



## EVALUATION OF PHYTOREMEDIATION POTENTIAL OF *CYPERUS PAPYRUS* FOR NI, CD AND PB REMOVAL FROM HEAVY METAL POLLUTED WATER

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### ABSTRACT

One of the emerging technologies which can provide effective, low-cost treatment is the use of hyper accumulator plants management to remove toxic heavy metals from polluted water. In this study, *Cyperus papyrus* (paper reed) plant was evaluated with respect to its potential to clean up heavy metal pollutants from synthetic heavy metal polluted water. A pot experiment was conducted using three heavy metal concentrations of Pb, Cd and Ni (i.e. ML<sub>1</sub>: 10, 1.0 and 0.1 mg l<sup>-1</sup>, ML<sub>2</sub>: 20, 2.0, 0.2 mg l<sup>-1</sup> and ML<sub>0</sub> as a control treatment (tap water), respectively). Both plant roots and shoots sampled were after 40, 80 and 120 days from transplanting. The results showed that studied heavy metals accumulated in the roots of the studied plant are higher than those in shoots. The main effective factor governing metal uptake was found soil pH. The results also showed that plant parts and heavy metal concentrations in synthetic polluted water had the strongest significant effect with Cd uptake after 80 days from transplanting than from low concentration treatments. A significant effect of the plant parts has been observed after 40 and 120 days from transplanting. In addition, Pb uptake has been affected by neither heavy metal concentrations in synthetic polluted water nor plant parts. Plant parts and heavy metal concentrations in synthetic polluted water interaction showed the effect on Cd uptake comparing to the other two studied metals (Ni and Pb). In attempting to predict metal uptake by plant, a multiple regression models was undertaken using studied soil parameters (e.g. pH and pe). It was observed that pH had a most significant effect in governing metal uptake mechanism and approximately 47%, 34% and 39% of the variability in the pM<sub>uptake</sub> (-log values) of Cd, Ni and Pb respectively, were explained by the variation in soil pH and pe.

**Key words:** Plant uptake; *Cyperus papyrus*; heavy metal; synthetic heavy metal polluted water.

### INTRODUCTION

Heavy metals, such as Nickel (Ni), cadmium (Cd) and lead (Pb), are released into the environment by natural process such as volcanic eruption and anthropogenic activities such as mining activities, industry, and agriculture, threatening environmental and human health (Marzouk *et al*, 2012).

Due to the severe toxicity of these pollutants, there is a crucial need to

develop low-cost, effective, and sustainable

methods to remove them from the environment or to decontaminate them. Plant-based approaches, such as

phytoremediation, are relatively costly cheap since they are implemented in situ and are solar-driven (Salt *et al.*, 1995, Samuelsen *et al.*, 1998). Dilute concentrations of trace element contaminants can be removed from large volumes of wastewater hyper-accumulated marsh plants.

They play an important but indirect role in that they supply fixed carbon and other nutrients to rhizosphere microbes accountable for the uptake and detoxification of contaminants. Plants also play a more direct role in remediation of soil.

They may be used to accumulate metals in their harvestable biomass (phytoextraction) and can also convert and release certain metals/ in a volatile form (phytovolatilization) (Duckart *et al.*, 1992).

Phytoremediation carried out by using hyper-accumulator plants, can absorb huge amounts of contaminants with their roots from soil-water system. In general, plants are involved in the uptake, translocation, and degradation of pollutants. Subsequently, the plants can be harvested, and processed by drying, ashing, composting or even manufacturing (Lee, 2013). As suggested by Robinson *et al.* (2000), a different approach lies in the use of plants which have deep root, are easily propagated and accumulates the target metal, combined with an increase of the phytoavailability of the metals from soil-water system (Felix, 1997).

Phytoremediation is not a remedying process in contaminated upland soil only but also in aquatic system; including both soil and solution phases. However, water pollution is considered to be one of the major dangerous hazardous in both developing and developed countries (Fawzy *et al.* 2012).

In Egypt, the pollution of the water streams, drains and canals has increased in the past few decades because of increases in human activities due to increase population (Fawzy *et al.* 2012). It is well known for long time that some aquatic plants is also Hyper-accumulator of metals and, therefore, the use of those plants to remove heavy metals from aquatic systems has gained some favours and interests (Kuyucak and Volesky 1989). The phytoremediation technology is considered as an alternative cost-effective solution for traditional methods to clean up heavy metals from contaminated waters (Khambhaty *et al.* 2009). The advantage of this technology is its implementation to both organic and inorganic metal forms present in soil (solid substrate), water (liquid substrate), or the air in high concentration levels (Salt *et al.* 1998).

Various plants have been employed in the treatment of waste waters. Biddlestone *et al.* (1991) used common reed (*Phragmites australis*) bed systems to reduce dairy waste with a BOD value of 1006 mgL<sup>-1</sup> down to 57 mgL<sup>-1</sup>. It has been reported that a common reed (*Phragmites australis*), grown in uranium-contaminated soils, accumulated uranium (U<sup>238</sup>) in the roots, and translocated to the shoots, in limited amounts (Cerne *et al.*, 2011).

In addition, a comparative study of *Cyperus papyrus* (paper reed) and *Miscanthidium violaceum*-planted wetlands for waste water treatment in Uganda revealed that common reed was the more efficient for removing metals (Kyambadde *et al.*, 2004). Moreover, the use of *Lemnagibba*, *Typhadomingensis* and *Ceratophyllum demersum* in the phytoremediation of wastewater was also reported by several authors (Ramadan, 2003 and Fawzy *et al.*, 2012).

In Egypt, the most dominant aquatic plants could be categorized into different groups according to the nature of their growth; (i) submerged species such as *Ceratophyllum demersum* (coontail) and *Myriophyllum spicatum* (parrot feather), (ii) floating species such as *Eichhornia crassipes* (water hyacinth) and *Lemna gibba* (duckweed) and (iii) emergent species such as *Phragmites australis* (common reed), *Typhadomingensis* (cattail) and *Cyperus papyrus* (paper reed).

