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RESEARCH ARTICLE

PHYTOEXTRACTION OF CD, CU, PB AND ZN BY THE PLANT SPECIES *DATURA INNOXIA*

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ABSTRACT

Background and Objectives: Nowadays, pollution problems have become very crucial. Anthropogenic activities are the main sources of pollution with high concentrations of Metallic Traces Elements (MTEs), that pollute the ecosystem and cause health issues. This work aims to contribute to the establishment of biological techniques, the phytoremediation by *Datura innoxia* for that purpose two soils polluted by the MTEs has been considered. **Methods:** The soils were taken from Komabangou area polluted by gold panning activities. They are distributed in pots and seeds of *Datura innoxia* were introduced. The plants are watered daily with tap water. **Results:** After one month of culture, *Datura innoxia* showed a good development similar to the one of the control grown in unpolluted soil. The lengths of the entire *Datura innoxia* plant were 65 cm in the control soil versus to 63 cm in the polluted soil. The lengths of the aerial and underground part of *Datura innoxia* were respectively 49 and 16 cm in the control soil versus 48 and 15 cm in the polluted soil. These results therefore show that *Datura innoxia* has a good tolerance to the toxicity of MTEs present in polluted soil. The phytoremediation of MTEs by *Datura innoxia* has shown that in low polluted soil, *Datura innoxia* reduced by 110.96%, 0.025% and 51.26% respectively an initial Zn concentration of 66.8 mg / kg, a Pb of 61.31 mg / kg and a Cu of 33.61%. In highly polluted soil, *Datura innoxia* reduced by 10.63%, 120%, 34.67% and 44.27% respectively an initial Pb concentration of 125 mg / kg, Cd of 0.58 mg / kg, Cu of 208.48 mg / kg and in Zn of 139.83 mg / kg. **Conclusion:** *Datura innoxia* is an excellent candidate for the phytoremediation of Pb, Cd, Cu and Zn.

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INTRODUCTION

For a longtime, soil has been defined as an inexhaustible resource. Today, this heritage is threatened both by the heavy legacy of the past and by the extension of areas devoted to industrial development (Lecomte, 1998).

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Due to the urbanization, cities are growing rapidly in the world in general and in Africa in particular. According to United Nations forecasts, in 2030, 70% of the world's population would live in cities in developing countries, (UNFPA, 2008). With a population of 1.011.277 inhabitants (INS, 2008), the city of Niamey has a vast natural agricultural potential formed by the Niger Valley. With this increase in anthropogenic pressure on the environment, contamination problem has become a critical issue. Indeed, it has consequences for human health and the environment.

Their presence in soils considerably modifies the floristic composition of the sites, allowing the installation of only a limited number of species supporting their toxicity (Antonovics, 1971; Gartiside, 1974). Defined by (Adriano, 2001) as being any metal with a high density greater than 5g / cm3, the Traces Metallic elements are toxic at high concentrations for most plants (McIntyre, 2003; Gardea-Torresdey *et al*., 2005). Their accumulation in the soil generates yield losses. In terms of health, the MTEs absorbed by plants enter the food chain and prove to be dangerous because they cause damage (Gonzales *et al*., 2008; McLean *et al*., 2009; De Burbure, 2006). The soil-plant transfer of MTEs is one of the major ways of exposure and contamination of humans via the food chain (Cui, 2003; Den, 2008). Site rehabilitation is therefore essential, especially in the case of soil deterioration caused by the presence of MTEs. These can have potentially toxic effects on humans and their environment. Specialist in environment haveset-up several methods to address these problems caused by MTEs. There comes, physico-chemical methods and biological methods or bioremediation. The treatment of soils polluted by physicochemical methods is very long and very expensive. This is why many authors are working on the use of biological methods. The ability of some plants species to extract pollutants has been shown. These new methods are inexpensive and more ecofriendly (Raskin *et al*., 1994; Salt, 1997). Phytoremediation, which uses, among other things, the extraction capacity of MTEs by higher plants has shown encouraging results. This research aims to contribute to a better understanding of this method and to bring new encouraging results. The aim is to test the capacity of the plant species *Datura innoxia* in order to know its extraction potential in the depollution of soils contaminated with Pb, Cu, Cd and Zn, considered among the pollutants of the ecosystems and cited as toxic for Man and his environment (Senou, 2014).

