Growth parameters measured were plant height and stem diameter, monitored every two weeks starting from 1st month after seed sowing until harvest time. Root and shoot dry biomass were taken separately after harvest and analyzed for total copper content. Descriptive signs of the plants' health were noted like indicators of herbivory, chlorosis, necrosis and leaf senescence (4).

Soil and compost samples were analyzed based on standard methods at the Agricultural Systems Cluster, College of Agriculture, and University of the Philippines Los Baños (UPLB). pH was measured using a pH pen. Extractable copper and total copper in plant tissues were determined using standard Atomic Absorption Spectroscopy (AAS) at the National Institute of Molecular Biology and Biotechnology (BIOTECH), UPLB. The humic acid concentration was also determined at this Institute following the protocol given in CFDA (8).

All the treatment data were tested using Analysis of Variance (ANOVA). Treatment means were compared using Scheffe's Test to detect which specific treatments are significantly different from each other.

Using the data of Cu content of plant tissues and initial and final concentrations of extractable soil Cu, plant's mode of phytoremediation was evaluated based from standards and factors (1) i.e. biological concentration factor (BCF), bioaccumulation factor (BAF) , translocation factor (TF).

RESULTS AND DISCUSSION

Properties of the potting media

Table 1 presents the chemical composition of soil and compost used in the study. Both the normal and contaminated soil samples have acidic pH - 4.9 and 5.3 respectively. Mankayan is located at 1,500 m elevation and receives an annual rainfall of more than 3,000 mm, characteristic of tropical highlands.Gurevitch et al (9) stated that high rainfall causes leaching of soil cation bases while retaining reactive H^+ that results to soil acidity. On the other hand, compost A and B that were mixed with the normal and contaminated soil in T2 A, T2 B, T4 A, T4B, T5A and T5B had alkaline pH at 8.6 and 8.1 respectively.

The pH of the growth medium has strong influence on bioavailability of Cu and plant nutrients (1, 10, 13). One significant effect of addition of compost to soil is its ability to improve acidic pH (2, 4). Table 2 presents the initial pH of the potting medium for each treatment just before seed sowing. As presented in the table pH of normal (T2A, T2B) and contaminated soils (T4A, T4 B) increased pH with compost addition. In this study compost A with initial pH of 8.6 was more effective in increasing pH as shown in its effect on T4A and T5A with soil pH of 5.3 significantly increased to 6.1 and in T2A with soil pH of 4.9 increased to pH 5.7. In comparison compost B with pH 8.1 barely increased pH of T2B from 4.9 to pH 5.3 and in T4B and T5B from 5.3 to 5.9. This greater pH increasing effect of compost A may be due to its higher pH of 8.6 compared to 8.1 of compost B and to its higherK_2O content of 3.31 % (Table 1) which can form bases and neutralize the acid pH of the soil.Compost B has only 1.12%K_2O.In this study the lowest pH was registered in T1 and T2B at 5.3 significantly lower from pH of T2A and T3 at 5.7, pH of T4B and T5B at pH 5.9 and pH of T4A and T5A at 6.1. However, pH of T4A and T5A at 6.1 was only significantly higher to T2A and T3 at 5.7. pH of T4B and T5B at 5.7 was not significantly different from T2A and T3 at 5.3. Table 2 also presented the final pH of the potting media at the end of the experiment. The importance of this final pH is discussed later.

Remediation Potential of *A. spinosus*

The remediation potential of *A. spinosus* was assessed by considering Cu tolerance, Cu accumulating capacity, root-shoot partitioning of accumulated Cu and Cu reduction in the soil. Copper tolerance was evaluated using three parameters: percent seed germination, plant growth assessed through height and stem diameter, and plant biomass produced. Seed germination is a very critical process in considering the life stages of *A. spinosus* which could only be cultivated by means of seeds (11).Seed germination of the plant was not significantly affected by differences in chemical properties notably pH and Cu content of the potting media as presented in Figure 1. In the contaminated soil with no compost amendment T3, the seed germination process of *A. spinosus* was similar to amended contaminated soil T4 A and T4 B and to normal soil in T1. This capability of the plant's seed to germinate in copper contaminated soil is one indication of the plant'scopper tolerance. Furthermore, growth parameters –plant heights and diameters exposed to the treatments in both normal and contaminated soil with no amendments(T1 and T3) were not significantly different (5% level) at all sampling periods as shown in Figure 2.This observation was further supported by non-significant difference of dry biomass data of plants harvested from T1 and T3 (Figure 3). Furthermore, the mean biomass of the plants in all potting media/treatments was not significantly different (5% level, Table 3).