However, phytoremediation technique considers a time consuming approach for clean-up metals from contaminated environment (**Lucian et al., 2011**).

It may take several years to remove a substantial amount of contaminants and this could be a main disadvantage point in using phytoremediation.

Urbanization and financial constraints led to an increase of wastewater generation against constant and/or degrading wastewater treatment facilities. Therefore the current study will extrapolate and speculate on viability of emergent macrophyte species, natively grown in wastewater in Egypt, in a potential metal removal and plant-uptake processes (*Cyperus papyrus*; paper reed) in wastewater treatment.

The aims of the current study are to; (i) compare the extent of metal removal (Ni, Cd and Pb) from artificial wastewater by one local plant species dominant in El-Arish, North Sinai, Egypt, (ii) investigate the metal accumulation in different plant parts as a result of synthetic wastewater enriched by different concentrations of Ni, Cd and Pb application and (iii) evaluate the factors that affect the metal removal rates from the soil.

## Materials and Method

The main target of the current study was to evaluate the paper reed marsh plant

as a phytoremediation tool to remove some heavy metals from enriched heavy metal synthetic polluted water.

### Soil used:

Soil sample was collected from experimental farm of faculty of Agricultural Environmental Sciences, El-Arish, Suez Canal University. The sample was air dried, crushed 2 mm sieved and then analysed for main physical and chemical properties according to standard methods (**Jackson, 1967**). The main physical and chemical properties of the soil used are presented in Table (1).

### Plant used:

Paper reed marsh plant was used as an indicator plant which collected from Grada Sewage Station, El-Arish. The initial concentrations of studied heavy metals in the studied plant are presented in Table (2).

### Enriched heavy metal synthetic polluted water used:

Enriched heavy metals synthetic polluted water was prepared using metal lead, cadmium sulphate and nickel nitrate as a source of lead, cadmium and nickel, respectively, which dissolved in tap water to obtain the required concentrations. The chemical properties of the tap water used are presented in Table (3).

## 1. Experimental setup

A pot experiment was carried out in a greenhouse to investigate the potential use of paper reed plant to extract and accumulate of Pb, Cd and Ni from artificially heavy metal water polluted.

Twenty kgs of the air-dried soil samples were packed in plastic containers (45 cm internal diameter and 36 cm in height). Six paper reed seedlings were transplanted in every pot.

The seedlings were collected from Garada swage station, North Sinai, Egypt.

**Table (1): Some physical and chemical characteristics of the soil used**

Soil parameter	value
Soil particle distribution (%)	
Sand	97.80
Silt	1.00
Clay	1.20
Soil texture	Sand
CaCO <sub>3</sub> (g kg <sup>-1</sup> )	160
EC (dSm <sup>-1</sup> )	1.81
pH	7.93
OM (g kg <sup>-1</sup> )	0.16
Cations and anions (mg kg <sup>-1</sup> )	
Ca <sup>2+</sup>	132
Mg <sup>2+</sup>	60.2
Na <sup>+</sup>	122
K <sup>+</sup>	42.9
CO <sub>3</sub> <sup>2-</sup>	n.d.*
HCO <sub>3</sub> <sup>-</sup>	19.2
Cl <sup>-</sup>	249
SO <sub>4</sub> <sup>2-</sup>	451
Total metal concentrations (mg kg <sup>-1</sup> )	
Pb	0.330
Ni	0.135
Cd	3.82

\*n.d.not detectable.

**Table (2): Initial heavy metal concentrations in paper reed plant shoots and roots, mg kg<sup>-1</sup>.**

plant		Pb	Cd	Ni
		mg kg <sup>-1</sup>		
<i>C. papyrus.</i>	Shoots	3.325	2.200	5.100
	Roots	8.825	2.225	7.950

**Table (3): Chemical analysis of fresh water using for preparing of synthetic enriched heavy metals irrigation water used.**

Parameters	Value
Ca <sup>++</sup> (meq.l <sup>-1</sup> )	1.50
Mg <sup>++</sup> (meq.l <sup>-1</sup> )	0.60
Na <sup>+</sup> (meq.l <sup>-1</sup> )	1.80
K <sup>+</sup> (meq.l <sup>-1</sup> )	0.20
CO <sub>3</sub> <sup>-</sup> (meq.l <sup>-1</sup> )	0.00
HCO <sub>3</sub> <sup>-</sup> (meq.l <sup>-1</sup> )	0.40
Cl <sup>-</sup> (meq.l <sup>-1</sup> )	1.80
SO <sub>4</sub> <sup>-</sup> (meq.l <sup>-1</sup> )	1.90
EC (dSm <sup>-1</sup> )	0.41
pH	7.92
N (mg.l <sup>-1</sup> )	2.0
P (mg.l <sup>-1</sup> )	10.0
K (mg.l <sup>-1</sup> )	15.0
Pb (mg.l <sup>-1</sup> )	Nil
Cd (mg.l <sup>-1</sup> )	Nil
Ni (mg.l <sup>-1</sup> )	Nil

Synthetic heavy metal polluted water enriched with three concentrations of Pb, Cd and Ni.

Three level of metal concentrations were prepared from the salt metal form; ML<sub>1</sub>: 10, 1.0 and 0.1 mg l<sup>-1</sup>, ML<sub>2</sub>: 20, 2.0, 0.2 mg l<sup>-1</sup> and ML<sub>0</sub> as a control (tap water), respectively.

The pot experiments were arranged in a complete randomized block experimental design. The heavy metal polluted water treatments were added to each pot to reach of 5 cm above the soil surface in order to mimic the natural used plant conditions.

A supplementary of deionized water was added if necessary to recover the water lost from each pot. Plant shoot samples were taken after 40, 80 and 120 days by cutting the stems approximately 2 cm above the soil surface while roots were collected, sieved to get rid of soil particles and washed with running water and distilled water. Eh and pH values of soil-water system in every pot were measured in situ immediately before each plant sampling course. Plant samples (shoots and roots) were dried at 60°C to a constant weight, grounded into fine powder, sieved with a 2 mm plastic mesh. One half g of the powdered plant samples was digested using 4 ml of concentrated sulfuric acid (~7 min) and subsequently with 10 ml of a H<sub>2</sub>O<sub>2</sub> solution which then analyzed for Pb, Cd and Ni concentrations using an Inductively Coupled Plasma (ICP) technique.

