Effects of Heavy Metals on Agronomic Attributes of Some Selected Cereal Crops (*Zea mays* and *Sorghum bicolor*)

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Authors' contributions

This work was carried out in collaboration among all authors. Author GIA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HON and CDN managed the analyses of the study. Author ECO managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Aims: To investigate the effect of Heavy metals on the growth of *Zea mays* (*Z. mays*) and *Sorghum bicolour* (*S. bicolour*).
Study Design: Laboratory-experimental design was used in this study.
Place of Study: The heavy metal polluted soil samples were collected from Crush Rock Industries Ishiagu, Ebonyi State, Nigeria, while control soil samples were obtained from the Zoological Garden of the Department of Applied Biology and Biotechnology, Enugu State University of Science and Technology.
Methodology: The seeds of the two plants were collected from the Enugu State Ministry of Agriculture. The experimental setup consisted of 16 contaminated potted soils, 8 each for *Z. mays* and *S. bicolor*. Another 8 potted soils not contaminated with heavy metals served as control. Fourteen days after germination, the following growth parameters were measured (in cm); plant heights, number of leaves, stem girth, and leaf area.
Results: The polluted soil sample was slightly acidic; (pH was 6.34±0.29). It had a higher cation exchange capacity (21.80±0.33), Cd (25.18±0.34), Cr (10.20±0.21), Cu (28.54±0.49), Pb

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(9.92±0.36), but lesser soil organic carbon (0.87±0.10). Plant samples cultivated in contaminated soil showed the least favourable vegetative growth.

Conclusion: Comparing the results obtained from the control sample, it was deduced that these heavy metals have adverse effect on the vegetative growth of *Z. mays* and *S. bicolor*.

1. INTRODUCTION

Heavy metals pollution is of primary concern in environmental pollutions as they can't be destroyed by degradation. It is a crucial environmental concern throughout the world. It occurs in the soil, in water, in living organisms, and at the bottom of the sediments. Geological and anthropogenic activities are sources of heavy metal contamination [1]. Sources of anthropogenic metal contamination include industrial effluents, fuel production, mining, smelting processes, military operations, utilization of agricultural chemicals, small-scale industries (including battery production, metal products, metal smelting and cable coating industries), brick kilns and coal combustion [2].

Plants take up metals from contaminated soil through the roots and incorporate them into the edible part of plant tissues or as a deposit on the surface of vegetables [3,4]. Food contamination with trace metals is important, particularly in agricultural production systems and human health. Factors influencing the concentration of trace metals in plants include climate, environmental pollution, nature of the soil on which the plant is grown, and the degree of maturity of the plant at the time of harvesting. Fertilizers also contain trace metals, thereby becoming an additional source of metal pollution in vegetables [5].

Maize is an important staple food and most important cereal crop in sub-Sahara Africa and Latin America [6]. In Nigeria, after *S. bicolour* and millet, *Z. mays* is the most important staple cereal with the widest geographical cultivation and utilization [7]. All the parts of maize can be used for food and non-food products [6]. Maize is a tall plant (2-3 m tall) with broad long leaves, and by both an adventitious and brace root system [7]. *S. bicolour* shares the same order and family as maize, *Poales* and *Poaceae* respectively, and is structurally similar to maize but taller (about 4 m tall). Sorghum are cultivated primarily for forage, syrup production and ethanol, although their grains are also processed and used for food. Although, these crops can be grown in a variety of soil, a soil with medium texture, fairly permeable and good water holding capacity is preferable because these crops are sensitive to water logging. The pH should be 6.5 – 7.5 along with cation exchange capacity of 20 meq/100 g [7].

Accumulation of trace metals in an agricultural environment has direct consequences for man and the ecosystem. The most significant problem associated with trace metals in the environment apart from accumulation through the food chain and persistence in nature is their toxicity. While cereals are consumed by human and animals for body nourishment, heavy metals effect on the cultivation of these food materials remains a challenge. Therefore, the study was aimed to investigate the effect of heavy metals in the vegetative growth of *Zea mays* and *Sorghum bicolour*.