However there are biological differences that were observed. Plants grown in contaminated soil tended to be shorter but wider in girth. This implied a possible coping mechanism of *A. spinosus* to copper toxicity. Though total biomass did not change, the allocation changed wherein the plants grown in the normal soil has higher aboveground biomass than belowground biomass while plants grown in contaminated soil allocated more to its belowground biomass (Figure 3). This is a possible way by which the plants cope with the stress attributed to copper toxicity in which the plant grows more roots as the roots are the first plant part to be damaged when exposed to toxic concentration of the metal (1). In this study, chlorosis was observed as one of the plant's responses to copper toxicity. Figure 4 shows highly chlorotic T3 plant leaves in comparison to the control plants in T1 grown in normal soil. Leaf chlorosis is a first response to copper toxicity whichmay be due to copper interfering with normal iron uptake or compromise chlorophyll synthesis which could in turn affect overall metabolic activities (12).The unusual red/pinkish color of the stems of the plant exposed to copper contaminated soil can also be attributed to nutrient deficiency especially phosphorus in the contaminated soil (4).

Copper toxicity also slowed down the rate of maturation or may even prevent the plant from reaching or completing the reproductive stage. Control plants in T1 exhibited development of young inflorescences as early as 42 days (6 weeks) and showed mature inflorescences which were ready for seed dispersal 98 days (14 weeks) from seed sowing. On the other hand, only one plant grown in the contaminated soil without amendment (T3) showed inflorescences and it was not until the 84th day that two other replicate plants had emerging inflorescences. None of the plants grown in T3 had a mature inflorescence at harvest time on the 105th day when control plants have mature seeds for dispersal. However it was noted that plants in T3 shed leaves earlier whereas control plants did not. Leaf shedding may serve a possible mechanism of Cu tolerance since leaves of plants grown in contaminated soil accumulate the heavy metal. Pre-mature leaf fall is also an indicator of copper toxicity (1). Leaf senescence decreases Cu content of plant tissues.These observations imply that although copper contamination in the soil did not significantly affect plant height, stem diameter and biomass production of the *A. spinosus*, the phytotoxic effects were shown within the plant's metabolic activity in that it slowed down the rate of maturation or may even prevent the plant from reaching or completing the reproductive stage.

On the average, *A. spinosus* was able to accumulate copper amounting to 97.84 μg g^{-1} in its roots and 12.35 μg g^{-1} in its shoots (Figure 5). The plant cannot be considered as a hyper accumulator but simply an excluder. Excluder plants are those that counteract heavy metal toxicity through their root system and are quantitatively characterized to have heavy metal shoot to root ratios of <1(1).Though the plant was not able to accumulate high concentrations of Cu in its aboveground biomass, it is remarkable that the plant was able to accumulate copper levels beyond the normal limit of 5 to 10 μg $g^{-1}$for plant shoot biomass(5). Phytoremediation factors for *A. spinosus* were also computed and gave values as follows: translocation factor – 0.13, bioaccumulation coefficient – 0.12, and biological concentration factor – 0.96 (Table 4). These values puts *A. spinosus*' mode of phytoremediation as phytostabilization (13).

Remediation Potential of Compost Amendments

The addition of compost amendments alone to the contaminated soil decreased the mean extractable copper concentration by 28.59% and 26.69% for low-OM compost A (T5A) and high-OM compost B (T5B), respectively which are not significantly different at 5% level of significance using Scheffe's Test. These results show that just by adding compost, regardless of the OM content, the soil copper concentration was reduced. This effect may be due to the OMcomponent of the compost. Humic and fulvic acids in OMpresent complexation surfaces or ligands for effective binding of copper (4). On the other hand, effective metal binding does not solely depend on the availability of surfaces to which it can bind to but more importantly on the mobility and availability of the metal itself. Sabir and Zia-ur-rehman (10), Ahmadpour et al. (1)stated that pH is the key player in controlling mobility and availability of metals in the soil both directly and indirectly. They mentioned that copper is highly mobile and available for plant absorption at acidic pH whereas at pH greater than 6 it tends to be less available due to complexation with organic matter present in the media. After 105 days of exposure to the compost amendments, the contaminated soil had a significantly different final pH (Table 2). In T5A (contaminatedsoil +Compost A, no plant) the pH of potting medium was final pH 7.4 while in T4B (contaminated soil + compost B , no plant) had a final pH of 6.7. Both pH levels would tend to make Cu less available. According to the United States EPA (14), low pH and low OM content (characteristics of soil in T3) increases the toxicity and the activity of copper in the soil. Addition of high pH composts i.e. compost A and B in this study, addresses both problems of copper-contaminated soils. Thus the decrease in copper content of the contaminated soil due to compost amendment in this study is through pH improvement and possibly through OM complexation.

