# EFFECTS OF CHROMIUM UPTAKE ON THE GROWTH CHARACTERISTICS OF *EICHHORNIA CRASSIPES* (MART.) SOLMS

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## ABSTRACT

*The uptake of chromium from fresh water by* Eichhornia crassipes *was studied under greenhouse conditions where the species was raised in culture solutions containing varying concentrations of chromium (VI) ions. There were positive correlations between the concentration of chromium in the culture media and the amounts of the metal accumulated in the tissues of* E. crassipes *at any given time. Furthermore, the total accumulated chromium in the tissues of E crassipes increased with increase in the duration for which the plant was exposed to the nutrient solutions containing chromium ions. Most of the absorbed chromium was accumulated in the roots of the treated plants and only a small fraction (1.71 – 4.37%) was translocated to the shoot system. The highest concentration factors of chromium in E. crassipes shoots and roots were 12.2 and 466.1 respectively. Plant growth analysis techniques were applied to assess the effects of chromium on the growth characteristics of the treated* E. crassipes *plants. It was observed that the accumulation of chromium did not result in significant differences ($p>0.01$) in the relative growth rates and net assimilation rates of* E. crassipes *between the various treatments at each harvest. On the other hand, the accumulation of chromium was positively correlated ($r = 0.8112$) with increases in the leaf are ratio and negatively correlated ($r = -0.6605$) with biomass increments of* E. crassipes *plants. The differences in leaf area ratio and biomass increments among the treatments were significant ($p<0.01$) from the third week of the experiment onwards for the plants exposed to culture media with chromium concentrations of 3.00 µg/ml. and above. The implications of these results in terms of the control of chromium pollution in fresh water lakes and rivers are discussed.*

## INTRODUCTION

The water hyacinth, *Eichhrnia crassipes* (Mart.) Solms, is a fresh water plant belonging to the family Pontederiaceae (Arber 1963, Cook *et al.* 1974). The mature water hyacinth plant consists of roots, a rhizomatous stem, stolons, a rosette of leaves, inflorescence and fruit clusters. It is free floating in fresh waters; and it is particularly abundant in those waters which are nutrient rich. Where the fresh waters are heavily polluted with such nutrients as $PO_4$ -P, $NO_3$-N and $NH4_4$-N the water hyacinth grows excessively and causes severe environmental problems which include

clogging of drainage ditches, irrigation canals, and run-off streams hence promoting backwater and flood conditions, hindrance to navigation, decrease of potential fishing areas as well as the blocking of rivers and anchorage sites for boats/steamers (Anon 1976, Anon 1978). Other problems associated with the excessive growth of *E. crassipes* are provision of sites for incubation of disease vectors such as mosquitoes, increased loss of water through the transpiration of the plant, restriction of the growth of desirable aquatic plants, loss of fish breeding sites and diminution of the recreational value of inland waters (Mitchell 1974, Anon 1978). It has been argued that by its prolific growth *E. crassipes* completes successfully with other aquatic plants and brings about destruction of the aquatic ecosystem (Odum 1971, McNaughton & Wolf 1973, Mugasha 1995).

However, inspite of the above-mentioned problems associated with the prolific growth of the water hyacinth, the species does have potential benefits to mankind and the environment, particularly in the secondary and tertiary treatment of sewage and industrial effluents (Tripath & Sureth 1991). *E. crassipes* helps in water purification for example by reducing biological oxygen demand (BOD), suspended solids, total alkalinity, $PO_4$-P, $NO_3$-N and $NH4_4$-N, acidity, water hardness and chemical oxygen demand (COD) (Tripath & Sureth 1991) and absorbing some heavy metals such as cadmium, iron, copper, nickel and zinc (Ajamal & Khan 1989). An increase in the concentration of dissolved oxygen in water inhabited by *E. crassipes* was observed by Tripath and Sureth (1991).

In a recent study (Mugasha 1995), it was revealed that chromium was among the heavy metals detected in the waters of Lake Victoria. Since previous studies have shown that *E. crassipes* has the ability to absorb some heavy metals, including those which are dangerous pollutants, it was therefore decided to investigate the efficacy of this plant at absorbing chromium from fresh waters so as to determine whether it would help to solve the problem of chromium pollution in Lake Victoria and other fresh water bodies. As a means of assessing the effectiveness of *E. crassipes* at removing chromium from fresh waters without impairment in its health, it was considered important to study the response of the plant's growth characteristics, i.e. its relative growth rate (RGR), net assimilation rate (NAR) and leaf area ratio (LAR), to treatment with chromium containing media.

## MATERIALS AND METHODS

The plants of *E.crassipes* used in the present study were raised in the greenhouse in static nutrient media contained in wooden culture tanks each with the following dimensions:

200cm (length) x 90cm (width) x 30cm. (depth).

Each culture tank was lined with plastic sheeting to prevent leakage of the nutrient media. The nutrient solution used in raising *E. crassipes* was similar to that developed by Gauch (1973), which is a slight modification of the nutrient solution formulated by Hoagland and Arnon (1950). The pH of the nutrient solution was adjusted to between 5.5 and 6.5 and maintained at that range by addition of a few drops of concentrated nitric acid whenever that became necessary (Eaton 1941). Addition of nitric acid served two purposes; first it helped to maintain the original level of the nitrate ions in the culture solution and hence hinder the release of hydroxyl and bicarbonate ions as well as associated bases from the roots of *E. crassipes* into the nutrient solution which would result from the rapid absorption of nitrate ions; and secondly it facilitated the solubilization of cations such as $Cu^{2+}$, $Zn^{2+}$ and $Mn^{2+}$ which tend to precipitate when the medium pH is 7.0 or above. The volume of the nutrient solution in

each culture tank was 3000 ml. and was monitored daily and maintained by adding distilled water whenever this became necessary.