MATERIALS AND METHODS

Research area: The soils studied are from the Komabangou gold zone at latitude 14°05'07.3" North and longitude 1°03'25.4" East. Indeed, it is known to be one of the largest and oldest of all gold panning sites in western Niger. The village is located in the region of Tillaberi, 150 km from Niamey capital of Niger.

Soil sampling: Three soils of sandy texture were used (soils not polluted by the MTEs and polluted by the MTEs).

It is: -An unpolluted control soil that is removed from any source of pollution (waste, roads, gold panning activities). This soil was used to compare the development of *Datura innoxia*;
-A moderately polluted soil lying next to roads leading to the Komabangou area used to view the MTEs extraction capacity by *Datura innoxia*;
-A heavily polluted soil from a cyanidation zone of the Komabangou gold zone that generates a large number of metal pollutants that have also been used to see the clearance capacity of *Datura innoxia*.

Soil preparation and dosage of MTEs: The soils were taken between 0 and 10 cm from the ground with a shovel and transported in bags to the soil science laboratory of the Faculty of Agronomy of Abdou Moumouni University of Niamey. Sandy texture, after drying at room temperature (<30 ° C), they are crushed and sieved at the fraction of 2 mm. The samples are then sent to the Geology Laboratory of the Faculty of Sciences of the University of Lomé in Togo for the determination of Pb, Cu, Cd and Zn by atomic absorption. They were also homogenized and 1.5 kg were weighed and placed in each pot. The pots used for experiments are plastic pots. The pots have a diameter at the top of 20 cm and a diameter at the base of 18 cm with a depth of 13 cm.

Plant species

Choice: The plant species used in this study is *Datura innoxia* belonging to the family Solanaceae. It was chosen becauseof its tolerance to metal pollution (Abdou gado *et al*., 2016). This choice is justified by the fact that these species are cited by the literature but also because they are locally known and used by the populations. They can therefore be easily adopted by the populations. Also, they are easy to reproduce and have multiple local uses.

Presentation: Known as vernacular prickly apple, leaf or devil's herb, *Datura innoxia* belongs to the family of Solanaceae. It is native to the tropics of North America, Central America and South America. It has been naturalized in all continents and temperate and warm regions. Occasionally, this species is grown as an outdoor ornamental for its beautiful flowers (Cheeke *et al*., 1985). In Niger, it is known as "SobiLobi".

Morphological characteristics: Datura are short-lived annual or perennial herbaceous plants, up to 2 m tall and often highly branched; slightly hairy stem. The whole plant is covered with trichomes that can be glandular and sticky or non-glandular. The leaves are whole or sinuate, petiolate and the flowers are erect (Nicole *et al*., 1998). The fruit is a capsule, 5 to 10 cm in diameter, covered with tapered spines and trichomes. It contains up to 500 brown seeds (Nicole *et al*., 1998).

Ecological characteristics: *Datura innoxia* grows in vacant lots, along roadsides and adapts well to clay and sandy soils (20). It is cultivated as an ornamental plant because of the richness of its colors and its forms and as an industrial plant for the extraction of tropanic alkaloids (Geeta, 2007).

Use: *Datura innoxia* is used dosewise, in traditional medicine, in religious rituals or for recreational drunkenness (Schmelzer, 2008; Khare, 2003; Daniel, 1993; Christina, 2007).

Experimental apparatus: The experimental setup is a completely randomized Fischer block. Soils are distributed at a rate of 1.5 kg. The seeds of *Datura innoxia* are introduced into pots that are irrigated daily with tap water. The length of the aerial part is measured each week using a graduated ruler. The one of the roots and stems was made at the end of the cultivation and after separation of the different vegetative parts.

Dosage of MTEs in the plant: After one month of culture, the plants are removed from the pots. They are carefully washed with tap water and then with distilled water and all precautions (contact between the different parts of the plant and the substrate) are taken to avoid possible contamination. The different plant parts (roots, stems and leaves) were separated and washed with distilled water. They are dried at room temperature and then in the 60 ° oven for 24 hours for complete dehydration.

