Tolerance of Tithonia diversifolia and Chromolaena odorata in heavy metal simulated-polluted soils and three selected dumpsites

S.A. Ayesa, K.S. Chukwuka, O.O. Odeymeci

Abstract

Soil heavy metals pollution is of global concern in view of their flow through the food chain. The conventional, physical, and chemical approaches to remediate polluted soils are usually expensive and not eco-friendly. Phytoextraction is a promising alternative because of the cost effectiveness and eco-friendliness. Therefore, this study was designed to determine the abilities of Chromolaena odorata (Co) and Tithonia diversifolia (Td) to extract heavy metals from polluted soil.

Soil analysis was done in part per million (ppm) before Td and Co were grown separately on sixty soil samples of 6.5 kg each collected from 3 selected dumpsites (Irese, New Stadium, and a control site (Ijare), Akure in Ondo State. Three replicates of the soil samples collected from Ijare were simulated with 10 g/kg each of cadmium (Cd), zinc (Zn), iron (Fe), copper (Cu) and lead (Pb) and used in assessing the phytoextraction capabilities of Co and Td. Two grams per kilogram of each of the heavy metals were mixed together and used in simulating three soil samples collected from Ijare and phytoextraction capabilities of Co and Td assessed. A control experiment using soil sample from Ijare was also set up in three replicates for Co and Td. Soil analyses were also carried out after the experiment in ppm. Plant biomass was assessed. Heavy metal contents in roots, shoots and soil samples were analyzed after harvest to determine the bioaccumulation (BF). Data obtained were subjected to one way Analysis of Variance at \( \alpha = 0.05 \).

The most contaminated soil sample before and after the experiment was obtained in soil sample (mg/kg) from OD with Cd = 0.08 and 0.071, Zn = 1.92 and 1.85, Fe = 8.44 and 6.94, Cu = 3.04 and 2.54 and Pb = 1.4 and 0.93 respectively. The highest fresh and dry weights (g) for Td and Co shoots and roots were 110.58 and 52.90; and 48.41 and 7.18 respectively. The dry weights (mg) for Td and Co shoots and roots were 20.56 and 4.68; and 16.66 and 0.36 respectively.

Uptake of heavy metals in T. diversifolia and C. odorata tissues (ppm) were Cd (0.43 and 0.06), Zn (6.57 and 3.8), Cu (3.93 and 2.21), Pb (2.37 and 1.94) and Fe (55.15 and 32.82) respectively.

This study showed Tithonia diversifolia and C. odorata were capable of reducing heavy metals in polluted soils. Thus the plants are good candidates for the phytoextraction of heavy metals from polluted soils.

1. Introduction

Heavy metal toxicity is a menace capable of reducing growth and development of plants, and seriously causing injury or hazard to the health of animals and humans [1] through their involvement in the food chain. Heavy metals, unlike organic contaminants, cannot be biodegraded. As a consequence, they accumulate in the environment [2]. In addition, HM from the environment also migrates toward and accumulates in the living organisms by the processes of bioaccumulation and biomagnifications through the trophic levels of the ecosystem [2].

Some Africa countries like Nigeria is rich with coal deposit especially in Enugu State. This coal is also one of the most important pillars of China’s economy [2]. The coal mining activity produces a large amount of coal gangues, from which toxic substances could be released during the destruction of gangue mineral structure under the combined effects of water, microorganisms, vegetation, sunlight radiation and heat [3].