2. MATERIALS AND METHODS

The seeds of *S. bicolour* and *Z. mays* were purchased from the Enugu State Ministry of Agriculture and were all authenticated by Prof. J.C. Okafor, a renowned Taxonomist of "Fame Agricultural Center, Independence Layout, Enugu". A voucher specimen was kept for referencing. The soil surface of the nursery was cleared and the seeds were cultivated for fourteen days prior to its use in the various experimental treatments. About ten kilograms of sub soil was collected from the Zoological Garden of the Department of Applied Biology and Biotechnology, Enugu State University of Science and Technology. About 10 kg of heavy metal polluted sub soil was also collected from Crush Rock Industry, Ishiagu Ebonyi State. The soil samples were subjected to soil analysis prior to and after heavy metal contamination.

2.1 Experimental Design

One-way classification design was employed in the study. Soils were introduced into 24 units of 7 L capacity experimental pots which were segregated into 2 groups (A and B). Group-A

contained heavy metal polluted soils, while Group-B contained the unpolluted soils which served as controls. There were a total of 16 pots in Group-A containing the heavy metal polluted soil, *Zea mays* was cultivated in 8 of the pots while *Sorghum bicolour* was cultivated in the remaining 8 pots, while Group-B served as the control containing a total of 8 pots of unpolluted soil and each of the two plants cultivated in two separate pots. Seedlings of each plant species were transplanted from the nursery bed to the potted media.

2.2 Digestion and Analysis of Soil Samples

Soil samples were digested prior to planting using dry-ash method according to Akio and Johannes [8]. One gram of the respective soil samples was weighed into a porcelain crucible and heated on a heating mantle to volatilize all organic matter. One ml of concentrated nitric acid was added and evaporated to dryness using a heating mantle. The sample was introduced into a muffle furnace and ashed at 450°c for four hours. After ashing, the dish was removed from the muffle furnace and 25 ml of aqueous hydrochloric acid solution (1:1) was used to wash out the sample into a 100 ml beaker. The solution was heated gently for 30 minutes for complete dissolution. It was allowed to cool and filtered into a 100 ml volumetric flask. The digest was made up to the mark using distilled water. The metals in the sample were determined using Atomic Absorption Spectrophotometry (AAS) AA-7000. The soil parameters investigated include; soil pH, cation exchange capacity, organic matter, nitrogen, phosphorous and potassium concentration, and soil texture. The heavy metals investigated were cadmium, chromium, copper, and lead. These parameters were tested in triplicates.

2.3 Growth Data Collection of Plant Samples

The growth and development of the plant were assessed from the observation made on the following parameters; plant heights, number of leaves, stem girth, and leaf area. Height of the plant (cm) was recorded on weekly basis. The first measurement was taken two weeks after germination from all the potted plants representing the treatments, using a ruler. The height was measured from the base of the stem to the tip of the leaf. Number of leaves and flowers were counted on weekly basis. The

counting was done per plant once every week to know the mean number of leaves and flowers that the crop produced.

For the stem girth (cm), the reading was taken using a thread, which was later superimposed on a meter rule. The data were collected from the eight replicates and the mean value was recorded.

The area of the leaf was obtained by multiplying the leaf length by the leaf width.

Leaf area = leaf length × leaf width × 0.75 (correction factor) [9].

2.4 Statistical Analysis

The data obtained from various determinations were subjected to one-way ANOVA, using a computer program SPSS version 19 and the significance was reported at $P < 0.05$ levels. The mean values were separated using Duncan New Multiple Range Test (DNMRT).

3. RESULTS

3.1 Analysis of Experimental Soil Samples

The results for the analysis of the experimental soil samples are shown in (Table-1). The table revealed that most of the measured parameters varied considerably in both soil samples. The pH for the unpolluted soil sample (control) was slightly neutral 7.41 while that of the polluted soil sample was slightly acidic 6.34. The polluted soil sample showed a higher cation exchange capacity of 21.80 meq/100g, which was lesser in the unpolluted soil sample (control sample) 11.20 meq/100g. The unpolluted soil sample showed higher soil organic carbon of 12.12%. The levels of N, P and K were higher in the polluted soil samples (0.05%, 9.10% and 8.8% respectively). The sand, silt, and gravel percentages of the unpolluted soil samples were higher than the percentages observed in the polluted soil samples (63.90%,15.30 and 5.05% respectively).

