Evaluation of the Bioavailability of Heavy Metals by Saline, EDTA and HCL Solutions in Agricultural Soil

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Abstract: - The objectives of this study is to determine the bioavailability of eight heavy metals (Cu, Cd, Pb, Mn, Co, Ni, Cr and Fe) by the different extractants (complexing agent EDTA and saline solutions: NH_4OAC, $NaNO_3$, $CaCl_2$ and NH_4NO_3, acid HCl) in an agricultural soil on the one hand and on the other hand in the different organs of a food plant (durum wheat) of the city of Hammam Boughrara-Algeria and this in order to evaluate the rate of contamination of these heavy metals.

It turned out that the part extracted is not very representative of the fraction actually bioavailable in agricultural soil and in the food plant, durum wheat.

As for the cultivated plant, the study indicates a potential ecological risk of durum wheat contaminated particularly by chromium, to a lesser extent by cadmium, lead and copper thus causing potential health risks, on the other hand manganese presents deficiencies in the soil and in the aerial parts.

All the results obtained constitute a first step towards understanding the effects affecting the soils irrigated by wastewater, the waters of the Tafna River and the Hammam Boughrara dam.

The first advantage of such an approach is that it provides a present state of the soil studied in the perimeter of Hammam Boughrara which can then be useful for monitoring the situation over the long term.

Key-Words: - durum wheat, extraction, aqua regia, heavy metals, EDTA

1 Introduction

Soil pollution by heavy metals is considered to be a long-term threat to the environment [1].

Contamination of an environment by heavy metals means an increase in the total levels of these elements in the environment following significant anthropogenic inputs. According to Akujobi (2012) [2], heavy metals constitute serious environmental pollutants, in particular in areas of high anthropogenic pressure; their presence in air, soil and water, even in trace amounts, can cause serious problems for all organisms. The accumulation of heavy metals in soils is a concern in agricultural production because of their detrimental effects on crop growth, food quality and environmental health (Augusto Costa AC, 2001) [3].

The behavior of heavy metals in soils depends on several factors that affect their dynamics, namely pH, cation exchange capacity, clay content, organic matter, hence their solubilization and availability for plants [4, 5].

According to Baize (1997) [6], the problem of contaminated soils is of great concern today for emerging countries. Heavy metals such as lead, cadmium, copper, zinc, and mercury cannot be biodegraded and therefore persist in the environment for long periods of time. In addition, they are continually added to the soil by various activities: in agriculture through the application of sewage sludge or in the metallurgical industry (Wang et al., 2003) [7].

The main risks associated with this type of contamination are the reduction or even the loss of ecosystem services linked to the soil (production of biomass, degradation of organic matter, water filtration), but they also constitute a significant potential danger for public health because some of them, such as Cd or Pb, are toxic at very low concentrations (Bliefert & Perraud, 2011) [8].

The sites affected by high concentrations are generally very large, with volumes too large for an excavation (Deneux-Mustin et al., 2003) [9].

Thus we propose in this present work on the one hand the extraction of heavy metals this by atomic absorption spectrometry (AAS) in an agricultural soil and in the different organs (the stems, the leaves, the grains and the roots) of a food plant durum wheat during the different seasons of the year

2020 in the city of Hammam Boughrara, in order to determine the bioavailability of these heavy metals in this soil and on the other hand to evaluate the contamination in this soil This agricultural soil is irrigated by water loaded with heavy metals, from the Hammam Boughrara dam, the Tafna River, sewage waste water and atmospheric emissions from the roads of the city of Hammam Boughrara located 50km from the city of Tlemcen -Algeria.

2 Materials and Methods

2.1 Soil and Plant Samples
Soil Samples: The ground surface has been collected in triplicate from the horizon-cultivated soils (0 to 30 cm) at two sampling stations located in Hammam-Boughrara, Tlemcen (Algeria) and distant at 100m from each other. The samples were air-dried, crushed, passed through 2mm sieve and stored at ambient temperature. Afterwards, the soil properties and the concentrations of the heavy metals have been examined [10].

Vegetable sample: Plant sample (durum wheat) has been also picked up in triplicate from the same field simultaneously. Replicate samples were washed using clean water and then separately oven dried at 80°C till constant weight was achieved.

The samples were then crushed separately through a steel grinder and the crushed material was passed through 2mm seive [10].

2.2 Chemical Characterization of the Soils
Three replicates of cach sample have been analysed. The pH was measured in water (1:2,5 w/v) using a pH meter (Allison, 1986) (HM-50V, Toadkk, Tokyo, Japan) [11].

The organic carbon has been determined using the Allison (1986) method, cation exchange capacity by cobaltihexamine chloride the Orsini and Remy's method (1976) [12]. The total concentration of $CaCO_3$ was measured in an acidic medium using a Bernard calcimeter (Allison and al, 1986) [11].

2.3 Selective Chemical Extracts

2.3.1 Simple Extraction with EDTA at pH = 7
The extraction of the soluble forms of Cu, Cd, Pb, Mn, Co, Ni, Cr and Fe carried out with a mixed solution of ammonium acetate and EDTA, at pH = 7 in a report: test portion on solution equal to 1/10 (m / v). This method leads to an estimate of the quantity of heavy metals likely to be assimilated by plants. It is mainly applied to agricultural soils.

Operating mode
Weigh 1g of dry soil to the nearest 0.01g and pour it into a 125mL flask.

Add 10mL of the EDTA extraction solution at 20 ° C ± 2 ° C. Stopper tightly without delay and shake vigorously so as to disperse the soil.