Plant growth and development is the primary source of energy for stability and functionality for plants which is photosynthesis. Therefore,
deviation of plant from normal structure in photosynthesis may result in the reduction of plant growth or biomass [4]. The ions of the heavy metals inhibit multiple metabolic processes in plants which are shown by changes in many chlorophyll a fluorescence parameters [5]. Some metals such as Fe, Pb, Hg, Cu, Cd, Ni or Zn may substitute the central Mg in chlorophyll molecule, consequently lowering PSII quantum efficiency [4]. Therefore, the formation of these chlorophyll-metal ions complexes is leading to a loss in efficiency in conversion of light energy into photochemical reaction [20]. The influence of particular heavy metal ion on the physiological features of plant may be different but in the case of naturally polluted soils, all pollutants act synergistically so detection is only possible on the cumulative effect of their influence. Our experiment was performed using simulated-polluted soil and selected dumpsites from rural and urban region of Ifedere and Akure south respectively. The experiment was undertaken to study the effect of the concentration of soil heavy metals ions on the growth and biomass T. diversifolia and C. odorata. The acquired knowledge is to be used in planning of biomass processing systems and, in parallel, phytoextraction of contaminated soils, using hyperaccumulator plants.

2. Materials and methods

The experiment was carried out in Green House of Bethel College of Education, Ijare, Ondo-State. The College lies between latitude 6°20'N and 7°50'E with mean value temperature of 33.5 °C.

The treatments followed a complete randomized design (CRD) with three replications.

The seeds of T. diversifolia and C. odorata were collected from the wild planted in all the contaminated and simulated soils for the phytoextraction of Cd, Pb, Cu, Fe and Zn.

Sixty (60) soil samples were used for this study. Soil samples were collected from four sites (Irese dumpsite (ID), New Stadium Dumpsite (NSD), Onyarugbulem Dumpsite (OD) and Ijare (control site)). Soil samples collected from each site were further sub-divided to accommodate two plant species (T. diversifolia and C. odorata) used for this study.

Phytoextraction experiments were carried out in polythene bags in Green House. For this purpose, the soil samples were air-dried and sieved through a 2 mm wire net sieve. Tithonia diversifolia and Chromolaena odorata were grown separately on sixty soil samples of 6.5 kg each collected from 3 selected dumpsites; Irese dumpsite (ID), Onyarugbulem Dumpsite (OD) and Ijare (control site). Three replicates from each dumpsite were assessed for phytoextraction using both plant species. Three replicates of the soil samples collected from IJ were simulated with 10 g/kg each of Cd, Pb, Cu, Fe and Zn.

From the above soil analysis before experiment, the heavy metals were heavily present in the simulated soils than in the already polluted soil samples (S2, S3, S4, S5, S6 > S1, S7, S8, S9 and S10). The soil samples had high quantity of Iron (Fe) before simulation except for the dumpsite soil samples (S6, S8 and S9). (Figs. 1 and 2)

Simulated-polluted soils of T. diversifolia and C. odorata had significant reduction in total chlorophyll content. Reduction in chlorophyll concentration in this study could be attributed to the inhibitory effect of accumulated ions.

The germination percentage of a seed may be influenced by the living environment. The present study established the effect of heavy metals on the germination of T. diversifolia and C. odorata as shown in Table 2 and 3 respectively. The results of this study indicated that the control soil treatment for T. diversifolia and C. odorata had the highest germination percentage with 93.33% and 86.67% respectively. This may be due to low concentration of heavy metals and high presence of iron (Fe). Germination was not recorded for soil treatment obtained from Onyarubulem dumpsite (OD) for both T. diversifolia and C. odorata which may be due to the spent engine oil level present in the soil which did not allow the percolation of water into the soil or delayed breaking of seed dormancy. The lowest germination percentage was evaluated in the soil treatment simulated with cadmium (13.33%) for both T. diversifolia and C. odorata. The decrease in germination of T. diversifolia and C. odorata seeds may be related to harmful effect of cadmium on water uptake and water movement [6]. The minimal seed germination may also be as a result of available enzyme inside the seed and acid phosphate that delays seed germination [7] which leads to reduced ATP production. The most toxic metals for seed germination was Cd, followed by Cu, and Pb. Delayed germination was also observed in all cases except in the control soil treatment.

The correlation between the mean relative growth rate (mRGR) and the biomass for Td and Co were very strong. However, Co had a better correlation than Td at shoot (0.97 and 0.85) and root (0.91 and 0.79) level respectively. These showed that the two plants experienced no disturbance despite the heavy metals present which contributed immensely to the product of the plant species.