The dry matter produced by the plant species is crushed and well-conditioned. The crushed parts of each part are sent to the Geology Laboratory of the Faculty of Sciences of the University of Lomé in Togo to determine the concentrations in the plant in Pb, Cd, Cu and Zn by atomic absorption.

Calculation of treatment efficiency: From the concentrations of metals in the soil before and after phytoremediation, the treatment efficiency (TE) can be calculated for plant specy according to the following formula:

$$TE (\%) = [(Ci - Cf) / Ci] \times 100$$

Ci (Initial Concentration) and Cf (Final Concentration) represent, respectively, the metal concentrations (in mg / kg) in the soil in the initial state before phytoremediation and in the soil in the final state after phytoremediation.

RESULTS AND DISCUSSION

Concentration in MTEs in soils: The results of the analyzes of the concentrations of MTEs in the three soil types (control, little polluted and highly polluted) in comparison with certain regulatory standards are summarized in Table 1.These results show that the Pb, Cd, Cu and Zn concentrations in the control soil do not exceed the French and Baize standards. In the low polluted soil, the concentrations of Pb (61.309 mg / kg) and Cu (33.615 mg / kg) exceed the Baize standards (1993-2005) which are respectively 54 and 28 mg / kg for Pb and Cu. However, Cd and Zn concentrations are below Baize standards. The concentrations of Pb, Cd, Cu and Zn in the low polluted soil do not exceed the standards of the French laws of 1998.

The concentrations of Pb and Cu in highly polluted soil exceed the standards of the French laws of 1998. But, the concentrations in Cd and Zn are below the French laws. Nevertheless, concentrations of Pb (125,056 mg / kg), Cd (0.5817 mg / kg), Cu (208.4805 mg / kg) and Zn (139.8387 mg / kg) in highly polluted soil exceed the Baize standards. (1993-2005) which are respectively 54, 0.5, 28 and 88 mg / kg for Pb, Cd, Cu and Zn. The concentrations of Pb and Cu in highly polluted soil are both superior to the 1998 French standards and the Baize standards (1993-2005). According to this author, high concentrations of metals in soils represent a risk to the population. Indeed, the presence of these contaminants in the soil poses problems of toxicity when these pollutants migrate and are found in the food chain or come into contact with humans via their diet (Krishna, 2007). They contaminate soils and groundwater that will later affect human health (Gigliotti *et al*., 1996). Several studies have shown the possible transfer of these MTEs from the soil through the roots of plants in the food chain (Cui, 2009). This soil-plant transfer of MTEs is one of the major way of exposure and contamination of humans via the food chain (Den *et al*., 2008; Kirpichtchikova *et al*., 2009). It is therefore necessary or even mandatory to clean up contaminated soils in order to preserve humans and their environment, particularly through the phytoremediation technique.

Phytoremediation of polluted soils

Extraction capacity of MTEs by *Datura innoxia:* To evaluate the effect of phytoremediation of polluted soils in MTEs by *Datura innoxia*, the approach consisted in determining the difference of the concentrations of MTEs in soils (little and very polluted) before and after phytoremediation. This made it possible to calculate the extraction rate of the ETMs by each plant species. This made it possible to calculate the MTEs extraction rate by *Datura innoxia*. The results (Table 2) of the concentrations of MTEs extracted by *Datura innoxia* show a more or less significant lowering of the concentrations of MTEs. These results are in line with those obtained by (Rock, 2003) who found a decrease of the initial concentration by three plants cultivated during fourteen (Raskin, 1994) months on a soil polluted by metallurgical activities. The results showing the amounts of MTEs extracted by *Datura innoxia* are summarized in Table 2. Table 2 shows the concentrations in soils after phytoremediation by *Datura innoxia* and the levels taken by this plant. Extraction of Zn (41%) is the most important by *Datura innoxia* in highly polluted soil. (Kirpichtchikova *et al*., 2009) found that Willow will extract more Zn than Pb and Cu. Zn is followed by Cd, Cu and Pb. The Zn element therefore appears as the most phytovailable. The effectiveness of the treatment in the highly polluted soil by *Datura innoxia* is 41% for Zn; 16.24% for Cu; 35.27% for Cd and 6.34% for Pb. On the other hand, the levels taken by *Datura innoxia* in the low polluted soil increase. However, it is still the Zn content (232.71%) that is highest.