The heavy metals analyzed (Cd, Cr, Cu and Pb) were far higher in polluted soil sample (Cd 25.18 mg/kg, Cr 10.20 mg/kg, Cu 28.54 mg/kg, Pb 9.92 mg/kg) than in the unpolluted soil.

3.2 Effect of Heavy Metals on Vegetative Growth

The effects of heavy metals on the vegetative growth of *Z. mays* and *S. bicolour* are

summarized in (Table-2) below. The table reveals the effect of heavy metals on plant samples in both the contaminated and uncontaminated soil. The heights of plant samples in the control were far higher than the measurements obtained in the polluted soil. The height of *Z. mays* in both polluted and unpolluted soil samples were higher than the heights measured in *S. bicolour*. Highest height of plant measured was observed in the third week of measurement for both *Z. mays* (145.0±0.48 cm unpolluted sample, 58.0±0.30 cm polluted sample) and *S. bicolour* (113.0±0.33 cm unpolluted sample, 26.0±0.28 cm polluted soil sample).

The number of leaves gradually increased as the period of growth was extended. Higher numbers of leaves were observed in *Z. mays* (12.0±0.10 for unpolluted soil, 10.0±0.03 for Cu polluted) than *S. bicolour* (10.0±0.05 for unpolluted soil, 8.0±0.05 for Cu polluted soil). Generally, higher numbers of leaves were observed in the control sample (unpolluted soil sample) compared to the soil samples treated with heavy metals (Table-2).

The table revealed higher leaf area for *S. bicolour* plant sample (in both polluted and unpolluted soil sample) than for *Z. mays*. The leaf areas measured in the control sample (unpolluted soil) were higher than the leaf areas measured in the polluted soil samples (Table-2). From the table it was observed that the stem girth of *S. bicolour* samples was higher than the stem girth measured in *Z. mays* samples.

Soil samples polluted with heavy metals showed lesser stem girth than unpolluted soil samples.

4. DISCUSSION

The present study investigated the effects of heavy metals (Cd, Cr, Cu and Pb) on the vegetative growth of *Z. mays* and *S. bicolour*. The analysis of soil properties which included soil pH, Cation Exchange Capacity (CEC), soil organic carbon and soil composition were also investigated to observe their role in facilitating the effects of these heavy metals on vegetative growth of cereals. Jung [10] opined that the major factor governing metal availability for plant uptake is the solubility and thermodynamic activity of the uncomplexed metal ion; since a soluble metal ion must exist adjacent to the root membrane in order for root uptake to occur. The solubility of these metal ions is dependent on the soil properties such as soil pH, soil moisture and structure etc.

The Cation exchange capacity (CEC) observed in the polluted soil sample (21.80±0.33 meq/100g) was above the CEC observed in the unpolluted soil sample (11.20±0.10 meq/100g). According to Brady and Well, [11] CEC is one of the ways that solid materials in soil alter the chemistry of the soil. CEC affects many aspects of soil chemistry, as it indicates the capacity of the soil to retain several nutrients in plant-available form. It also indicates the capacity to retain pollutant cations.

Table 1. Characteristics of the experimental soil samples

Parameters	Unpolluted soil	Polluted soil
pH-H$_2$O	7.41±0.15	6.34±0.29
CEC (meq/100g soil)	11.20±0.10	21.80±0.33
Organic carbon (% wt)	12.12±0.21	0.87±0.10
Nitrogen (% wt)	0.02±0.00	0.05±0.00
Phosphorus (% wt)	4.4±0.12	9.10±0.20
Potassium (ppm)	3.2±0.15	8.80±0.42
Sand (% wt)	63.90±0.43	28.90±0.31
Silt (% wt)	15.30±0.22	12.00±0.28
Gravel (% wt)	5.05±0.11	2.12±0.30
Clay (% wt)	19.00±0.47	21.32±0.38
Cadmium (ppm)	1.00±0.00	25.18±0.34
Chromium (ppm)	0.50±0.00	10.20±0.21
Copper (ppm)	2.50±0.02	28.54±0.49
Lead (ppm)	2.85±0.05	9.92±0.36