Claire al et [8] obtained similar results in a study using nickel and other heavy metals on cabbage, lettuce, millet, radish, turnip, and

### Table 1

Soil analysis before experiment (mg/kg).

| Parameters       | Ijare dumpsite | Irese dumpsite | New stadium dumpsite | Onyarubulem dumpsite |
|------------------|----------------|----------------|-----------------------|----------------------|
| pH               | 6.78           | 6.23           | 5.7                   | 5.2                  |
| % O.C            | 0.05           | 5.21           | 0.02                  | 0.016                |
| % T.N            | 0.15           | 7.24           | 0.08                  | 0.06                 |
| g/kg P           | 0.03           | 0.05           | 0.014                 | 0.011                |
| % Sand           | 63.74          | 83.31          | 93.21                 | 96.11                |
| % SiO2           | 13.98          | 1.68           | 2.69                  | 1.89                 |
| % Clay           | 22.28          | 15.04          | 4.04                  | 2.03                 |
| Cmol/Kg Ca       | 2.1            | 0.01           | 0.009                 | 0.007                |
| Cmol/Kg Mg       | 1              | 1.11           | 0.004                 | 0.002                |
| Cmol/Kg K        | 0.38           | 0.25           | 0.001                 | 0.001                |
| Cmol/Kg Na       | 0.21           | 0.56           | 0.001                 | 0.003                |
| PPM Cd           | 0.01           | 0.01           | 0.07                  | 0.08                 |
| PPM Zn           | 0.54           | 0.09           | 0.48                  | 1.92                 |
| PPM Fe           | 354            | 0.99           | 10.06                 | 8.44                 |
| PPM Cu           | 0.1            | 1.11           | 2.42                  | 3.04                 |
| PPM Pb           | 0.44           | 0.2            | 0.4                   | 1.4                  |
wheat. The heavy metals (Cd and Ni) at higher concentration inhibit the seed germination and growth of sunflower plant [9]. The failure of the seeds of *T. diversifolia* and *C. odorata* to germinate at soil treatment got from Onyarubulem dumpsite (OD) may be as a result of retarded water uptake, inhibited cell divisions and enlargements in the embryo and or an overall decrease in metabolic activity relevant to these steps. The blockage of any one of the phases may inhibit the germination process [10]. In this respect, Bazzaz et al. [11] demonstrated that interference with stomata function is a primary mode of action of cadmium and several other heavy metals. (Tables 4 and 5)

The highest value of heavy metals (Cd, Zn, Cu and Fe) in the root and shoot was found in *T. diversifolia* except for Pb that had highest value in *C. odorata*. Concentrations of heavy metals (Cd, Zn, Cu, Pb and Fe) in roots of the studied plants were higher than the concentration in the shoots. Özkan [12] also established this fact.

Metal concentrations in the tissue of the plants varies according to the treatment but not above the threshold limit according to National Standard Environmental Regulatory Agency (NSERA), European Regulatory Standard (ERS), World Health Organization (WHO) etc.

For a plant to be efficient tool in phytoextraction of heavy metals in a polluted soil, the bioaccumulation factor and translocation factor must be higher than one [13,14] which is in agreement with our
findings.

Heavy metals are considered as the most dangerous elemental pollutants and are of particular concern because of their toxicities to human health [15].

This might also contribute to the performance of *T. diversifolia* and *C. odorata* in the phytoextracted soil.

Heavy metals (Fe, Zn, Cu, Cd and Pb) concentrations in plant tissues collected from the polluted soils (Figs. 3 and 4) revealed that the metal contents in the plant tissues differed among species from the heavy metal contaminated soil indicating their different capacities for heavy metal uptake.

The reduction in growth of *T. diversifolia* and *C. odorata* in the simulated-polluted soils could be due to decreased water uptake, toxicity of zinc, cadmium and copper ions as well as reduced photosynthetic rates [16].