The source of chromium used in this study was a solution of potassium dichromate ($K_2 Cr_2 O_7$) of analar quality. A stock solution of potassium dichromate was prepared by dissolving 2.828g. of potassium dichromate crystals in one liter of distilled water (Allen 1974) so as to make a concentration of 1000 µgCr./ml. Aliquots of this stock solution were added to the nutrient media in the culture tanks in varying amounts to attain varying concentrations of chromium in the five treatments indicated in Table 1. The concentration of chromium ions in treatments $T_2$ $T_3$, $T_4$, and $T_5$ (Table 1) were respectively 3, 6, 9 and 12 times the normal background concentration of the metal found in fresh water bodies (see, for example, Allen 1974). Each treatment was replicated 20 times. The replicates were laid out on benches in the greenhouse in a randomized complete block design (Gomez & Gomez 1984).

In order to determine the levels of absorption and translocation of chromium in the treated water hyacinth plants, the plants were harvested at intervals of seven days. At the first harvest the outlines of the leaves of each plant were traced on graph paper to determine their surface areas and then the length (L) and breadth (B) at ýL of each leaf were measured so as to calculate the coefficient, *b*, that would be used to calculate the leaf area, A, from measurements of L and B at subsequent harvests in accordance with the formula (Chattarjee & Dutta 1961, Stickler *et al.* 1961, Carleton & Foote 1965, Jain & Misra 1966, Rulangaranga 1980):

$$A = b.\ LB$$

Where *b* is the coefficient which depends on leaf shape.

Assessment of the assimilatory surface area was necessary for purposes of growth analysis (see below). Immediately after assessing the assimilatory surface area, the root system of each plant was washed in distilled water to remove any chromium ions adhering on the surfaces of the roots, and each plant was then separated into the root system and shoot system which were wrapped in old newspapers, labeled and subsequently separately oven-dried to constant weight at a temperature of 60°C. The dried specimens were each separately finely ground using an analytical blender (Model type A10, Janke & Kunkel GMBH & CO. KG). One gramme of each ground specimen was digested using the wet digestion method (Allen 1974) and the resulting extracts were analysed by atomic absorption spectrometry (AAS) to determine the concentration of chromium in the different organs of the treated *E. crassipes* plants. Blank digestions were also carried out.

**Table 1. The concentrations of chromium ions in the various nutrient solutions used to treat *Eichhornia crassipes* plants**

| Treatment | Volume of the stock solution of $K_2 Cr_2 O_7$ (mls.) added to 3000ml. of nutrient solution | Resultant concentration of chromium ions in the nutrient solution (µgCr.ml$^{-1}$) |
|---|---|---|
| $T_1$ | 0.00 | 0.00 |
| $T_2$ | 3.00 | 1.50 |
| $T_3$ | 6.00 | 3.00 |
| $T_4$ | 9.00 | 4.50 |
| $T_5$ | 12.00 | 6.00 |

Growth analysis techniques (Briggs, Kidd & West 1920, Williams 1946, Jarvis *et al.* 1971, Rulangaranga 1980) were used to assess the effects of chromium on the growth of the treated *E. crassipes* plants. The RGR, NAR and LAR of individual *E. crassipes* plants treated with varying chromium concentrations, as shown in Table 1, were determined. In the determination of these parameters use was made of the data on the assimilatory surface area and the total dry weight of each of the variously treated *E. crassipes* plants. For the determination of RGR the following formula was used:

$$RGR = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{1}{W} \cdot \frac{\delta W}{\delta t} \delta t$$

$$= \frac{1}{t_2 - t_1} \int_{W_1}^{W_2} \frac{\delta W}{W}$$

$$= \frac{l_n W_2 - L_n W_1}{t_2 - t_1} \; g.g^{-1}. \; day^{-1}$$

Where $W_1$ and $W_2$ were the mean dry weights of *E. crassipes* plants and $t_1$ and $t_2$ were the times (in days) at consecutive harvests.

The relationship between the assimilatory surface area and the biomass of *E.crassipes* plants was examined and found to be linear in all treatments. Therefore in the calculation of the mean net assimilation rate (NAR) the formula advanced by Williams (1946) was used, i.e.

$$NAR = \frac{W_2 - W_1}{A_2 - A_1} \cdot \frac{l_n A_2 - l_n A_1}{t_2 - t_1} \; g.cm^{-2}.Day^{-1}$$

Where $A_1$ and $A_2$ were the mean assimilatory surface areas and $W_1$ and $W_2$ were the mean dry weights of *E. crassipes* at times $t_1$ and $t_2$ (in days).

The mean leaf area ratio (LAR) was calculated using the formula given by Radford (1967):

$$LAR = \frac{A_2 - A_1}{W_2 - W_1} \cdot \frac{l_n W_2 - l_n W_1}{l_n A_2 - l_n A_1} \; g. \; cm^{-2}.$$

Where $A_1$ and $A_2$ were assimilatory surface areas and $W_1$ and $W_2$ were dry weights of *E. crassipes* plants at consecutive harvests.

In addition to the calculation of the RGR, NAR and LAR, also the concentration factors of chromium in the shoots, roots and the whole plant were calculated using the formula:

$$\left( \frac{\text{Total Cr Accumulation in the plant or organ}}{\text{Oven dry wt. of the plant or organ}} \right) \Big/ \text{Conc of Cr. in the culture medium used to raise the plant}$$

The relationship between the concentrations of chromium in the culture media and the amounts of the metal accumulated in the tissues of *E.crassipes* plants under the various treatments was determined using regression analysis (Clarke 1994). The same statistical technique was used to determine the relationship between the amounts of chromium accumulated by *E. crassipes* under the various treatments and the various growth characteristics (i.e. RGR, NAR and LAR) as well as the plant's biomass increments.

The differences in the mean amounts of chromium taken up by *E. crassipes* plants at each harvest under the various treatments were compared using analysis of variance (Gomez & Gomez 1984). The same statistical method was used to compare the mean results of RGR, NAR and LAR of *E. crassipes* plants obtained at each harvest under the different treatments.