## 2. Translocation factor and prediction model:

Translocation factor parameter is necessary for environmental transfer models which are useful in prediction of the pollutant concentrations in agricultural crops for estimating dose intake by man. TF is calculated by the relation: the ratio

of concentration of metal in the shoot to the concentration of metal in the roots (Cui *et al.*, 2007).

$$TF = \left( \frac{M_{Sh}}{M_{Ro}} \right) \quad (1)$$

Where TF is a translocation factor, M<sub>Sh</sub> and M<sub>Ro</sub> are the metal concentration in shoot and root systems respectively (mg kg<sup>-1</sup>). This factor was used to evaluate the Ni, Cd and Pb phyto-extraction capacity of the plant.

However, multiple regression models have been developed to predict metal uptake by paper reed plant. The models have been developed using solver, Excel 2010 programme.

## 3. Statistical analysis:

Data were statistically analyzed to test the ANOVA and Pearson correlation coefficient using IBM SPSS Statistics v. 20 and Microsoft Excel 2010. drastically limits exchange of gases between soil and the atmosphere and an oxygen-deprived environment is established. The oxygen diffusion in water is lower than that of air by 10,000 times (Ponnamperuma 1972).

## RESULTS AND DISCUSSION

### 1. Soil reaction (pH) and redox potential (Eh, mV) changes over growing periods:

Soil flooded with water is usually affecting its pH and Eh values. Hypothetically, under anaerobic condition, the soil pH alters toward neutral plant (pH 7), irrespective of its initial pH value, in both alkaline and acidic soils (Ponnamperuma 1972, MacBride 1994). However, in alkaline soils, soil pH may be lowered by the accumulation of CO<sub>2</sub> gas and, consequently, produce carbonic acid (Fiedler *et al.*, 2007).

Therefore it is expected that with undergoing Eh to decrease, the soil pH may move toward neutral conditions. Obtained data in Fig. 1 show the effect of elapsed time on pH and Eh in the soil cultivated with *C. papyrus* under different heavy metal polluted water concentrations (Metal Level1; ML1 and Metal Level2; ML2 of Pb, Cd and Ni). Soil flooding resulted in changes in pH and Eh. All treatments exhibited decreasing in Eh following soil flooding by heavy metal enriched polluted water (Fig. 1). The Eh values of the soil cultivated with *C. papyrus* was in average +288 mV. Over a growing period of 40 days, Eh values fell from +540 mV at experimental zero time to approximately +190 mV. The redox potential then remained fairly constant over 80 days so that the soil-solution systems appeared to be strongly poised around this region.

In this concern, **Ponnamperuma (1972)** referred to that plant is hard hit by anaerobic conditions and some plants are specially adapted to survive waterlogged conditions, e.g. rice and marsh plants and here O<sub>2</sub> is transported through the plants from shoots to roots. The decrease in Eh with time suggests the development of anaerobic conditions in the soil cultivated with paper reed plant. Such anaerobic conditions result from microbial respiration during which readily available organic carbon is metabolized and soil oxygen is exhausted depleted.

Moreover, soil pH (Fig. 1) was initially lowered by about 0.5 – 1.0 units after 40 days from transplanting in the soil but then tend to fluctuate within a narrow range of pH changing (pH between 6.4 to 7.0) after 80 days till the end of growing period. There was a general increase in pH values of the soil-water system with decreasing soil redox potential (Fig. 2).

The correlation coefficients (r values) showed a significant relationship at P value

less than 0.01 ( $r = -0.74$ ). This is in agreement with the trends obtained by **(Ponnamperuma 1972, Hesterberg 1998, Miao *et al.* 2006, Fiedler *et al.* 2007)**.

Such effect could be due mainly to the consumption of H<sup>+</sup> ions during reduction processes, balanced by a build up of CO<sub>2</sub> from organic matter decomposition and plant roots respiration **(Ponnamperuma 1972)**.

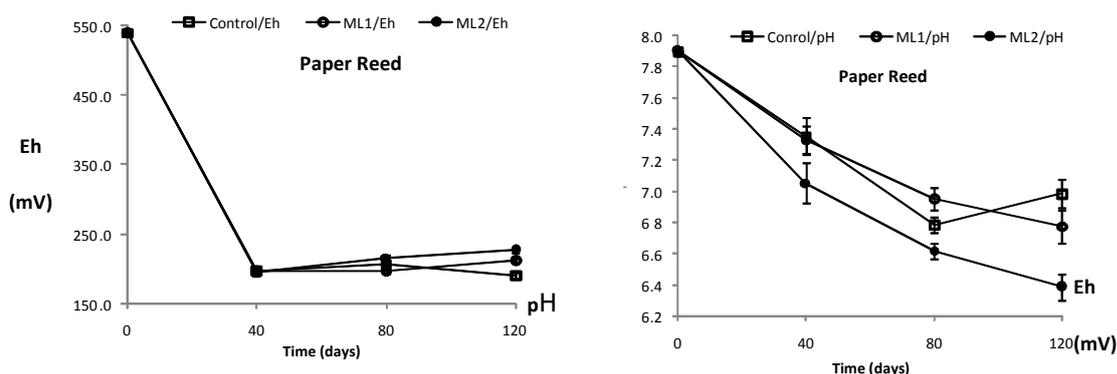
Under anaerobic condition due to flooding the soil using heavy metal enriched polluted water, the soil pH alters toward neutral (pH 7), irrespective of initial pH, in calcareous soil (pH 8.0) as illustrated by Ponnamperuma **(1972)** and **MacBride (1994)**.

The slope of the observed Eh/pH relationship depends partly on the proton-electron stoichiometry ( $n_H/n_e$ ) of the redox reactions poisoning the soil system as shown from a well known Nernst equation (eq.2).