Heavy metal accumulation in agricultural soils and water bodies poses a considerable risk to human health by different exposure pathways which could be direct ingestion, dermal absorption, inhalation and food chains [17,18].

Mohammed and Mohammed, [19], reported that the target hazard

### Table 2

Effects of heavy metals concentrations on the biomass of *T. diversifolia*.

| Parameters   | SL (m) | RL (m) | SG (m) | SW (FW) | RW (FW) | SW (DW) | RW (DW) |
|--------------|--------|--------|--------|---------|---------|---------|---------|
| T1           | 1.855f | 0.454f | 0.069f | 110.58g | 48.41g  | 20.56g  | 16.66g  |
| T2           | 0.603f | 0.092a | 0.024a | 19.13c  | 7.03c   | 3.85c   | 1.18c   |
| T3           | 0.330b | 0.185b | 0.017a | 8.82b   | 3.06b   | 1.32b   | 0.59b   |
| T4           | 0.194a | 0.139a | 0.015b | 5.58b   | 1.02b   | 0.92b   | 0.22b   |
| T5           | 0.733c | 0.235c | 0.097b | 36.2c   | 9.12c   | 7.2c    | 1.56c   |
| T6           | 0.663cd| 0.272c | 0.050b | 29.15cd | 6.96c   | 5.24c   | 1.49c   |
| T7           | 0.586e | 0.093a | 0.023a | 18.61c  | 7.21c   | 3.55c   | 0.69c   |
| T8           | 1.160f | 0.152a | 0.050b | 45.83g  | 12.99g  | 10.08g  | 3.04g   |
| T9           | 1.47cd | 0.229c | 0.059b | 52.29g  | 20.64g  | 11.45g  | 3.25g   |
| T10          | –      | –      | –      | –       | –       | –       | –       |

T1 (Control: no simulation), T2 (soil simulated with 2 g each of all heavy metal), T3 (soil simulated with Iron-Fe), T4 (soil simulated with Cadmium-Cd), T5 (soil simulated with Copper-Cu), T6 (soil simulated with Zinc-Zn), and dumpsite soils; T7 (soil collected from Irese dumpsite-ID), T8 (soil collected from New stadium dumpsite-NSD), T9 (soil collected from Onyarubulem dumpsite-OD). SL = shoot length, RL = root length, SG = stem girth, SW = shoot weight, and RW = root weight. Means followed with the same letters down the columns are not significantly different at P = 0.05 according to Duncan’s multiple range test.

### Table 3

Effects of heavy metals concentrations on biomass of *C. odorata*.

| Parameters   | SL (m) | RL (m) | SG (m) | SW (FW) | RW (FW) | SW (DW) | RW (DW) |
|--------------|--------|--------|--------|---------|---------|---------|---------|
| C1           | 0.900g | 0.261e | 0.023d | 52.9f   | 7.18f   | 4.68f   | 3.63f   |
| C2           | 1.842f | 0.233d | 0.026d | 45.63g  | 5.98g   | 0.93g   | 0.28g   |
| C3           | 0.821f | 0.146d | 0.021d | 43.21g  | 3.52g   | 0.85g   | 0.26g   |
| C4           | 0.146b | 0.055b | 0.009a | 2.41b   | 0.39b   | 0.10a   | 0.05a   |
| C5           | 0.459d | 0.102b | 0.018bc | 20.43d | 2.51c   | 0.59b   | 0.23b   |
| C6           | 0.306b | 0.145c | 0.011c | 9.36c   | 2.63c   | 0.17c   | 0.08c   |
| C7           | 0.379b | 0.160a | 0.015b | 11.30b  | 2.40b   | 0.38b   | 0.09b   |
| C8           | 0.436c | 0.120b | 0.015b | 18.10c  | 2.60b   | 0.45b   | 0.12b   |
| C9           | 0.519f | 0.071b | 0.015d | 25.63f  | 3.94f   | 0.62f   | 0.22f   |
| C10          | –      | –      | –      | –       | –       | –       | –       |