**RESULTS**

With the exception of the control treatment, the results show that the water hyacinth plants treated with chromium kept on absorbing chromium throughout the duration of the study as evidence by the increasing amounts of chromium accumulated by the plants that had been exposed to the metal for longer periods (Table 2). Regression analyses showed that there were significant positive correlations (Figure 1) between the amounts of chromium absorbed by *E. crassipes* from the culture media and the increases in both the concentration of chromium in the culture media as well as the time for which the plants were exposed to the chromium containing culture media. Analysis of the rates of chromium absorption show that there were increases in the rates of absorption of the metal during the first two weeks of the experiment in all treated plants (Figure 2). The rates of absorption were also higher with higher concentrations of the metal in the culture media. But during the period subsequent to the second week of the experiment the absorption rates generally showed a progressive decline. Some of the absorbed chromium was translocated from the roots to the shoots during the first week of the experiment at rates which increased with increases in the concentrations of chromium ions in the culture media (Figure 3). However during the period between the first and fifth weeks the translocation rates showed a progressive decline in all but treatments $T_2$ and $T_3$ where the plants had been treated with culture media containing chromium concentrations of 1.50μg.ml$^{-1}$ and 3.00μg.ml$^{-1}$ respectively. In the case of these latter treatments, the translocation rates started off at comparatively low levels at the first harvest and then increased during the period between the first and second weeks of growth before showing a progressive decline during the period subsequent to the second week of growth. In the final analysis, however, the total amounts of chromium translocated to the shoots were very low (Table 2). Of the total chromium absorbed by *E. crassipes* under the various treatments, only between 1.71 and 4.37% was actually translocated to the shoots. Thus the bulk of the absorbed metal (95.63 - 98.83%) was confined to the root system.

The accumulation of chromium by *E. crassipes* was further demonstrated by the results on the concentration factors of the metal in the shoots, roots and the whole plant (Table 3) which, generally, increased with increases in both the concentration of the metal in the culture media and the duration for which the experimental plants were exposed to the culture media. The highest concentration factors in the organs of *E. crassipes* were 14.1 in the shoots of the plants subjected to culture media with a chromium concentration of 1.50 μg.ml$^{-1}$ harvested at the end of the 5$^{th}$ week of the experiment; and 466.1 in the roots of the plants subjected to culture media with a chromium concentration of 6.00 μg.ml$^{-1}$ again harvested at the end of the fifth week of the experiment. In the case of the whole plant, the highest concentration factor was 241.9. This was observed in the plants subjected to culture media with a chromium concentration of 6.00μg.ml$^{-1}$ harvested at the end of the fifth week of the experiment (Table 3).

**Table 2: Average levels of chromium accumulated in the roots and shoots of E. crassipes raised in culture media with varying concentrations of chromium.**

| Period of Growth (weeks) | Concentration of Cr in culture media ($\mu g.ml^{-1}$) | Mean total amount of Cr absorbed (μg.) | Amount of Cr retained in the roots (μg) | Amount of Cr translocated to the shoots system (μg) | %-age of Cr translocated to the shoot |
|---|---|---|---|---|---|
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.50 | 272.72± 19.21 | 266.52±12.42 | 6.20±0.05 | 2.27 |
| 1 | 3.00 | 526.23±37.06 | 510.99±21.01 | 15.24±1.00 | 2.89 |
| | 4.50 | 942.38±62.6 | 907.02±51.28 | 35.36±2.88 | 3.75 |
| | 6.00 | 1474.26±82.07 | 1431.32±88.47 | 42.94±3.74 | 2.91 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.50 | 768.04±43.16 | 736.04±47.11 | 32.00±2.77 | 4.17 |
| 2 | 3.00 | 1587.70±117.50 | 1540.10±97.48 | 47.60±3.44 | 3.00 |
| | 4.50 | 2423.10±142.24 | 2361.42±178.52 | 61.68±5.65 | 2.55 |
| | 6.00 | 3610.36±251.27 | 3533.46±198.57 | 76.90±4.48 | 2.13 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.50 | 1157.90±82.28 | 1112.04±66.72 | 45.86±3.21 | 3.96 |
| 3 | 3.00 | 2470.80±191.18 | 2405.72±81.93 | 65.08±4.33 | 2.63 |
| | 4.50 | 3593.09±220.81 | 3498.57±77.46 | 94.52±4.87 | 2.63 |
| | 6.00 | 4865.99±306.23 | 4782.87±119.57 | 83.12±6.22 | 1.71 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.50 | 1546.62±131.67 | 1479.02±58.27 | 67.60±5.23 | 4.37 |
| 4 | 3.00 | 3486.07±240.84 | 3415.17±70.12 | 70.90±4.62 | 2.03 |
| | 4.50 | 4744.17±312.60 | 4646.17±110.36 | 98.00±7.41 | 2.07 |
| | 6.00 | 6220.22±432.66 | 6074.76±121.84 | 145.46±9.55 | 2.34 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.50 | 2003.65±131.50 | 1933.09±91.47 | 70.56±4.17 | 3.52 |
| 5 | 3.00 | 4143.17±380.01 | 4056.37±107.61 | 86.80±5.77 | 2.10 |
| | 4.50 | 5475.22±378.69 | 5347.18±132.18 | 128.04±9.25 | 2.34 |
| | 6.00 | 7141.14±525.44 | 6963.14±435.41 | 178.00±11.37 | 2.50 |

**Table 3: Concentration Factors of Chromium in the roots and shoots of *E. crassipes* with respect to the corresponding concentrations of the metal in the culture media used to raise the plant**