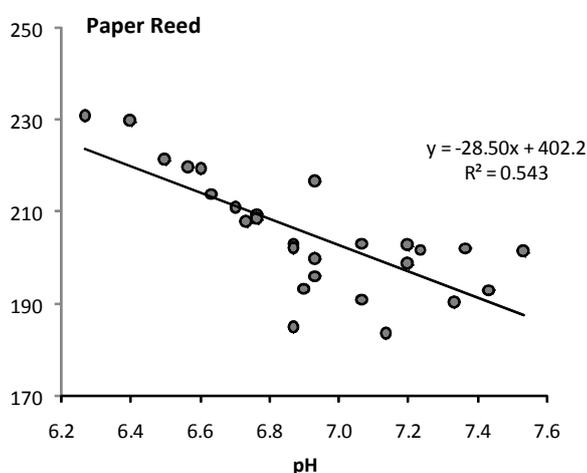
$$Eh = Eo - \frac{RT \ln(10)}{F} \frac{n_H}{n_e} pH \approx Eo - 59 \left( \frac{n_H}{n_e} \right) pH \quad (\text{at } 25^\circ \text{C}) \quad (\text{eq. 2})$$

For example, for ferric hydroxide reduction to ferrous iron, the ( $n_H/n_e$ ) stoichiometry is 3 and so the slope would be expected to be approximately 177 mV pH<sup>-1</sup> (59x3) at 25°C. However, the presence of non-redox proton buffer reactions, such as H<sup>+</sup> adsorption on humus, ensures that the slope of pH against Eh is always vary from predicted redox reactions **alone (Menzies, 2007)**.

For instance, it has been found that the soil-solution Eh/pH slopes were -504 mV pH<sup>-1</sup> during redox cycling **(Miao *et al.*, 2006)**, -359 mV pH<sup>-1</sup> in oxidized fresh water sediment **(DeLaune and Smith, 1985)**, -330 mV pH<sup>-1</sup> **(Marzouk, 2012)** and between -206 and -256 mV pH<sup>-1</sup> in acid sulphate soil solutions **(Charoenchamratcheep *et al.* 1987)**.



**Fig. (1):** Changes in soil pH and Eh (mV) during the term of experimental period.



**Fig. (2):** Soil pH as a function of soil Eh (mV) values in the soils cultivated with paper reed plants.

In the current study, the Eh/pH slope was approximately  $-30 \text{ mV pH}^{-1}$  (Fig. 2)

## 2. Factors affecting metal uptake by *C. papyrus* plant:

### Effect of Soil pH and Eh

Fig. (3) and (4) show the effect of pH and Eh on metal uptake of both shoots and roots of paper reed plant. The results showed that a negative significant relationship has been found between all metals taken up by both roots and shoots of and pH (root;  $r$  value for Ni, Cd and Pb=  $-0.36$ ,  $-0.70$  and  $-0.49$ , and shoot;  $r$

value=  $-0.43$ ,  $-0.49$  and  $-0.46$  respectively,  $P < 0.05$ ).

However, a positive relationship has been found between studied heavy metal uptake and Eh values of the soil-water system. The results indicated that the uptake of the studied heavy metal pool increased with decreasing soil pH.

The increasing metal uptake under relatively high Eh values may be explained mainly by the changes in soil pH.

The metal uptake is significantly correlated to the solubility forms of metals in the soil solution phase which, in turn,

related to their available pool in soil solid phase. **Miao *et al.* (2006)** studied Zn solubility under both oxic and anoxic conditions by controlling soil pH (from 5.8 to 7.1) and Eh (from 500 to -200 mV).

They found that Zn concentrations were mainly dependent on pH and were at a maximum under oxic conditions (at pH = 5.8) which increase the proportional of metal that could be taken up by plants.

This pattern of dependence of metal uptake by plants on soil pH is fairly well recognized in previous studies (**Mench *et al.*, 1994, Mench *et al.*, 2000, Lombi *et al.*, 2002, Cappuyns and Swennen, 2005**).

### 3. Effect of metal concentrations and elapsing time:

The overall results show that obtained in figs (5-10) metal uptake by studied plant showed an increase with increasing heavy metal concentration in synthetic polluted water comparing to the control treatment under different plant part. The highest value was corresponded with high heavy metal

concentrations in synthetic polluted water after 80 days in roots.

This might suggest that loss of metals from soil solution is primarily due to process associated with the presence of plant. Generally the uptake process was enhanced by increasing metal concentrations in all treatments. However, these variations from main trend were almost recovered when plant metal uptake was calculated using the whole plant as seen in Figs 5-7.

Therefore, Analysis of variance (ANOVA) test has been undertaken to show the effect of heavy metal concentrations in synthetic polluted water and plant parts (roots and shoots) on metal uptake by paper reed plant. ANOVA results given in Table 3 show that the highest significant variables were plant

parts and high heavy metal concentrations treatments with being more Cd uptake by paper reed plant after 80 days than from low heavy metal concentration water treatment.

The studied heavy metal water metal concentrations and their interactions with plant parts did not show any significant effect. The results also showed that a significant effect of the plant parts has been observed after 40 and 120 days from transplanting. In addition, Pb uptake by paper reed plant has been affected by neither heavy metal water concentrations nor plant parts.