C1 (Control: no simulation), C2 (soil simulated with 2 g each of all heavy metal), C3 (soil simulated with Iron-Fe), C4 (soil simulated with Cadmium-Cd), C5 (soil simulated with Copper-Cu), C6 (soil simulated with Zinc-Zn), and dumpsite soils; C7 (soil collected from Irese dumpsite-ID), C8 (soil collected from New stadium dumpsite-NSD), C9 (soil collected from Onyarubulem dumpsite-OD). SL = shoot length, RL = root length, SG = stem girth, SW = shoot weight, and RW = root weight. Means followed with the same letters down the columns are not significantly different at P = 0.05 according to Duncan’s multiple range tests.

### Table 4

Concentration of heavy metals in the shoot of *T. diversifolia* and *Chromolaena odorata* (mg/kg).

| PARAMETERS | T.Cd | C.Cd | T.Zn | C.Zn | T.Fe | C.Fe | T.Cu | C.Cu | T.Pb | C.Pb |
|------------|------|------|------|------|------|------|------|------|------|------|
| S1         | 0.05b| ND   | 0.84g| 0.81f| 3.98g| 0.99d| 0.53f| 0.08bc| 0.50c| 0.07 cd|
| S2         | 0.1a | ND   | 0.31d| 0.03a| 1.44c| 0.91c| 0.11c| 0.09cd| 0.05ab| 0.03ab|
| S3         | 0.01a| ND   | 0.11b| 0.08b| 3.42f| 0.52a| 0.18d| 0.03a| 0.10b| 0.03ab|
| S4         | ND   | ND   | 0.05a| 0.07b| 0.98a| 0.98d| 0.02a| 0.11d| 0.08ab| 0.07c |
| S5         | ND   | 0.01| 0.14b| 0.09bc| 1.49c| 2.13e| 0.07b| 0.16e| 0.02a| 0.10d |
| S6         | 0.01a| ND   | 0.24c| 0.34e| 1.25b| 1.05d| 0.06b| 0.16e| 0.02a| 0.10d |
| S7         | ND   | ND   | 0.22c| 0.11c| 1.80d| 1.02d| 0.06b| 0.16e| 0.02a| 0.10d |
| S8         | 0.01a| ND   | 0.58f| 0.15d| 2.19e| 0.96d| 0.32e| 0.18f| 0.01a| 0.03ab|
| S9         | ND   | ND   | 0.39e| 0.08b| 1.01a| 0.77b| 0.16d| 0.01a| 0.03ab| 0.01a |
| S10        | –    | –    | –    | –    | –    | –    | –    | –    | –    | –    |

T = *T. diversifolia*; C = *C. odorata*; Cd = Cadmium; Zn = Zinc; Fe = Iron; Cu = Copper; Pb = Lead. ND = Not detected. S1 (Control: no simulation), S2 (soil simulated with all heavy metal with 2 mg each), S3 (soil simulated with Iron-Fe), S4 (soil simulated with Cadmium-Cd), S5 (soil simulated with Copper-Cu), S6 (soil simulated with Zinc-Zn), and dumpsite soils; S7 (Irse dumpsite-ID), S8 (New stadium dumpsite-NSD), S9 (Onyarubulem dumpsite-OD).
T. diversifolia