Concentrations in MTEs in different parts of *Datura innoxia:* Concentrations of MTEs in the roots, stems and leaves of *Datura innoxia* grown on low and heavily polluted soils are reported in Table 3. In low polluted soil, the Pb, Cd, Cu and Zn concentrations are respectively 0.7038; 0.0001; 29.3589 and 27.84 mg / kg in the roots of *Datura innoxia*. These concentrations show that *Datura innoxia* roots have been able to accumulate MTEs. This absorption of MTEs by the roots is by simple diffusion through the apoplast of the root cortex and the endoderm (Briat, 1999). However, the root uptake mechanism of some metals such as Cu is not yet known (Greger, 2004; Chaignon, 2001). The Pb concentration (0.7038 mg / kg) in the *Datura innoxia* roots is lower than that found by Esteban *et al*. (2006) in the roots of *Achillea millefolium, Chondrilla Juncea, Elytrigiacampestris* and *Hieraciumpilosella* respectively 4.8: 3.1; 5.8 and 9.2 mg / kg. The concentration of Cu (29.3598 mg / kg) in the roots of *Datura innoxia* is lower than that found by (34) in the roots of *Chondrilla Juncea* in which they detected a Cu concentration of 30.1 mg / kg.

In the *Achillea millefolium, Elytrigiacampestris* and *Hieraciumpilosella* roots, respectively, they detected 6.4; 11 and 14.3 mg / kg Cu concentration. These concentrations are much lower than those recorded in the *Datura innoxia* roots. With regard to Zn, the concentrations recorded in the roots of *Datura innoxia* on the lightly polluted soil (27.84 mg / kg) are higher than those recorded in the roots of *Achillea millefolium* (9.8 mg / kg) and *Hieraciumpiloselle* (24.6 mg / kg) (Esteban, 2006). On the other hand, these authors recorded much higher concentrations in the roots of *Chondrillajuncea* and *Elytrigiacampestris* respectively 76.4 mg / kg and 44.9 mg / kg. In the stems of *Datura innoxia*, the MTEs concentrations are respectively 0.4569; 0.0860; 8.2102 and 66.62 mg / kg for Pb, Cd, Cu and Zn. On the other hand, in the *Datura innoxia* leaves, the concentrations of MTEs are respectively 2.0057; 0.0686; 13.9221 and 62.33 mg / kg for Pb, Cd, Cu and Zn. The transport of these MTEs from the stems to the aerial parts requires the management of these ETMs by complexing agents

Table 1: Concentrations of MTEs in soils before phytoremediation and their regulatory limit values (mg / kg)

	Control soil	Lesspolutesoil	Polutesoil	French standards (1998)	Baize (1993-2005)
Pb	0.7155	61.309	125.056	100	54
Cd	0.00015	0.0005	0.5817	2	0.5
Cu	12.89	33.615	208.4805	100	28
Zn	18.222	66.7030	139.8387	300	88

Table 2: Concentrations in mg / kg in the low and highly polluted soils extracted by *Datura innoxia* as well as the levels taken by the specy

	Concentrations (mg/kg) in MTEs extract by *Datura innoxia*		Teneurs (%) in MTEs extract by *Datura innoxia*	
	Less soil polute	Polutesoil	Lesssoilpolute	Polutesoil
Pb	3.1664	7.9345	5.16	6.34
Cd	0.1546	0.2052	nd	35.27
Cu	35.8598	33.8727	106.68	16.24
Zn	155.23	57.3413	232.71	41

Table 3. Concentrations of Pb, Cd, Cu and Zn in the different parts of *Datura innoxia* grown on the soil with little pollution and very polluted

Concentrations in MTEs (mg/kg)						
	Little pollution			Very pollutedsoil		
Roots	Rods	Leaves	Roots	Rods		Leaves
Pb	0.7038	0.4569	2.0057	5.8261	<0.01	2.1084
Cd	0.0001	0.0860	0.0686	<0.0005	0.0633	0.1419
Cu	29.3589	8.2102	13.9221	5.6797	9.9461	18.2469
Zn	27.84	66.62	62.33	4.8913	25.1278	27.3222