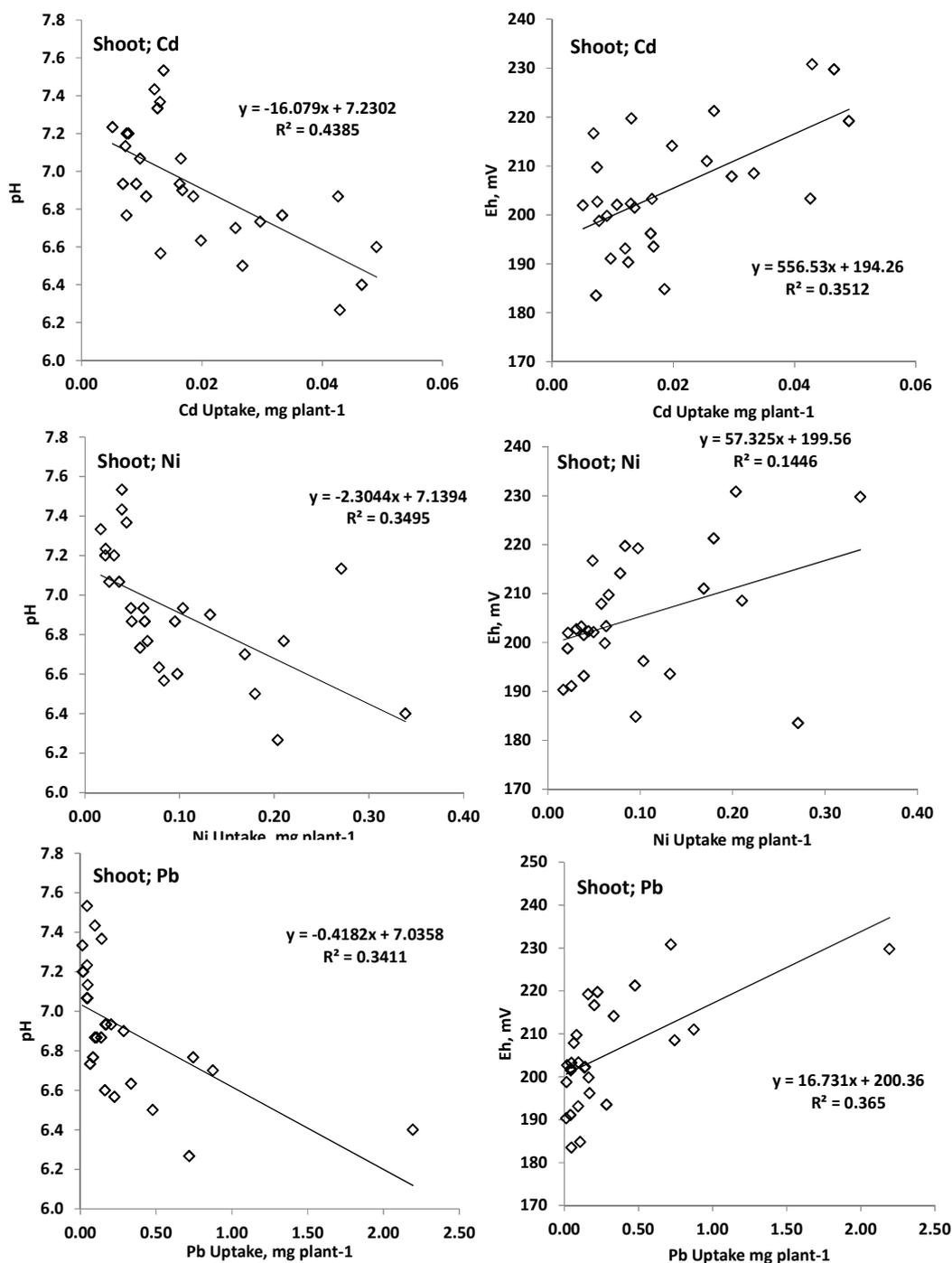
Specially on Cd uptake by plant comparing to the other studied metals (Ni and Pb).

Such effect may be due to the competing effect of Cd ions over other heavy metals. Such heavy metals may effectively compete for the same transmembrane carriers used by other heavy metals. Toxic heavy metals such as cadmium may effectively compete for the same transmembrane carrier as used by micronutrient heavy metal.

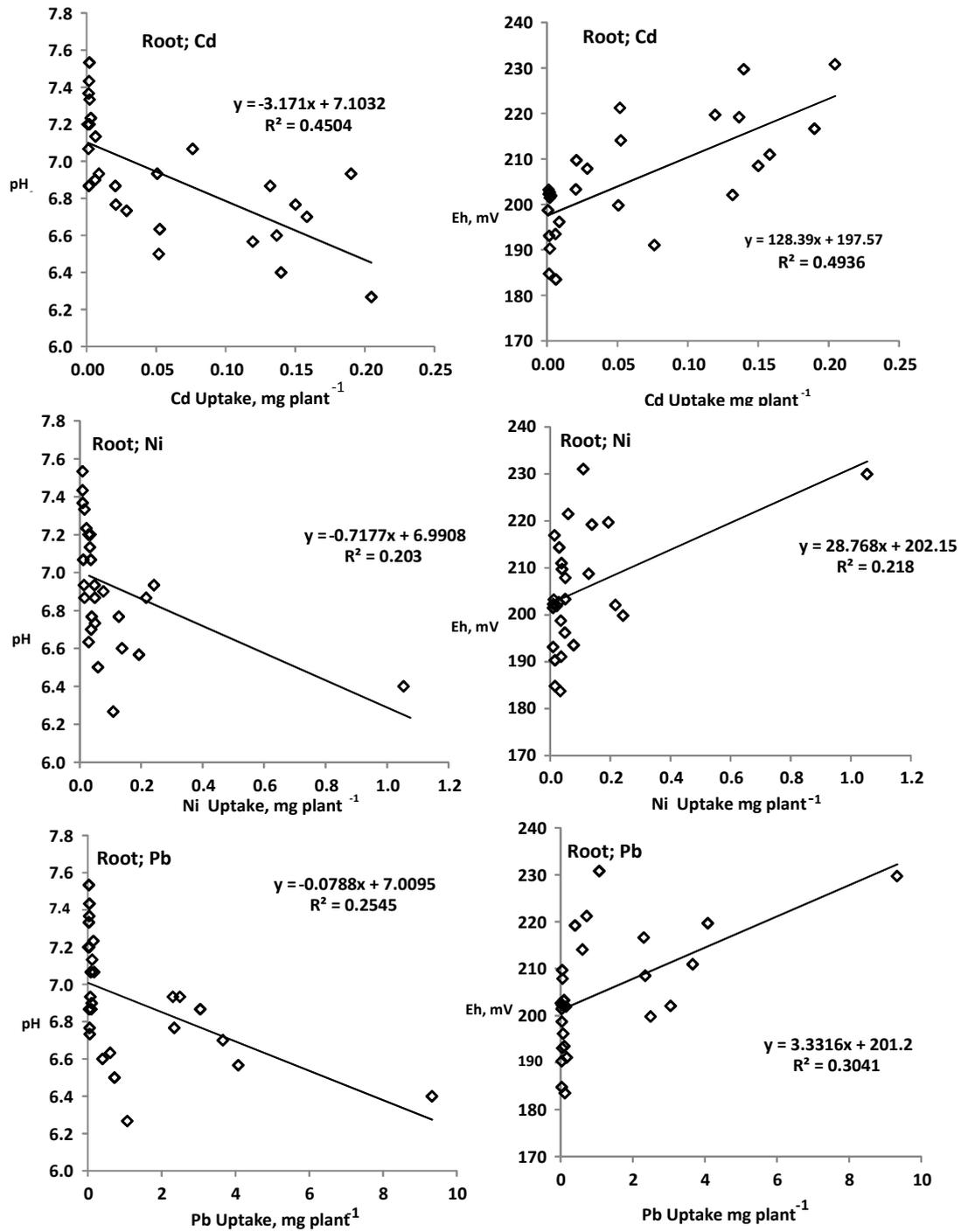
This relative lack of selectivity in transmembrane ion transport may partially explain why toxic heavy metals can enter cells, even against a concentration gradient. Kinetic data demonstrate that essential  $\text{Cu}^{2+}$  and  $\text{Zn}^{2+}$  and nonessential  $\text{Ni}^{2+}$  and  $\text{Cd}^{2+}$  compete for the same transmembrane carrier (**Crowley *et al.*, 1991**).