Remediation Potential of the Cooperative Remediation Setup

The effects of compost to the *A. spinosus*' growth and copper accumulation were considered in T4 A and T4 B. The addition of compost, regardless of the type, did not have a statistically significant effect on the height, stem diameter and biomass of *A. spinosus.* These findings can be attributed to the specific organic matter content requirement of *A. spinosus*. According to Huang et al. (15), there are two types of organic matter based from plant community use: high-quality and low-quality OM. High-quality OM is characterized by high N and low lignin contents which supports growth of fast-growing and short lived plants like *A. spinosus* while low-quality OM has low N and high lignin and phenolic contents. Composts A and B were of the low-quality OM type (total N content 1.2% and 0.70% respectively – Table 1) both of which did not adequately supply the nutrients needs of the test plant. Perhaps if the compost used has much higher N contents, compost amendment would have increased the plant's ability as a phytoremediator.

The addition of compost may not have an effect on the physical properties of the plant, i.e. height, stem diameter and biomass, but it had a positive effect on the rate of development and maturation of the plant.As mentioned earlier T1 plants produced young inflorescences at day 42 (6^{th} week) and in 92 days (13^{th} week) mature inflorescences had mature seeds ready for dispersal, whereas plants grown in T3(unamended contaminated soil), did not produce mature inflorescences. The addition of compost, regardless of type, hastened plant development towards reproductive maturity, exhibited in both normal and contaminated soil (Figure 6). For both T2A and T2B (normal soil + compost A and B respectively) the plant had mature inflorescences in 56 days (week 8) much earlier than T1 plants. Natural senescence which was not observed in the plant grown in T1 within the 105 daysobservation period, was observed in T2 A and T2 B in 84 days (week 12). Natural senescence was also observed on the 79^{th} day (11^{th} week) for 2 replicate plants in T4 A and 1 replicate plant in T4 B. These results therefore show that compost amendment negated or ameliorated the copper toxicity effect on delay of flowering discussed earlier and observed in plants in T3.In addition, T4 A and T4 B young inflorescences emerged as early as 35th day (5thweek) and which matured towards harvest time similar to what was observed in T2 A and B. Moreover, the addition of both type of compost resulted in non-observance of chlorosis in the leaves and stem. This observation implies that compost amendment resulted in minimal Cu translocated to the shoot from the roots. Metal immobilization via compost amendment is achieved by complexation of organic products and alteration of soil physicochemical properties like pH (10).

The two remediation setups have equal potentials in remediation of Cu contaminated soil considering the amount of copper reduced in the soil. *A. spinosus* is a copper excluder and phytostabilizer, while compost amendments help as copper immobilizer. Both facilitated approximately 30% recoverable Cu reduction (not statistically different at 5% at Schffe's test – Table 5) in the soil in just a span of 105 days. Contrastingly, the cooperative remediation set-up, did not have a significant difference with using the components separately. The purpose of using the two components together to increase accumulated copper therefore, was not achieved. Though no significant effect was observed in terms of Cu reduction, adding compost to the plant speeds up the rate of sexual maturation thus the life span of the plant without significantly lessening the accumulated copper. As mentioned above the low – quality compost used in the study was not able to increase the copper extracting ability of *Amaranthus spinosus.* Neither compost A nor B was able to supply the needed nutrients of the plant to significantly increase its growth. This was shown by almost similar dry biomass produced by the plant in all treatments (Table 3).

Table 1. Some chemical properties of the soil and compost samples used in the study.