| PARAMETERS | T.Cd | C.Cd | T.Zn | C.Zn | T.Fe | C.Fe | T.Cu | C.Cu | T.Pb | C.Pb |
|------------|------|------|------|------|------|------|------|------|------|------|
| S1         | 0.11 | ND   | 0.91 | 0.26 | 6.31 | 2.4  | 0.66 | 0.1  | 0.2  | 0.1  |
| S2         | 0.03 | ND   | 0.48 | 0.09 | 3.69 | 2.87 | 0.27 | 0.11 | 0.1  | 0.1  |
| S3         | 0.03 | ND   | 0.19 | 0.31 | 5.91 | 1.87 | 0.25 | 0.07 | 0.2  | 0.1  |
| S4         | 0.01 | 0.01 | 0.12 | 0.11 | 7.84 | 1.42 | 0.12 | 0.15 | 0.2  | 0.2  |
| S5         | ND   | 0.02 | 0.22 | 0.26 | 2.92 | 3.66 | 0.09 | 0.21 | 0.05 | 0.21 |
| S6         | 0.01 | ND   | 0.37 | 0.52 | 2.7  | 3.2  | 0.17 | 0.28 | 0.1  | 0.3  |
| S7         | 0.01 | 0.01 | 0.36 | 0.17 | 2.77 | 2.77 | 0.12 | 0.09 | 0.1  | 0.09 |
| S8         | 0.04 | 0.01 | 0.61 | 0.18 | 3.57 | 3.72 | 0.49 | 0.27 | 0.1  | 0.2  |
| S9         | 0.01 | ND   | 0.43 | 0.14 | 1.88 | 1.56 | 0.25 | 0.03 | 0.1  | 0.01 |
| S10        | –    | –    | –    | –    | –    | –    | –    | –    | –    | –    |

T = T. diversifolia; C = C. odorata; Cd = Cadmium; Zn = Zinc; Fe = Iron; Cu = Copper; Pb = Lead.
ND = Not detected.

S1 (Control: no simulation), S2 (soil simulated with all heavy metal with 2 mg each), S3 (soil simulated with Iron-Fe), S4 (soil simulated with Cadmium-Cd), S5 (soil simulated with Copper-Cu), S6 (soil simulated with Zinc-Zn), and dumpsites; S7 (Irese dumpsite-OD), S8 (New stadium dumpsite-NSD), S9 (Onyarubulem dumpsite-OD).

4. Conclusion and recommendation

This study was conducted to screen plants growing on a contaminated site to determine their potential for metal accumulation. The plant species examined in this study grew very well and propagated quickly in substrata with Fe-contaminated, Pb-contaminated, Cu-contaminated soil conditions which would be an advantage in the re-vegetation of polluted soil as cost would be reduced without fertilizer.

The plant species can colonize heavy metal-contaminated sites, because they were able to absorb a wide range of soil heavy metals (Fe, Zn, Cu, Cd and Pb), and were not affected by high concentration of heavy metal contents which implies they have higher tolerance than more sensitive species.

This study showed Tithonia diversifolia and Chromolaena odorata reduced heavy metals in polluted soils. Thus the plants are good candidates for the phytoextraction of heavy metals from polluted soils. However, Tithonia diversifolia was considered as a promising species for phytoextraction of heavy metal-contaminated sites because of its performance.

The phytoremediation of T. diversifolia, especially for Irese dumpsite, needed to be investigated.