Moreover, Pb and Ni may show low solubility under the current study where increasing Pb and Ni solubility is likely to be affected significantly by higher decomposable organic carbon (DOC) concentrations under anoxic conditions as it is well recognised that Pb and Ni is more strongly bound to soluble humus ligands (**Sauve *et al.*, 1997, Cances *et al.*, 2003, Grybos *et al.*, 2007**).

Metal selectivity is the preferential uptake of one metal over another and can be defined in terms of total uptake or



**Fig. (3): Influence of pH and Eh (mV) of the soil-water system on Cd, Ni and Pb (mg plant<sup>-1</sup>) taken up by shoots of paper reed plant under using of heavy metal enriched water.**



**Fig. (4): Influence of pH and Eh (mV) of the soil-water system on Cd, Ni and Pb ( $\text{mg plant}^{-1}$ ) taken up by roots of paper reed plant under using of heavy metal enriched water.**

concentration in either the entire plant or plant parts.

#### 4. Translocation factor (TF):

Translocation factor was determined by dividing the total shoot concentration by the concentration in the plant roots (Do Nascimento *et al.*, 2006).

Important differences in translocation of metals within the plants were noted in paper reed plant. In most cases metal translocation into paper reed upper plant parts did not affect by increasing heavy metal water concentration (Table 4).

Metals taken up from metal concentration treatments were found in higher amounts in the roots when compared with the shoots for Cd and Ni (Figs 5-7). This trend suggests that translocation of metal into upper vegetative plant parts is driven by the concentration of that metal and by the presence of other metals (competing effect as discussed above). However, the data shown in table 4 suggested that the efficiency of this translocation mechanism is plant species dependent.

#### 5. Predicting metal uptake using multiple regression analysis:

According to the correlation analysis between metal uptake and studied soil parameters (pH, Eh or pe), multiple regression models were used to predict the metal uptake by paper reed plant as illustrated by the following equation (3) :

$$pM_{\text{uptake}} = a + b \text{pH} + c \text{pe} \quad (3)$$

Where regression coefficients (a, b and c), can be positive or negative (as shown in Table 8), and  $pM_{\text{uptake}}$  is metal taken up by plant expressed as  $\text{mg plant}^{-1}$  (pM refers to  $-\log$  values) while pH and pe refer to soil reaction and electron activity ( $-\log_{10}$ ; pe) as shown from equation (4).

$$pe = \frac{Eh \times F}{RT \ln(10)} = \frac{Eh(\text{mV})}{59.16} \text{ at } 25^{\circ}\text{C}, 1\text{atm.} \quad (4)$$

The ( $-\log_{10}$ ) electron activity (pe), is derived from the Nernst equation (eq. 1), where F is the Faraday constant, R is the transformed to  $-\log_{10}$  ( $pM_{\text{uptake}}$  and pe) values as they showed good log-normal distribution and promoted good prediction results compare to normal values to find Gas constant and T is the temperature (K). The uptake values and Eh values were best prediction model.

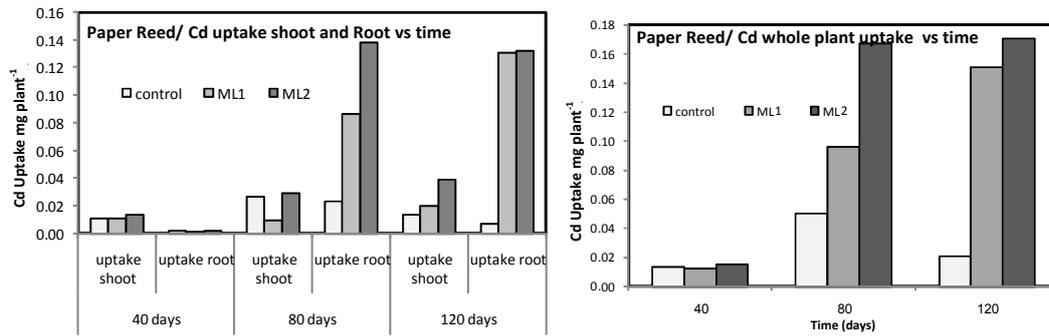
The overall goodness fit for all measured and modelled metal uptake was determined based on R<sup>2</sup> and the residual standard deviation (RSD) as following (equation 5):