| Period of Growth (Weeks) | Cr conc. in culture media (ppm) | Mean shoot dry wt (g) | Mean total amount of Cr accumulted in the shoot system (µg) | Mean conc. of Cr per unit shoot dry wt (ppm) | Mean root dry wt (g) | Mean Total amount of Cr retained in the roots (µg.) | Mean conc Cr per unit root dry wt (ppm) | Cr conc. factor in the shoot | Cr conc. factor in the root | Cr. conc in the whole plant |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0.00 | 1.65±0.24 | 0.00 | 0.00 | 1.75±0.31 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| | 1.5 | 1.60±0.36 | 6.20±0.05 | 3.88±0.37 | 1,74±0,30 | 266.52± 12.41 | 153.17± 9.75 | 2.6 | 102.1 | 4.4 |
| | 3.00 | 1.81±0.42 | 15.24±1.00 | 8.44±0.62 | 1.41±0.21 | 510.99±21.01 | 362.40±18.62 | 2.8 | 120.8 | 54.5 |
| 1 | 4.5 | 1.61±0.32 | 35.36±2.88 | 21.94±1.82 | 1.71±0.14 | 907.02±51.28 | 530.42±23.84 | 4.9 | 117.9 | 63.1 |
| | 6.00 | 1.75±0.10 | 42.94±3.74 | 24.54±3.35 | 1.53±0.18 | 1431.32±88.47 | 935.50±37.57 | 4.1 | 155.9 | 74.9 |
| | 0.00 | 2.32±0.24 | 0.00 | 0.00 | 2.05±0.17 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| | 1.50 | 2.04±0.39 | 32.00±2.77 | 15.69±1.24 | 2.37±0.42 | 736.04±47.11 | 310.57±17.31 | 10.5 | 207.0 | 116.1 |
| 2 | 3.00 | 2.38±0.51 | 47.60±3.44 | 20.00±1.31 | 1.96±0.31 | 1540.10±97.48 | 785.77±25.62 | 6.7 | 261.9 | 121.9 |
| | 4.50 | 1.93±0.33 | 61.68±5.65 | 31.96±3.70 | 2.09±0.33 | 2361.42±178.52 | 1129.87±43.21 | 7.1 | 251.1 | 133.9 |
| | 6.00 | 1.89±0.25 | 76.90±4.48 | 40.69±5.43 | 2.07±0.36 | 3533.46±198.57 | 1706.99±87.63 | 6.8 | 284.5 | 152.0 |
| | 0.00 | 2.57±0.46 | 0.00 | 0.00 | 2.67±0.40 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| | 1.50 | 2.51±0.25 | 45.86±3.41 | 18.27±1.66 | 2.84±0.19 | 1112.04±66.72 | 391.56±43.24 | 12.2 | 261.0 | 144.3 |
| 3 | 3.00 | 2.57±0.53 | 65.08±4.33 | 25.32±2.47 | 2.29±0.43 | 2405.72±81.63 | 1050.53±88.15 | 8.4 | 350.2 | 169.5 |
| | 4.50 | 2.53±0.32 | 94.52±4.87 | 37.36±4.37 | 1.92±0.28 | 3498.57±77.46 | 1822.17±126.38 | 8.3 | 404.9 | 269.9 |
| | 6.00 | 1.97±0.14 | 83.12±6.22 | 42.19±3.53 | 1.67±0.21 | 4782.87±119.57 | 2863.99±143.17 | 7.0 | 477.3 | 222.8 |
| | 0.00 | 2.98±0.20 | 0.00 | 0.00 | 3.18±0.29 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| | 1.50 | 3.44±0.61 | 67.60±5.23 | 19.65±2.14 | 2.57±0.32 | 1479.02±58.27 | 575.49±29.84 | 13.1 | 383.7 | 171.6 |
| 4 | 3.00 | 2.60±0.38 | 70.90±4.62 | 27.27±2.72 | 2.82±0.34 | 34515.17±70.12 | 1211.05±81.80 | 9.1 | 403.7 | 214.4 |
| | 4.50 | 2.45±0.27 | 98.00±7.41 | 40.00±2.11 | 2.34±0.38 | 4646.17±110.36 | 1985.54±116.65 | 8.9 | 441.2 | 220.1 |
| | 6.00 | 2.51±3.48 | 145.46±9.55 | 57.95±4.32 | 1.96±0.32 | 6074.76±121.84 | 3099.37±178.37 | 9.7 | 516.6 | 231.9 |
| | 0.00 | 3.63±0.57 | 0.00 | 0.00 | 3.68±0.42 | 0.00 | 0.00 | 0.0 | 0.0 | 0.0 |
| | 1.50 | 3.33±0.41 | 70.56±4.17 | 21.19±1.78 | 3.09±0,24 | 1933.09±91.47 | 625.60±36.36 | 14.1 | 417.1 | 208.1 |
| 5 | 3.00 | 2.88±0.36 | 85.80±5.77 | 30.14±2.58 | 3.05±0.31 | 4056.37±107.61 | 1329.96±102.21 | 10.0 | 443.3 | 232.9 |
| | 4.50 | 2.76±0.47 | 128.04±9.25 | 46.39±3.88 | 2.62±0.51 | 5347.18±132.18 | 2040.91±125.32 | 10.3 | 453.5 | 226.6 |
| | 6.00 | 2.43±0.51 | 178.00±11.37 | 73.25±6.21 | 2.49±0.47 | 6963.14±435.41 | 2796.44±202.13 | 12.2 | 466.1 | 241.9 |