References

[1] G. Kvesitadze, G. Khatisashvili, T. Sadunishvili, J.J. Ramsden, Biochemical Mechanisms of Detoxification in Higher Plants 3 Springer Verlag, Berlin Heidelberg, 2006, pp. 67–74.
[2] K. Li, Z. Lun, L. Zhao, Q. Zhu, Li M. Gu, Screening for autochthonous phytoreactors in a heavy metal contaminated coal mining area, Int. J. Environ. Res. Public Health 14 (9) (2017) 1068.
[3] A.C. Larouque, P.E. Rasmussen, An overview of trace metals in the environment, from mobilization to remediation, Environ. Geol. 33 (1998) 85–91.
[4] G. Zurek, M. Pogrzeba, k. Ryba, J. Krzyzak, K. Prokopick, The Effect of Heavy Metal Contaminated Soil on Growth and Development of Perennial Grasses E3SWeb of Conferences :Published byEDPSciences, (2013) 201 / 301130 / 1 conf e3s 06 13006.
[5] M.K. Joshi, P. Mohanty, Chlorophyll a fluorescence as a probe of heavy metal ion toxicity in plants, in: G.C. Papageorgiou, Govindjee (Eds.), Chlorophyll a Fluorescence: A Signature of Photosynthesis, Springer Science + Business Media B.V., 2010, pp. 637–661.
[6] J. Barcelo, C. Poschenrieder, Plant water relations as a growth criteria as a tool for testing heavy metal contaminated sites, Environ. Geol. 33 (1998) 85–91.
[7] J. Barcelo, C. Poschenrieder, Plant water relations as a tool for testing heavy metal contaminated sites, Environ. Geol. 33 (1998) 85–91.
[8] J.C. Claire, D.C. Adrian, K.S. Sajwan, S.L. Abel, D.P. Thoma, J.T. Driver, Effects of selected trace metals on germinating seeds of six plant species, Water Air Soil Pollut. 59 (1991) 231–240.
[9] S.U. Khan, A. Moheman, Effect of heavy metals (Cadmium and Nickel) on the seed germination, growth and metals uptake by chilli (Capsicum frutescens) and sunflower plants (Helianthus annuus), Poll. Res. 25 (2006) 99–104.
[10] M.A. Shaddad, A.F. Radi, A.E. El-Enany, Seed germination transpiration rate and growth criteria as affected by various concentrations of CdCl2, NaF and 2, 4-NP, J.
[11] F.A. Bazzaz, R.W. Carlson, G.L. Rolfe, The effect of heavy metals on plants: Part I. Inhibition of gas exchange in sunflower by Pb, Cd, Ni and Ti, Environ. Pollut. 7 (1974) 241–246.

[12] E.Y. Orkan, A New Assessment of Heavy Metal Contaminations in an Eutrophicated Bay (Inner Izmir Bay, Turkey), Turk. J. Fish. Aquat. Sci. 12 (2012) 135–147.

[13] A.H. Mohabbi, S.S. Harutyunyan, M. Chorom, Phytoremediation potential of three plant grown in monoculture and intercropping with date palm in contaminated soil, Int. J. Agric. Crop Sci. (2012) Available online at www.ijacs.com/IJACS/2012/4-20/1523-1530 ISSN 2227-670X, IJACS Journal.

[14] P. Zhuang, Q.W. Yang, H.B. Wang, W.S. Shu, Phytoextraction of heavy metals by eight plant species in the field, Water Air Soil Pollut. 184 (2007) 235–242.

[15] M. Boran, I. Altunok, A Review of Heavy Metals in Water, Sediment and Living Organisms in the Black Sea, Turk. J. Fish. Aquat. Sci. 10 (2010) 565–572.

[16] V. Atlassipak, M. Nabipour, M. Meskarbashee, Effect of salt stress on chlorophyll content, fluorescence, Na+ and K+ ions content in rape plants (Brassica napus L.), Asian J. Agric. Res. 3 (2009) 28–37.

[17] N. Sarwar, M. Imran, M.R. Shaeen, W. Ishaq, A. Kamran, A. Matloob, A. Rehim, S. Hussain, Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives, Chemosphere 171 (2017) 719–721.

[18] C. Sun, J. Liu, Y. Wang, L. Sun, H. Yu, Multivariate and geostatistical analyses of the spatial distribution and sources of heavy metals in agricultural soil in dehui, northeast China, Chemosphere 92 (2013) 517–523.

[19] A. Mohammed, T. Mohammed, Mercury, arsenic, cadmium and lead in two commercial shark species (Sphyrna lewini and Caraharinus porosus) in Trinidad and Tobago. Mar. Pollut. Bull. 119 (2017) 214–218, https://doi.org/10.1016/j.marpolbul.2017.04.025.

[20] R. Popovic, D. Dewez, P. Juneau, Applications of chlorophyll fluorescence in ecotoxicology: heavy metals, herbicides, and air pollutants, in: J.R. DeEll, P.M.A. Toivonen (Eds.), Practical Application of Chlorophyll Fluorescence in Plant Biology, Kluwer Academic Publishers, Norwell, MS, USA, 2003, pp. 151–184 Ralph PJ, Burchett MD.