$$RSD = \sqrt{\frac{1}{n-c} \sum_{i=1}^n (M_i - P_i)^2} \quad (5)$$

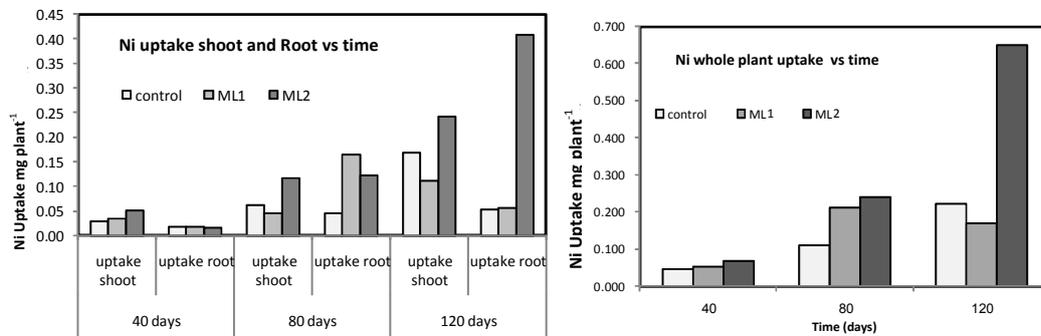
(Table 5); RSD values were lower than 5% in all treatments and under different plant types. Figs 8-10 show that the predicted  $pM_{\text{uptake}}$  results were generally in reasonable agreement with the measured values Gray and McLaren (2006) used some basic soil properties (pH, total carbon and total metal content) to predict metal solubility in a wide range of soils.

However, the model could be improved by including other different soil characteristics. Soil pH had a significant effect on prediction of metal uptake as seen from the correlation results.

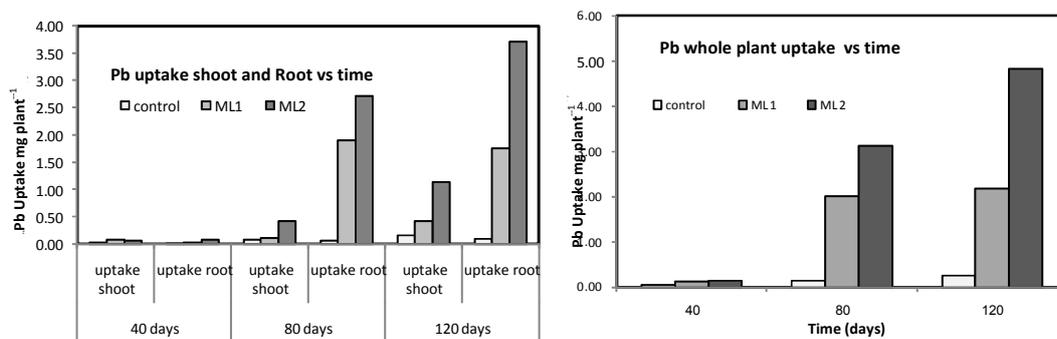
Although soil pH is important in governing strength of adsorption (Gabler *et al.*, 2007), which may influence metal bio-availability, the significance of soil pH ( $P < 0.001$  in all cases) in the empirical model may also illustrate the effectiveness of soil pH in controlling metal uptake.



**Fig. (5): Cadmium taken up (mg plant<sup>-1</sup>) by paper reed roots and shoots and whole plant during the term of experimental periods.**



**Fig. (6): Nickel taken up (mg plant<sup>-1</sup>) by paper reed plant roots and shoots and whole plant during the term of experimental periods.**



**Fig. (7): Lead taken up (mg plant<sup>-1</sup>) by paper reed plant roots and shoots and whole plant during the term of experimental periods.**

**Table (3): Analysis of variance (ANOVA) performed for Cd, Ni and Pb uptake as a function of different metal concentrations and plant parts.**

	Cd uptake		Ni uptake		Pb Uptake	
	F-ratio	P-value	F-ratio	P-value	F-ratio	P-value
<b>Paper reed Uptake after 40 days</b>						
concentrations	0.30	0.74	0.48	0.63	2.90	0.09
Plant parts	38.32	<0.001	5.50	0.04	0.22	0.65
Interaction	0.17	0.84	0.65	0.54	1.05	0.38
<b>Paper reed uptake after 80 days</b>						
Plant Type	11.35	<0.001	1.99	0.18	3.13	0.08
Plant parts	35.94	<0.001	1.68	0.22	7.57	<b>0.02</b>
Interaction	10.80	<0.001	2.22	0.15	2.03	0.17
<b>Paper reed Uptake after 120 days</b>						
Plant Type	5.35	0.02	1.82	0.20	1.85	0.20
Plant parts	10.48	0.01	0.00	0.99	1.71	0.22
Interaction	3.21	0.08	0.59	0.57	0.61	0.56

\*, Bold figures represent significant values

However, pe values had no significant effect ( $P > 0.05$ ) under different studied treatments.

It is possible that such multiple regression models used to predict metal uptake by plant could be improved by including more variables such as the cation exchange capacity (CEC), soil organic matter or free ion concentration in the soil solution phase.

## ACKNOWLEDGEMENT

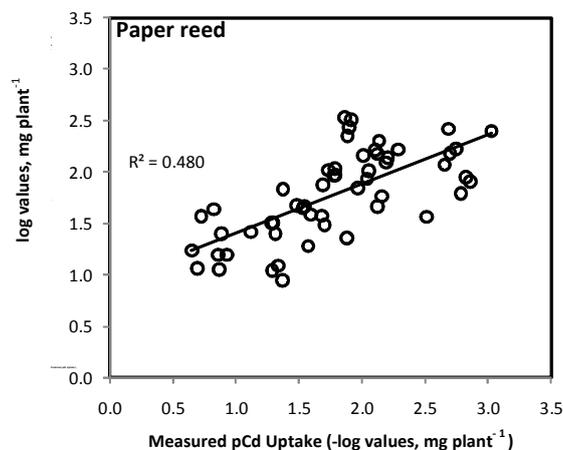
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**Table (4): Percentage of total metals found in plant tissues that were transported into the shoots of common reed under different metal concentration treatments and over different growing periods.**