Results are in mean ± SE. mean value of three replicates

Table 2. Effect of heavy metals on the growth parameters of *Zea mays*

Duration	Plant height (cm)		No of leave		Leaf area (cm^2)		Stem girth (cm)	
	P-soil	UP-soil	P-soil	UP-soil	P-soil	UP-soil	P-soil	UP-soil
Week 1	53.2±0.05[a]	138±0.40[b]	6.0±0.05[b]	8.0±0.05[b]	54.0±0.20[a]	208.0±0.30[b]	8.0±0.05[a]	10.0±0.10[a]
Week 2	56±0.11[a]	140±0.30[b]	8.0±0.15[a]	10.0±0.10[a]	60.2±0.20[a]	216.2±0.30[b]	9.0±0.10[a]	12.0±0.08[b]
Week 3	58.0±0.30[a]	145.0±0.48[b]	10.0±0.03[a]	12.0±0.10[a]	64.0±0.22[a]	220.0±0.48[b]	10.0±0.10[a]	14.0±0.10[b]

P-soil: Polluted soil; UP-soil: Unpolluted soil; Results are in mean ± SE. mean value of eight replicates; Similar alphabets in a row are not significantly different

Table 3. Effect of heavy metals on the growth parameters of *Sorghum bicolor*

Duration	Plant height (cm)		No of leave		Leaf area (cm^2)		Stem girth (cm)	
	P-soil	UP-soil	P-soil	UP-soil	P-soil	UP-soil	P-soil	UP-soil
Week 1	18.2±0.13[a]	108±0.22[b]	4.0±0.02[a]	6.0±0.03[a]	140.0±0.20[a]	447.8±0.33[b]	10.2±0.10[b]	13.8±0.09[a]
Week 2	21.3±0.10[a]	110±0.10[b]	6.0±0.05[a]	8.0±0.10[a]	168.2±0.48[a]	486.4±0.46[b]	11.0±0.08[a]	15.1±0.10[b]
Week 3	26.0±0.28[a]	113.0±0.33[b]	8.0±0.05[b]	10.0±0.05[b]	180.0 ±0.66[a]	520.0±0.48[b]	12.0±0.15[a]	17.0±0.10[b]

P-soil: Polluted soil; UP-soil: Unpolluted soil; Results are in mean ± SE. mean value of eight replicates; Similar alphabets in a row are not significantly different

Maize and Sorghum both had stunted growths in the polluted soil samples against the unpolluted soil, also confirming the study by Ghani [12] who examined the effect of 6 heavy metals (Cd, Cr, Co, Mn, and Pb) on the growth of maize. The result showed that the presence of these metals in soil reduced the growth and protein content of maize. This can be attributed to the antagonistic relationship which exists between heavy metals. Furthermore, the negative influence heavy metals have on the growth and activities of soil microorganisms may also indirectly affect the growth of plants. For instance, a reduction in the number of beneficial soil microorganisms due to high metal concentration may lead to decrease in organic matter decomposition leading to a decline in soil nutrients. Enzyme activities useful for plant metabolism may also be hampered due to heavy metal interference with activities of soil microorganisms. These toxic effects (both direct and indirect) lead to a decline in plant growth which sometimes results in the death of plant [13].

The results from the present study revealed that heavy metals have an adverse effect on the vegetative growth of cereals when measurements from the unpolluted and polluted soil samples were compared. This lends support to Sharma [14] that heavy metal accumulation in plant parts interferes with the biological activities of the plant. Yang et al., [15] opined that plant species accumulates heavy metals in different concentrations, depending on the plant species. The growths observed in unpolluted soil samples (control) were far better than the growth observed in polluted soil samples. From the study it can be seen that the presence of heavy metals in soil reduces the growth rate of cereals. Most of the reduction in growth parameters of plants growing on polluted soils can be attributed to reduced photosynthetic activities, plant mineral nutrition, and reduced activity of some enzymes [16].

5. CONCLUSION

From this study, it is evident that the presence of heavy metals in the soil has an adverse effect on the vegetative growth of *Z. mays* and *S. bicolour*. These metals disrupt the soil properties making the soil inadequate to support proper, healthy growth of the crops. The soil pH, CEC, and organic carbon were affected by the metal contamination. Heavy metal contamination of soil is a great threat to food security and therefore more researches on ways of preventing and remediating metal contamination is recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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