Sample/ Treatments where samples were used	Parameter							
	Cu Concentration ($\mu g\ g^{-1}$)		pH	%OM	%N	% P_2O_5	% K_2O	Humic Acid Concentration (g/100g)
	Extractable	Exchangeable						
Normal Soil – T1, T2	50.65	13.09	4.9	3.42	–	–	–	0.20 ± 0.01
Contaminated Soil – T3, T4, T5	102.18	26.63	5.3	1.81	–	–	–	0.15 ± 0.00
Compost A – T2 A, T4 A, T5 A	–	–	8.6	17	1.04	3.99	3.31	0.92 ± 0.06
Compost B – T2 B, T4 B, T5 B	–	–	8.1	28	0.70	0.27	1.12	2.73 ± 0.33

**OM – organic matter*

Table 2. Mean pH values of all potting media at the start and end of study(105 days after treatment)

Treatment	Mean Initial pH base soil	Mean Initial pH of compost added	Mean pH of soil + compost at start of expt*	Mean final pH at the end of expt*
T1 – plant + normal soil	4.9	-	5.3**D**	5.2 **C**
T2 A – plant+ normal soil + compost A	4.9	8.6	5.7 **C**	6.7 **B**
T2 B – plant + normal soil + compost B	4.9	8.1	5.3 **D**	5.2 **C**
T3 – plant + contaminated soil	5.3	-	5.7**BC**	6.4 **B**
T4A – plant + contaminated soil + compost A	5.3	8.6	6.1**A**	7.5 **A**
T4B – plant + contaminated soil + compost B	5.3	8.1	5.9 **AB**	6.7 **B**
T5A – 0 plant + contaminated soil + compost A	5.3	8.6	6.1 **A**	7.4 **A**
T5B -0 plant + contaminated soil + compost B	5.3	8.1	5.9 **AB**	6.7 **B**

**Means with a common letter in a column are not significantly different at 5% level of significanceusing Scheffe's Test where A > B> C > D.*

Table 3. Shoot and root dry weights (biomass) (g) of *Amaranthus spinosus* grown in different potting media for 105 days.

Treatments	Mean dry weight (g)	
	Shoot	Root
T1	1.26**A**	0.77 **A**
T2A	1.43 **A**	2.02 **A**
T2B	0.77 **A**	1.90 **A**
T3	0.58 **A**	1.00 **A**
T4A	0.76 **A**	0.91 **A**
T4B	0.43 **A**	0.84 **A**

**Means with a common letter in a column are not significantly different at 5% level of significance.*

Table 4. Computed phytoremediation factors of *A. spinosus* on copper-contaminated soil.

Phytoremediation Factor	Value
Translocation Factor (TF)	0.13
Bioaccumulation Factor Coefficient (BAC)	0.12
Biological Concentration Factor (BCF)	0.96

Table 5. Mean percent extractable soil copper level reduction after exposure to different treatments for 105 days.

Treatment	Initial Cu Concentration ($\mu g\ g^{-1}$)	Final Cu Concentration ($\mu g\ g^{-1}$)*	Cu Reduction (%)
T3 High-Cu content Soil +*A. spinosus*	102.18	72.80 **A**	28.75
T4 A High-Cu content Soil +*A. spinosus* + Compost A	102.18	70.30 **A**	31.20
T 3 High-Cu content Soil +*A. spinosus*	102.18	72.15 **A**	29.39
T4 A High-Cu content Soil +Compost A	102.18	72.97 **A**	28.59
T4 B High-Cu content Soil +Compost B	102.18	74.91 **A**	26.69

**Means with a common letter in a column are not significantly different at 5% level of significance using Scheffe's Test.*