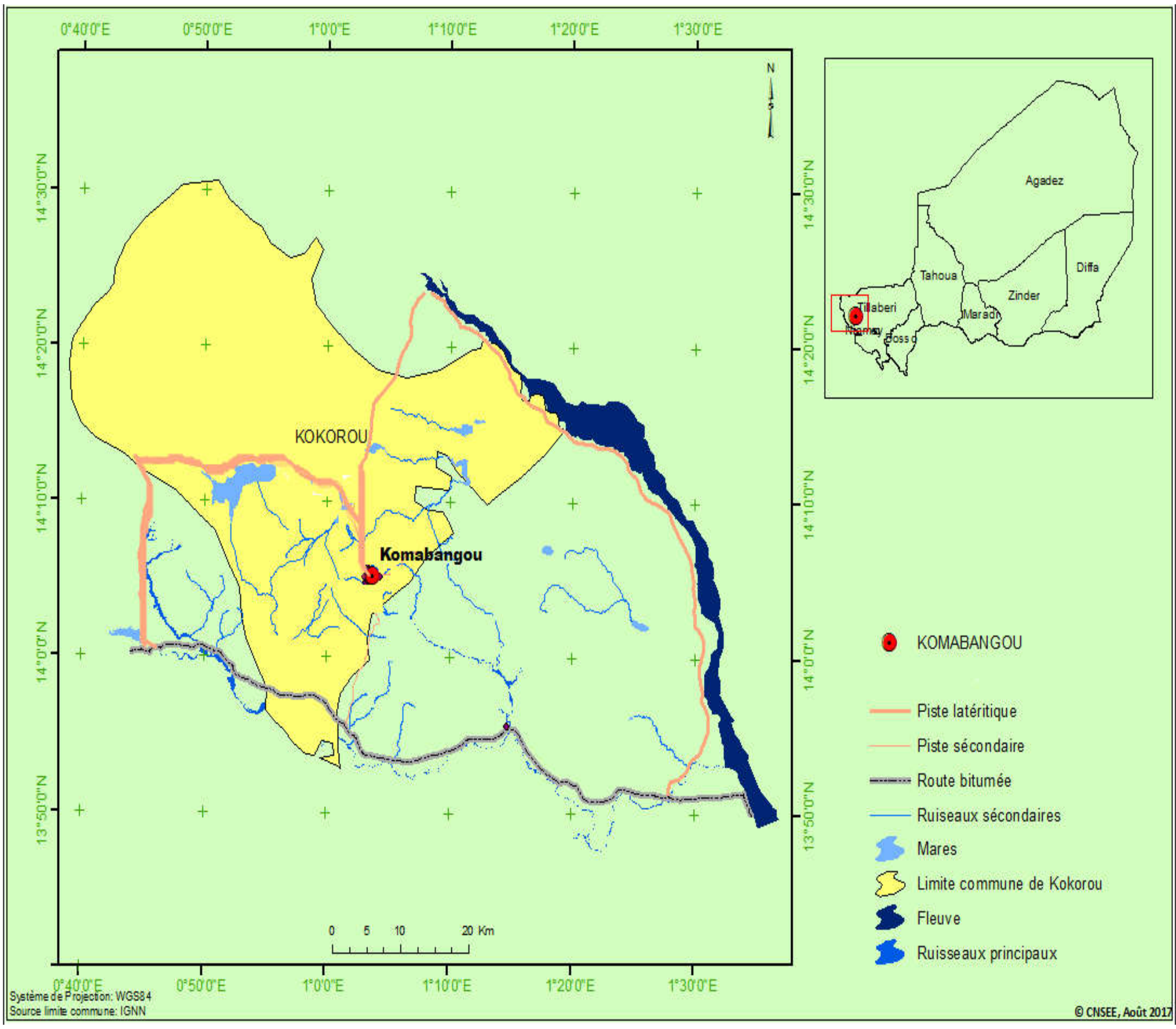

Figure 1:Location of the study area.