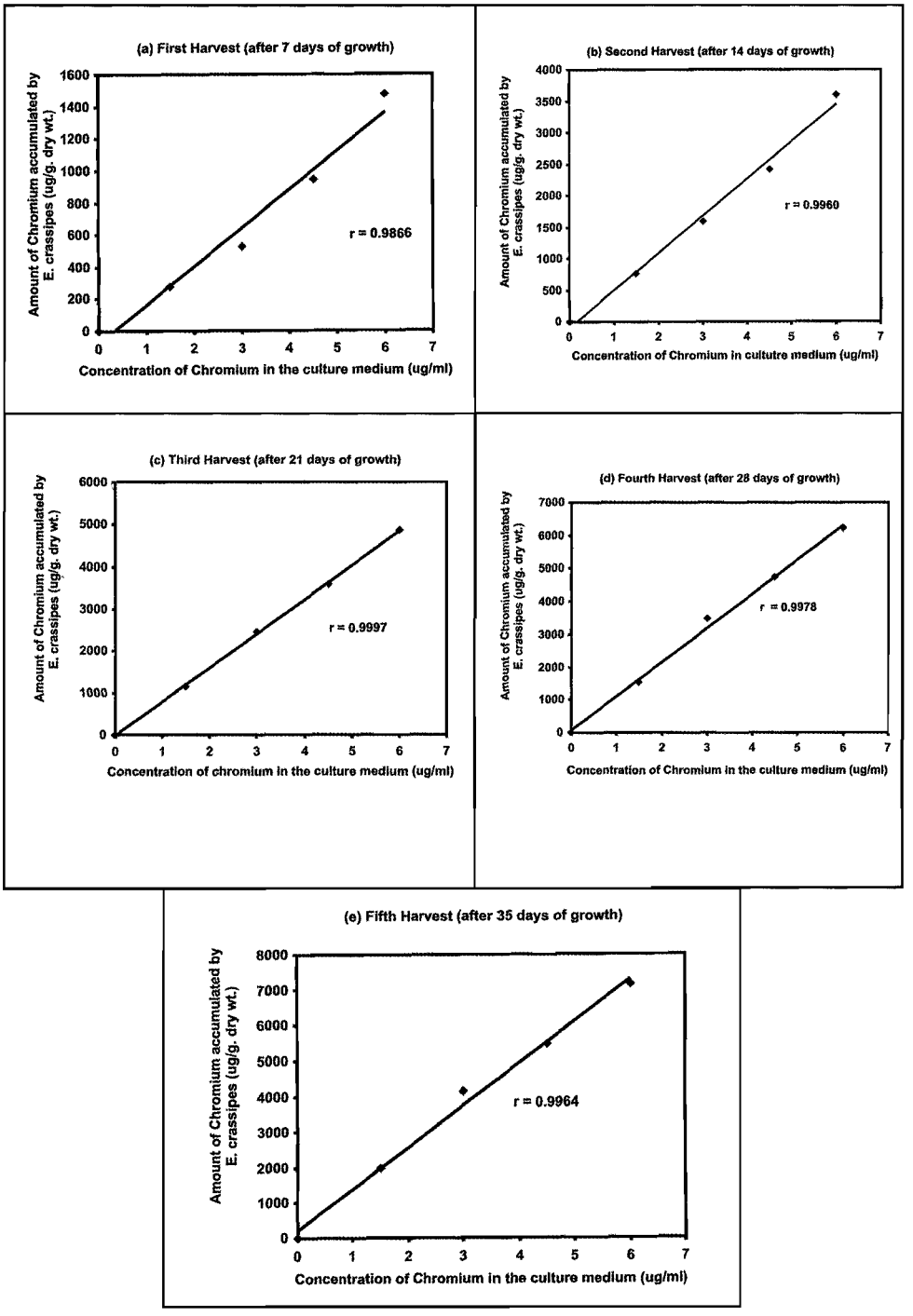


Figure 1 Correlation between the concentration of chromium in the culture media and the amounts of chromium accumulated by *E. crassipes* with time.

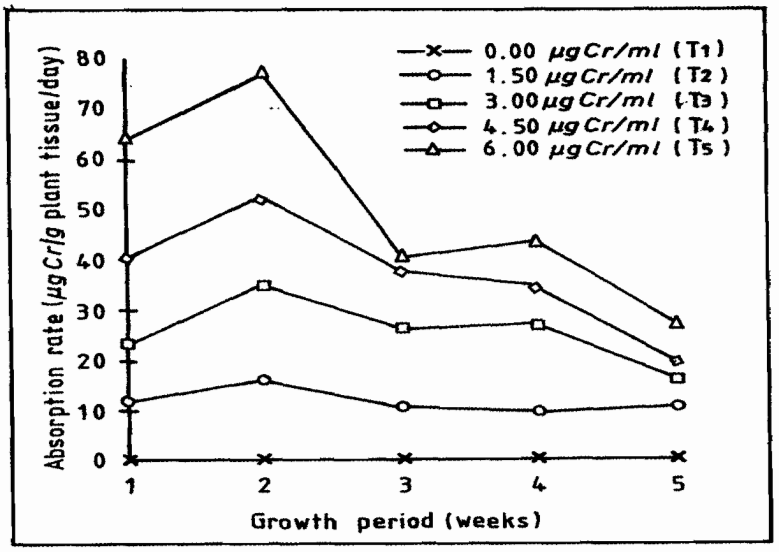


Figure 2: Mean absorption rates of chromium by *E. crassipes* raised on culture media containing varying concentration of potassium dichromate.

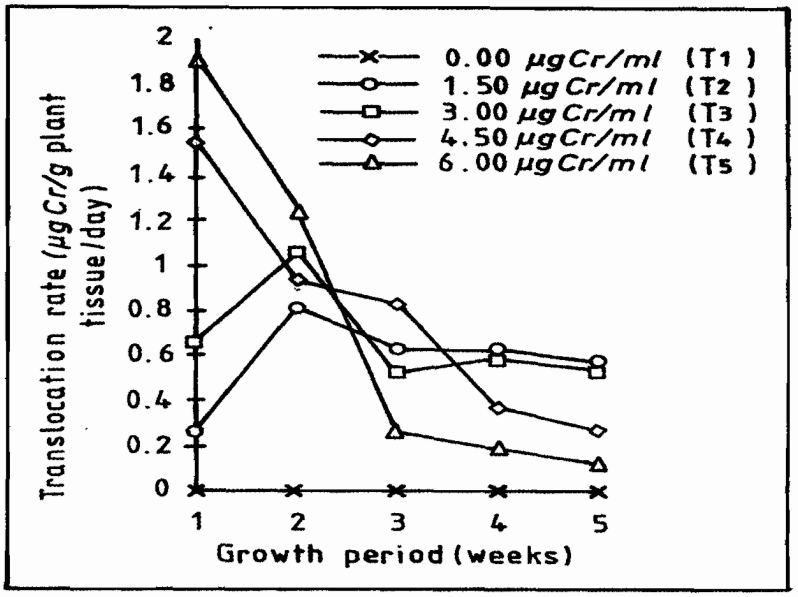


Figure 3: Mean translocation of chromimum from the roots to the shoots of *E. crassipes* plants grown in culture media containing varying amounts of potassium dichromate

However, the increased absorption of chromium by *E. crassipes* did not result in significant differences ($p>0.01$) in either the net assimilation rate (Figure 4) or the relative growth rate (Figure 5) of the plant between the different treatments at all harvests. But, that accumulation of chromium by the water hyacinth was positively correlated ($r = 0.8112$) with significant increases in the leaf area ratio of the plants exposed to culture media with chromium concentrations of $3.00\mu g.ml^{-1}$ and above between the third and fifth weeks of the experiment (Figures 6 and 7). The increase in the leaf area ratio associated with chromium accumulation was negatively correlated ($r = -0.5401$) with weekly biomass increments of the studied *E. crassipes* plants (Figure 8).