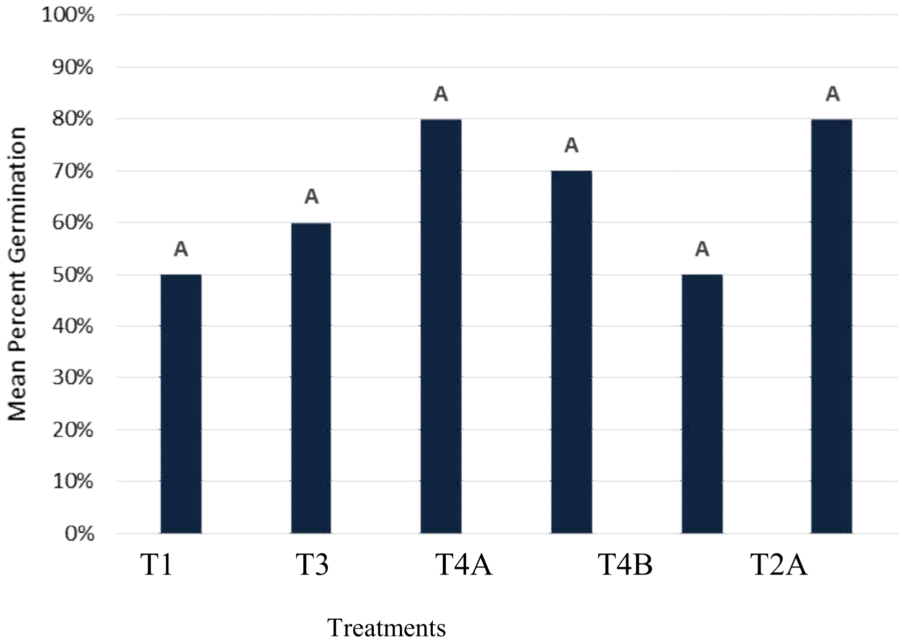

Figure1. Mean percent germination of *A. spinosus* seeds recorded two weeks after seed sowing in different treatments: T1 (normal soil- 0 compost), T2A & T2B (normal soil amended with compost A & B, respectively), T3 (contaminated soil, 0 compost), and T4 A & T4B (contaminated soil amended with compost A & B, respectively).

**Mean values with a common letter are not significantly different at 5% level of significance.*

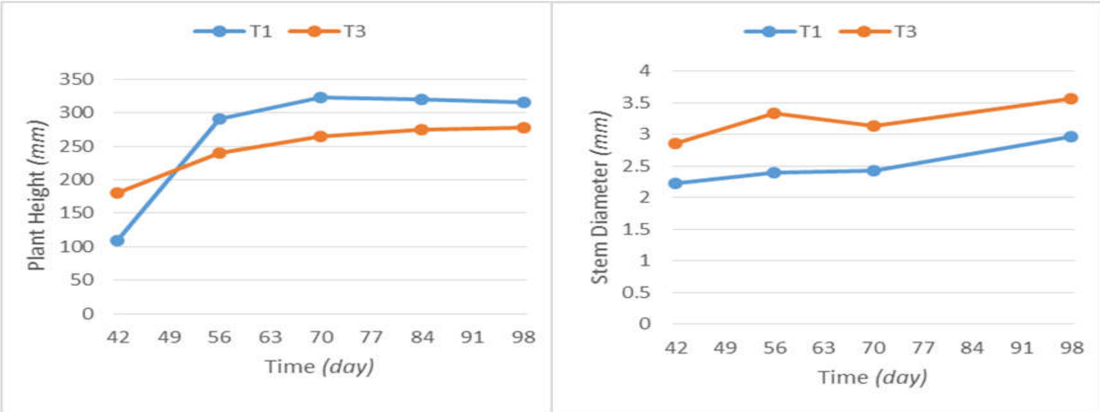

Figure 2. Growth of *A. spinosus* in T1 (uncontaminated soil) and T3 (contaminated soil) monitored thru plant height (left) and stem diameter (right) measured every 14 days for 56 days**.
**Mean values with a common letter are not significantly different at 5% level of significance.*
***The first data point was recorded at Day 42 of the plant in reference to the time of seed sowing.*

Figure 3. Biomass of *A. spinosus* after 105 days culture in T1 (normal soil, 0 compost) and T3 (contaminated soil, 0 compost).
**Mean values with a common letter are not significantly different at 5% level of significance.*

Figure 4. Chlorosis (A) and reddening of stems (B) of *A. spinosus* grown in T3 (contaminated soil), T4 (contaminated soil amended with compost A), and T4B (contaminated soil amended with compost B) relative to those grown in normal soil – T1 (C) observed 5 weeks after seed sowing.
Photo taken November 14, 2014