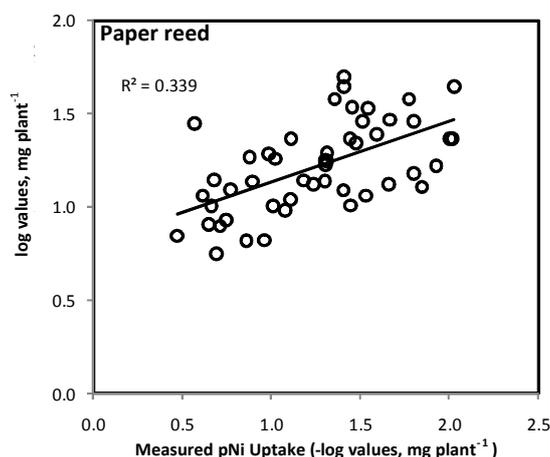
days	Cd			Ni			Pb		
	40	80	120	40	80	120	40	80	120
Control	50.9	49.7	51.6	60.0	54.1	69.9	44.2	54.2	60.2
ML1	53.9	82.3	26.4	60.4	20.5	29.5	45.6	11.9	30.0
ML2	<b>70.7</b>	42.9	28.1	65.1	16.0	15.8	64.5	3.15	33.7

**Table (5): Linear regression coefficients (a, b and c), RSD and R<sup>2</sup> values of individual equations for prediction heavy metal uptake model ( $pM_{\text{uptake}}$ ); P-values are in brackets.**

Parameter	Heavy metal		
	Cd	Ni	Pb
a (intercept)	-3.07 (0.29)	-3.26 (0.58)	-6.37 (0.005)
b (pH)	<b>1.01</b> ( <b>&lt;0.001</b> )	<b>0.71</b> ( <b>&lt;0.001</b> )	<b>1.21</b> ( <b>&lt;0.001</b> )
c (pe)	-0.60 (0.12)	-0.11 (0.90)	-0.30 (0.82)
RSD	0.45	0.41	0.37
R <sup>2</sup>	0.48	0.34	0.39



**Fig. (8): Predicting Cd uptake by paper reed plant ( $pM_{\text{uptake}}$ ) from pH and pe values (equation 2); solid lines represent fit liner.**



**Fig. (9): Predicting Ni uptake by paper reed plant ( $pM_{\text{uptake}}$ ) from pH and pe values (equation 2); solid lines represent fit liner.**

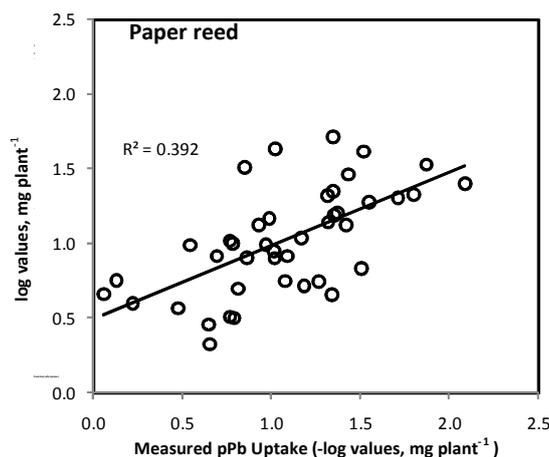


Fig (10): Predicting Ni uptake by paper reed plant ( $pM_{\text{uptake}}$ ) from pH and pe values (equation 2); solid lines represent fit liner.

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## المُلخَص العَرَبِي

### تقييم إمكانية المعالجة النباتية باستخدام نبات البردي لإزالة عناصر النيكل والكاديوم والرصاص من المياه الملوثة بالعناصر الثقيلة

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تعتبر عملية المعالجة النباتية إحدى الطرق الفعالة ومنخفضة التكلفة لإزالة التلوث بالعناصر الثقيلة من التربة والمياه. استخدم نبات البردي كنبات دليل لإزالة العناصر السابقة من مياه مدعمة بتلك العناصر للوصول إلى ضعف وضعف التركيز المسموح به في مياه الري بينما استخدم ماء الصنبور كمعاملة مقارنه. نمت البردي في أصص احتوت على ٢٠ كجم تربة وأضيفت المياه المدعمة بتلك العناصر الثقيلة وتم الحفاظ على ارتفاع الماء عند ٥ سم أعلى سطح التربة وذلك خلال فترة التجربة التي استمرت ١٢٠ يوم وذلك بإضافة الماء المقطر تم قياس رقم pH وكذلك جهد الأكسدة والاختزال (Eh) مباشرة في الأصص لنظام تربة - ماء عند فترات صفر، ٤٠، ٨٠، ١٢٠ يوم من بداية الشتل للنبات في الأصص. أخذت عينات من النبات عند الفترات السابقة وتم تقدير العناصر الثلاثة الثقيلة المدروسة وهي الرصاص والكاديوم والنيكل في كل من المجموع الجذوري والمجموع الخضري.

وكانت أهم النتائج المتحصل عليها كما يلي:

- ١- أوضحت النتائج المتحصل عليها تراكم العناصر الثقيلة الثلاثة بالمجموع الجذوري لنبات البردي أكثر من المجموع الخضري.
- ٢- أن العامل المهم في امتصاص العناصر الثلاثة بواسطة النبات كان رقم pH نظام (تربة - ماء).
- ٣- أوضحت النتائج باستخدام معامل الانحدار أنه يمكن تفسير عملية امتصاص وتراكم العناصر الثقيلة المدروسة بواسطة النبات باستخدام pH و Pe لنظام (تربة - ماء).
- ٤- أظهرت النتائج أن حوالي ٤٧%، ٣٤%، ٣٩% من معدل امتصاص النبات للعناصر الثلاثة يمكن تفسيره عن طريق قياس رقمي pH و Pe النظام (تربة - ماء).

**الكلمات الاسترشادية:** العناصر الثقيلة، المعالجة النباتية، نبات البردي، المياه الملوثة، قياس رقم pH.

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