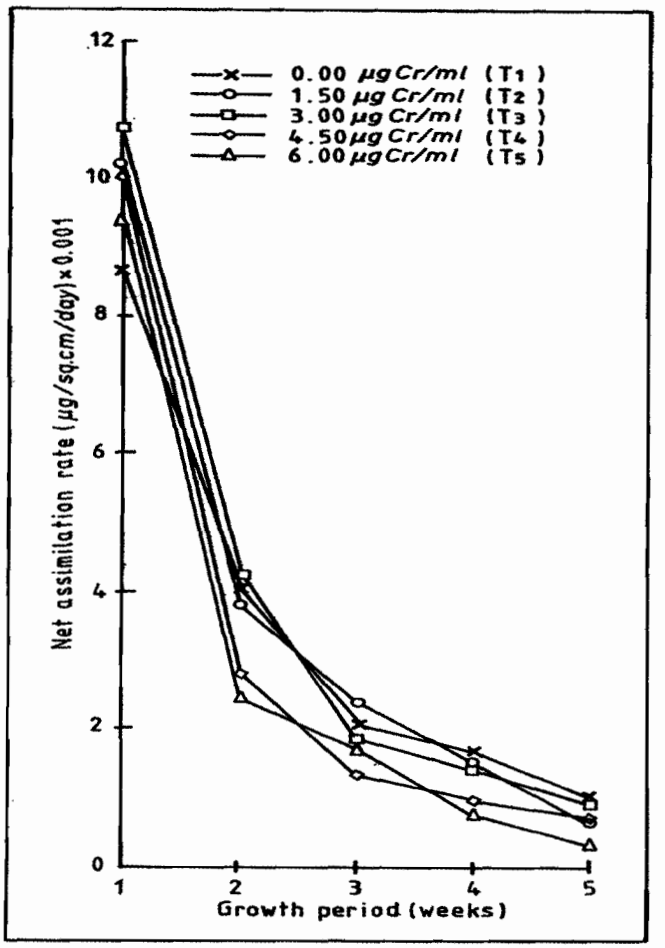


Figure 4: Mean net assimilation rates of *E. crassipes* plants grown in culture media containing varying concentrations of chromium

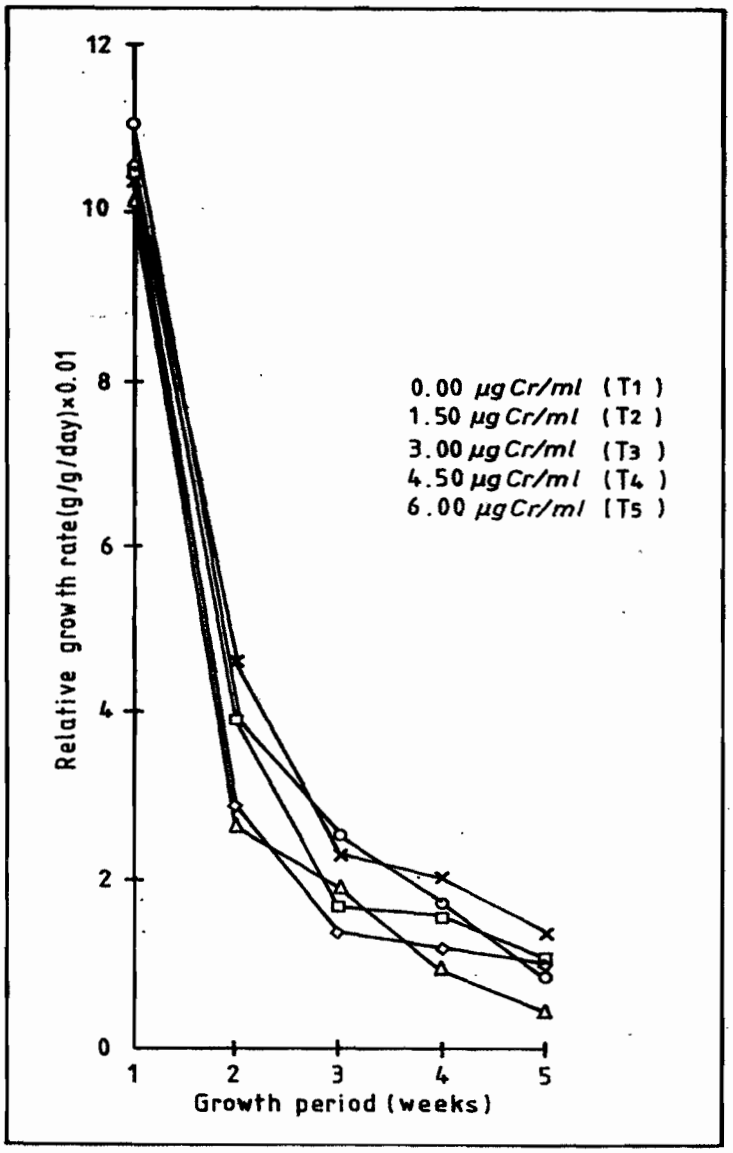


Figure 5: Mean relative rates of *E. crassipes* plants grown in culture media containing varying concentrations of chromium