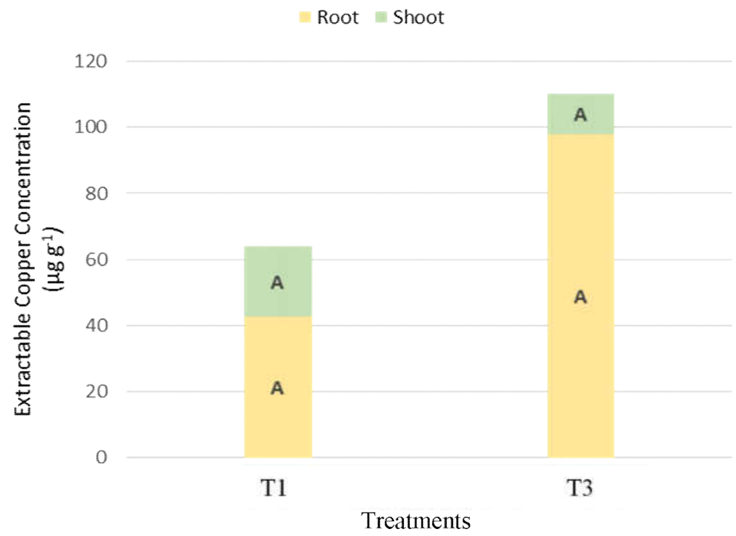

Figure 5. Total copper accumulated in *A. spinosus'* biomass and its root-shoot copper partitioning after culture in T1 (normal soil, 0 compost) and T3 (contaminated soil, 0 compost) for 105 days.
**Mean values with a common letter in same colored bars are not significantly different at 5% level of significance using Scheffe's Test*

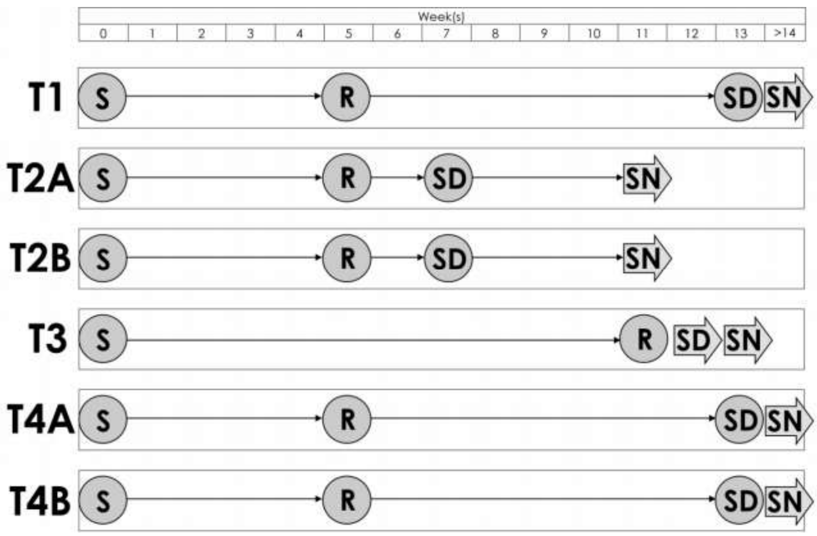

Figure 6. Modified life cycle graph of *A. spinosus* grown in T1 (normal soil), T2A & T2B (normal soil+ compost A & B, respectively), T3 (contaminated soil), and T4A & T4B (contaminated soil + compost A & B, respectively) for 105 days. S – seed sowing, R- flowering; SD – seed dispersal, SN - senescence
**Circles indicate direct observation within the period of the study while arrows indicate indirect and/or expected observations.*

CONCLUSION

A. spinosus did not exhibit statistically significant differences in the mean seed germination, plant heights, stem diameters and biomass in both normal or Cu contaminated soil treatments but extensive chlorosis was observed in plants grown in unamended contaminated soil. Copper toxicity slowed down maturation of the plant. *A. spinosus* accumulated higher copper concentration in its roots and was classified as a metal excluder. The plant was able to reduce approximately 30% of the recoverable copper in the soil and was considered a phytostabilizer. For the heavy metal bioavailability manipulation component, the addition of compost amendments, regardless of the type of compost, was able to decrease the recoverable copper concentration in the soil by approximately 27% through copper immobilization and improvement of pH of potting media. For the cooperative setup, the addition of compost to contaminated soil had no significant effect on *A. spinosus*' height, stem diameter, biomass, and accumulated copper but hastened development and maturation of the plant at a rate similar to plants grown in normal soil. There was also no significant difference in the reduction of recoverable copper in the soil when comparing the cooperative setup and the individual components probably due to low plant nutritional value of the compost. Compost was not able to adequately supply plant nutrients that will boost plant growth and enhance its copper extracting ability.

These findings suggest that compost amendment and *A. spinosus* are good remediation agents of Cu contaminated soil. For more effective remediation both components can be combined but mineral fertilizer should be added to increase plant growth and enhance the capability of the plant to extract copper from the soil.

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