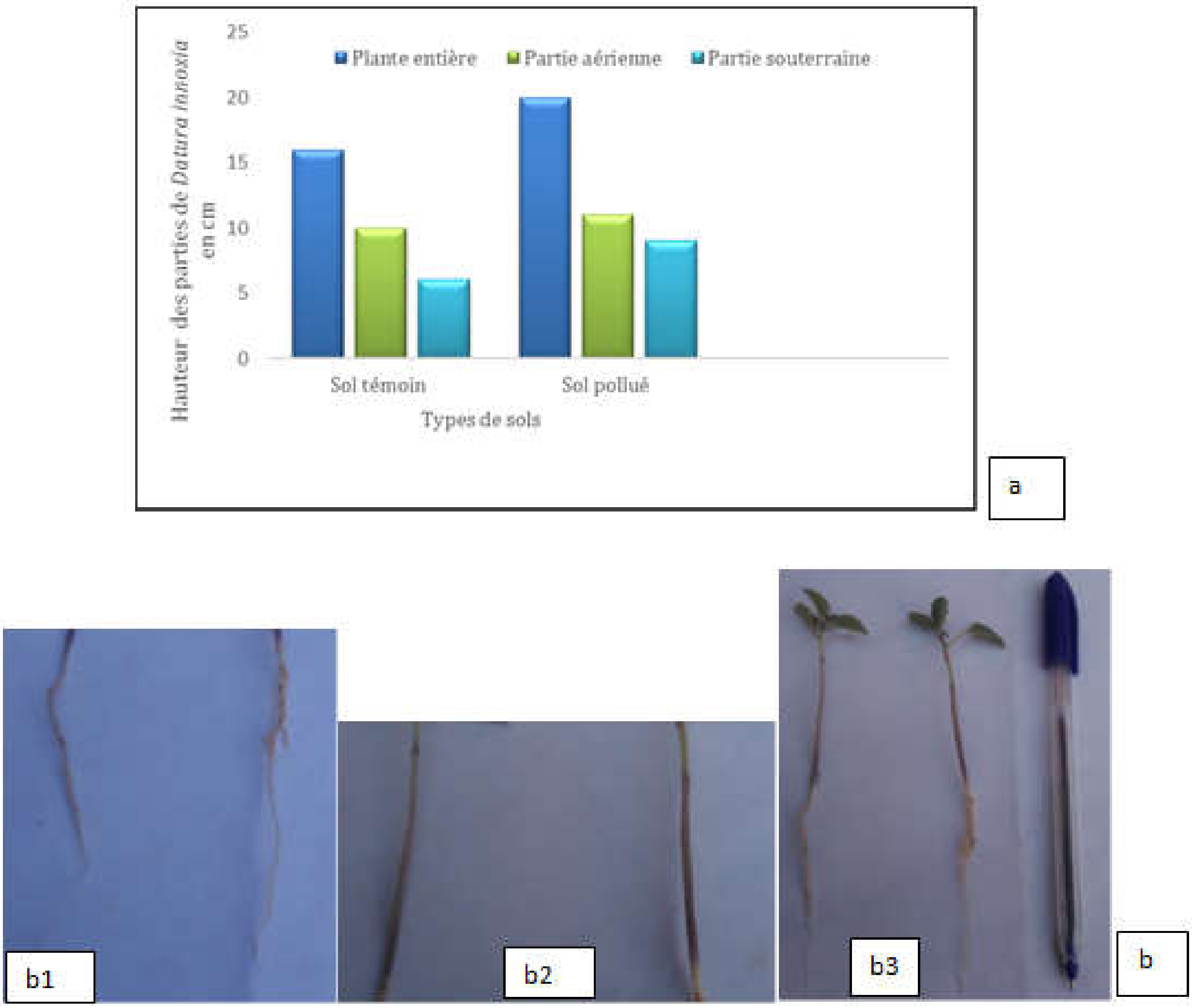

Figure 3. a. Height of *Datura innoxia* on control soil and polluted soil and b. morphology in control soil and polluted soil: b1. the roots (control, polluted), b2. leaves (control, polluted) and b3. the whole plant (witness, polluted).