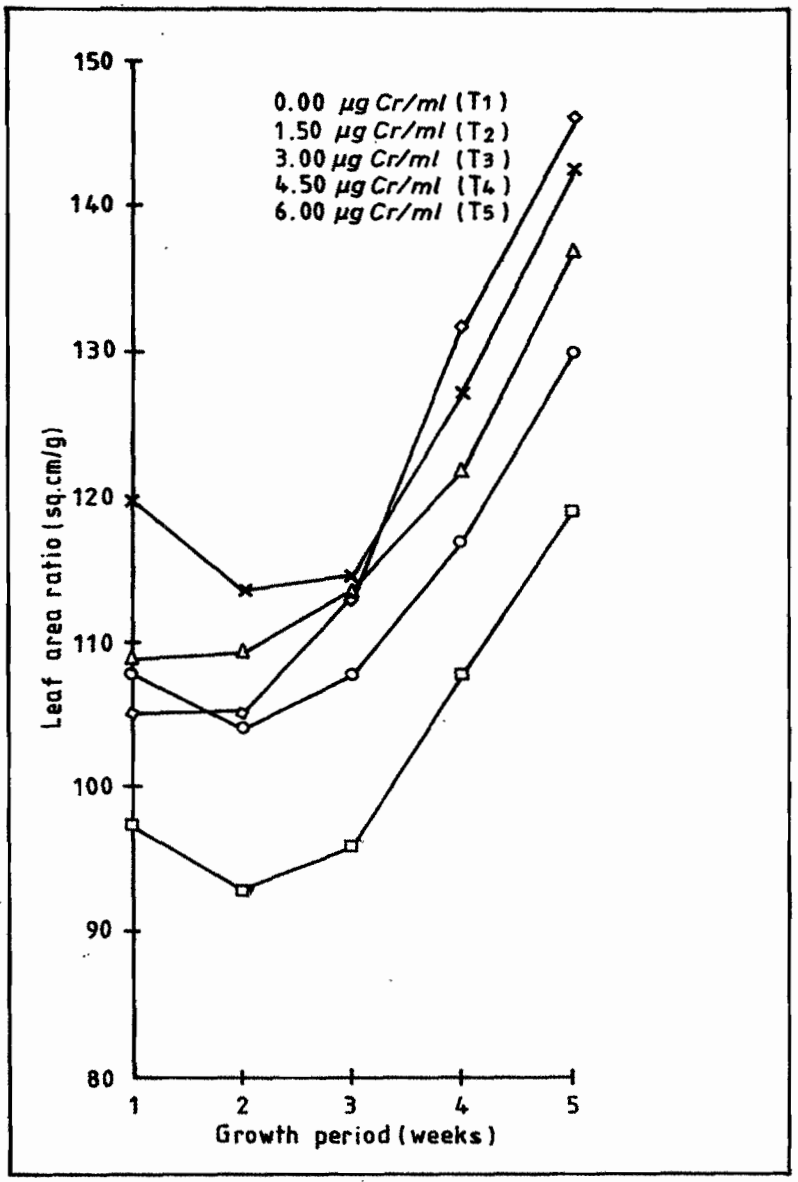


Figure 6: Mean leaf area ratios of *E. crassipes* plants grown in culture media containing varying concentrations of chromium.

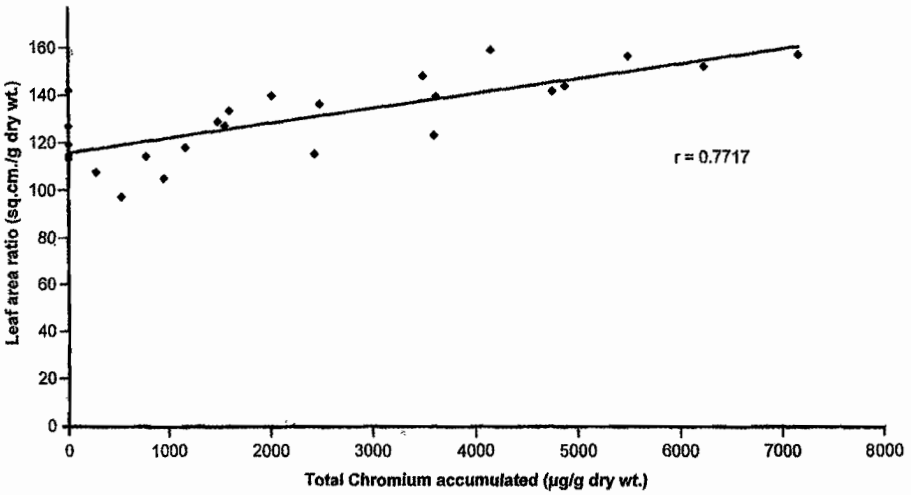


Figure 7: Relationship between the total amount of chromium accumulated by *E. crassipes* and 21 the leaf area ratio of the plant.

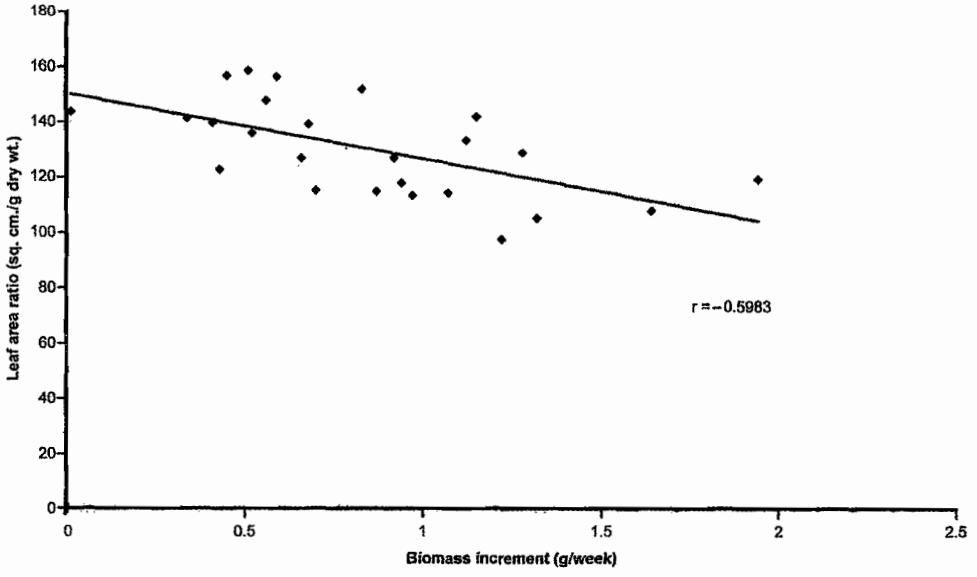


Figure 8: Relationship between the leaf area ratio of chromium-treated *E. crassipes* and its biomass increment per week

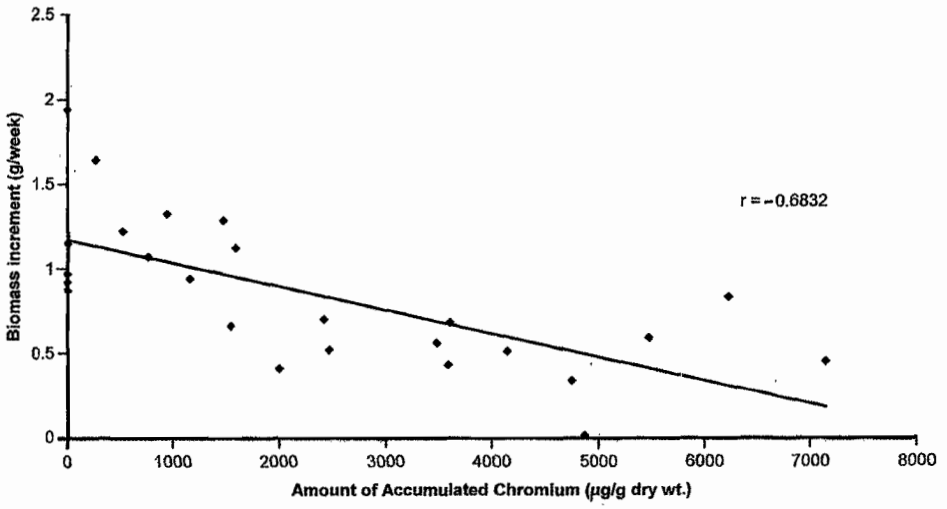


Figure 9: Relationship between the amounts of chromium accumulated by *E. crassipes* and the plant's biomass increment

The results of regression analysis also show that the accumulation of chromium by *E. crassipes* was negatively correlated (r = -0.6605) with the weekly biomass increments of the plant (Figure 9).

**DISCUSSION:**

The results of the present study show that *E. crassipes* has the ability to absorb chromium from nutrient media and accumulate it in its tissues in proportion to the concentration of the metal in the culture media and the length of time for which the plant is exposed to the chromium containing culture media.

The increases in the accumulation of chromium in *E. crassipes* tissues with increasing concentrations of chromium in the culture media were to be expected since, as the number of $Cr_2 O_7^{-2}$ ions increased in the culture media, there were increased chances of such ions making contact with the plant roots. Therefore, the chances of chromate ions being absorbed were increased and, if there was any competition for binding sites among the various divalent ions present in the culture media (Sutcliffe 1962, Mugasha 1995), chromate ions were more likely to occupy many of those sites when present in the culture media at higher concentrations. The interesting result of this study from a pollution control stand point is that although chromium is not necessary for the physiological processes of *E crassipes,* the experimental plants nonetheless accumulated amounts of chromium in their biomass far higher than the concentrations of the metal in the culture media. This, however, is not unique to the water hyacinth, for, it has been observed that other plant species are able to accumulate

heavy metals to levels far higher than those found in the environment even where those metals did not have any apparent function in the normal physiology of those plants (Fitter & Hay 1980). What is of importance, however, is that *E. crassipes* is a convenient plant for controlling chromium pollution in fresh waters because it is a free-floating fast-growing fresh water plant. Furthermore, when exposed to culture media with a chromium concentration of 1.50 $\mu g.ml^{-1}$, the *E. crassipes* plants used in the present study showed the ability to accumulate the chromium in their tissues without any apparent ill-effects on their growth characteristics (i.e. their RGR, NAR and LAR) which did not significantly differ ($p>0.01$) from those of the control plants at all harvests. This clearly shows that *E. crassipes* can be conveniently used to remove chromium from surface fresh water bodies such as waste water treatment ponds, lakes and rivers if the effluents or underground drainage water received by such water bodies do not contain chromium at concentrations higher than 1.50 $\mu g.ml^{-1}$.

However, at concentrations of 3.00 $\mu g.ml^{-1}$ and above chromium may impair the physiological activities of *E. crassipes*. For, statistical analyses in the present study showed that although when present in the culture media at concentrations of 3.00 $\mu g.ml^{-1}$ and above chromium did not cause any significant differences ($p>0.01$) in the RGR and the NAR, it nonetheless caused a significant increase ($p<0.01$) in the LAR. It has been observed that there is a mutual relationship between the instantaneous values of RGR, NAR and LAR through the relation:

$R' = E'. F'$ (Kvet *et al.* 1971)

Where $R'$ = instantaneous RGR;
$E'$ = instantaneous NAR; and
$F'$ = instantaneous LAR.

From the above relation, it follows that any effects of chromium on *E. crassipes* growth rate can be interpreted in terms of effects either on its net assimilation rate, or on its leaf area ratio or both. In the case of the present study it was the leaf area ratio (Figure 6) which had been affected by the accumulation of chromium and, in turn, may have had a significant effect on the biomass increment of *E. crassipes* plants treated with chromium concentrations of 3.00$\mu g.ml^{-1}$ and above as indicated in (Figure 8). This is indicative of the fact that the accumulation of high levels of chromium by *E. crassipes* may have interfered with the plant's physiological activities resulting in changes in the LAR which, in turn, may have led to the decreased biomass increment of the plant. It could also be argued that probably the *E. crassipes* plants used in this experiment used up a lot of energy to carry out the sequestering of the chromium in safe forms in their tissues with the consequence that little energy then remained available for biomass increment per unit time, hence the negative correlation between the weekly biomass increment of the plants and the accumulated chromium (Figure 9). Gutschick (1987) suggested that accumulation of high levels of heavy metals can be metabolically disruptive or energy costly to sequester in safe forms internally. One of the possible physiological disruptions of chromium accumulation in *E. crassipes* would be to reduce its mineral nutrient uptake which would inevitably result in impairment of some or all of its growth characteristics (Watson 1952, Ruck & Bolas 1956, Delap & Ford 1958, Blackman 1968) ending up in its reduced biomass increment per unit time.

Inspite of the observed poor growth of *E. crassipes* under the influence of chromium concentrations of 3.00$\mu g.ml^{-1}$ and above, for which any or all of the explanations given above may be valid, still it is noteworthy that the plant survived and continued to accumulate

chromium in its tissues against a concentration gradient. Therefore, it is safe to conclude that the use of *E. crassipes* to absorb chromium from polluted waters coupled with periodic harvesting and incineration of old stocks of the plant from such waters can help to curb the problem of chromium pollution in fresh water bodies. Its use in the control of such pollution should therefore be given serious consideration by the authorities responsible for environmental protection. Ashes from the incinerated *E. crassipes* materials from chromium-polluted water bodies could be treated with EDTA to complex the chromium and thus prevent it from re-entering the environment.

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