such as organic acids (Esteban, 2004). For example, Cu accumulation by *Datura innoxia* leaves is by a polyamino-polycarboxylic acid (Foy *et al*., 1978), whereas Cd passes into the leaves in a free form (32) and Zn by an anionic complex (Alloway, 1995). All these mechanisms therefore participate in the accumulation of Pb, Cd, Cu and Zn by the roots, stems and leaves of *Datura innoxia*. In highly polluted soil, the roots, stems and leaves of *Datura innoxia* accumulated Pb concentrations respectively 5.8261; <0.01 and 2.1084 mg / kg. For Cd, these same parts accumulated respectively <0.0005; 0.0633 and 0.1419 mg / kg. As for Cu, they accumulated respectively 5.6797; 9.9461 and 18.2464 mg / kg. For Zn, the roots accumulated 4.8916 mg / kg; stems 25.1278 mg / kg and leaves 27.3222 mg / kg. These results show that the Cd, Cu and Zn MTEs follow this accumulation gradient: roots, stems and leaves. In other words, their concentrations increase from roots to leaves. This shows that these MTEs are more accumulated by the leaves except for Pb, for which the concentration is higher in the roots than in the leaves. This difference could be explained by the fact that the complexing agents that come into play to allow the passage of Pb from the roots to the leaves are non-existent or in low numbers (Greger, 2004). While for the other MTEs, the presence of these agents would facilitate their passage of absorbent hairs to the leaves through the xylem of the stems.

In the *Melilotusalbus* leaves (Esteban, 2006) from the Lay region, a site contaminated by metallurgical activities, a concentration of 1.19 mg / kg Pb was determined. This concentration is lower than than the one in Pb that we measured in the leaves of *Datura innoxia*. The same authors found a concentration of 0.22 mg / kg Cd in the leaves of *Artemisia campestris* grown on a site polluted by metallurgical activities. This concentration is higher than the one in Cd that we measured in the leaves of *Datura innoxia*. The concentration of Cu, 18.2464 mg / kg, that we measured in *Datura innoxia* leaves was significantly higher than the one measured in the leaves of *Clematis vitalba* (6.50 mg / kg) from the contaminated site of Dor (Esteban, 2006). For Zn, we found in the leaves of *Datura innoxia* a concentration of 27.3222 mg / kg versus 15.89 in *Geranium pyrenaicum* leaves from the site of Dor contaminated by landfills.

Plant development in soils under study: Figure 3 shows that roots development of *Datura innoxia* in the polluted soil is greater than the one in the control soil. Indeed, the length of the roots in polluted soil is 9 cm versus 6 cm in the control soil. This difference between the *Datura innoxia* root development in the control soil and the polluted soil indicates that this plant has very interesting capacities in the sense that it could have a good extraction of the MTEs in its root parts, so a very good (high) phytoextraction. This difference,also resides in a greater root development in the polluted soilwould imply a better phytoextraction because the plant increases its ability to explore larger volumes of soil. Which, probably, would allow greater uptake of MTEs by the roots. The length of the aerial part of *Datura innoxia* in the polluted soil (11 cm) is similar to the one in control soil (10 cm). On the other hand, a significant difference is noted in the length of the whole plant in the control soil which is only 16 cm versus 20 cm in the polluted soil. However, this development of the entire *Datura innoxia* plant is law compared to the one of *Cymbopogon citratus* which is 55 cm in polluted soil after 3 months of culture (Senou, 2014). However, given that it shows better growth, this result shows that *Datura innoxia* has adapted well to pollution and may even use the soil MTEs for its development, as some hyperaccumulative plants extract the metals and use them for their growth. This confirms its ability to tolerate pollution by MTEs and phytoextraction too.

Conclusion

The phytoremediation test carried out with *Datura innoxia* showed that the plant tolerates pollution because it has developed well in both polluted soil and in the control soil. The *Datura innoxia* plants used in this phytoremediation study accumulated MTEs in their roots, stems and leaves. The extraction depends on the metal and its concentration. These results show that *Datura innoxia* is a good species that could decontaminate a soil polluted by several metals. Indeed, at the end of this study, we propose *Datura innoxia* for the decontamination of soils contaminated with Cd and Zn which are very toxic metals. The Zn can be recovered (in only 4 weeks) from the vegetative parts of these plants and be used for other purposes such as its use as a trace element at very low levels. For the extraction of Pb, we also recommend*Datura innoxia*. To summerise, *Datura innoxia* is a plant species that adapts to all types of soils and all types of stress.

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