Stir immediately for 2 hours at 20 ° C ± 2 ° C.

Filter immediately (prolonged contact can continue extraction).

Collect the filtrate in a 125 ml conical flask and stopper immediately.

Leave to settle and then centrifuge the supernatant for 10 minutes at 2000 rpm, so as to have a translucent liquid free from all impurities, pour the liquid into a 125mL conical flask and stopper immediately.

After adjusting the atomic absorption spectrophotometer, pass successively the standard solutions and the test solution.

After each measurement, rinse with the extraction solution [13].

2.3.2 Extraction of Heavy Metals by Saline Solutions and by HCl Acid
The main points of the extraction protocols with unbuffered saline solutions are given in Table 1, prepared after [14].

The principle is the same for the four reactants $CaCl_2$ at 0.01 mol.l-1, NaNO3 at 0.1mol.l-1, NH4OAC at 1 mol.l-1 and NH_4NO_3 at 1 mol.l-1. The air-dried earth sample is stirred for two hours in the salt solution at a ratio of 1/10 or 1 / 2.5 (M / V). The suspension is then centrifuged and filtered.

Table 1. Procedure for the extraction of heavy metals by saline solutions ($CaCl_2$, $NaNO_3$, NH_4NO_3, NH_4OAC) and by acid HCl.

Reactant	$CaCl_2$ 0,01 mol.l^{-1}	$NaNO_3$ 0,1mol.l^{-1}	NH_4NO_3 1 mol.l^{-1}	NH_4OAC à 1 mol.l^{-1}	HCl 0,1 mol.l^{-1}
Test sample	5 g	20 g	20 g	20 g	1 g
Solution volume	50 ml	50 ml	50 ml	50 ml	5 ml
Agitation	20°C±2°C, 120min±5mi, turnaround at 30 rpm^{-1}	20°C±2°C, 120min±5min, turnaround at 30 rpm^{-1}	20°C±2°C, 120min±5min, turnaround at 30 rpm^{-1}	20°C±2°C, 120min±5min, turnaround at 30 rpm^{-1}	20°C±2°C, 120min±5min, turnaround at 30 rpm^{-1}
Centrifugation	15 min à 1000 g	15 min à 1000 g	15 min à 1000 g	15 min à 1000 g	1 h
Filtration	0,22 µm	0,22 µm	0,22 µm	0,22 µm	0,22 µm
Acidification	0,5 ml HCl	0,5 ml HNO3	0,5 ml HNO3	0,5 ml HNO3	0,5 ml H2O

2.4 Metal Extraction of Plants

Durum wheat sample weighing approximately 10 g were carbonized on an electrothermal plate and ashed at 500°C in a furnace for 3 h. A 0,1 g of ash was digested with 2 mL of a mixture of concentrated HCl (37,5%) and HNO3 (65%) in 3:1 ratio at 80°C until a transparent solution was obtained (Allen and al, 1986) [15] . The solution was filtered through Whatman No. 42 filter paper and diluted to 50 mL with distilled water to estimate the amount of metals absorbed from the soil.

3 Results

3.1 Chemical Characterization

All the results of the physico-chemical parameters of the soils are listed in Table 2.

Table 2. Summarizes the results of the different physico-chemical parameters of soils.

Parameters / Soil		Residual humidity (%)	pH eau	CEC (meq/100g)	Total calcareous	Matter Organic (%)	Total carbon
S1	Winter	19.55	8.10	11,48	38.56	3.79	2.19
	Spring	11.78	8,77	12,78	38.87	3.64	2.10
	Summer	10.88	8,84	13,94	38.44	3.44	1.98

3.2 Extraction of Heavy Metals by Saline Solutions, EDTA and by Hydrochloric Acid

All the results obtained from the analysis of the heavy metal contents are given in tables (3-5) and shown as histograms in figures (1-3).

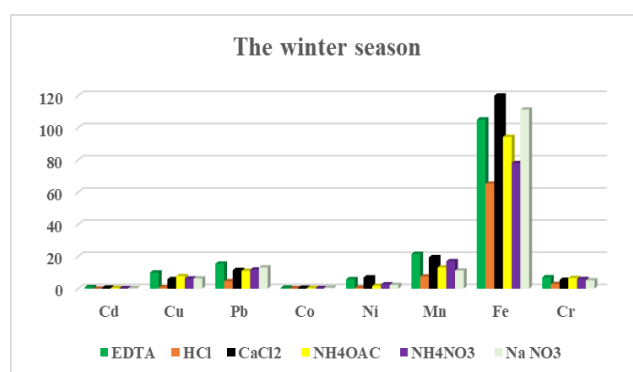Table 3. The heavy metal contents (mg/kg of MS) extracted by the saline solutions, HCl and EDTA in the winter season of the year 2020 of the soil S1.

Extractants / ETM	Cd	Cu	Pb	Co	Ni	Mn	Fe	Cr
EDTA	0.80	9.83	13.95	0.50	4.28	20.71	80.50	6.73
HCl	00	0.73	4.54	0.18	0.51	7	45.61	2.75
CaCl₂	0.63	5.74	10.73	0.45	4.87	17.28	96.77	5.50
NH₄OAC	0.45	7.62	10.47	0.38	1.45	12.71	80.85	6.12
NH₄NO₃	0.32	6	11.23	0.33	1.95	15	48.56	5.61
Na NO₃	0.30	6.23	12.74	0.61	1.90	10.83	91	4.80

Table 4. The heavy metal contents (mg / kg of MS) extracted by saline solutions, HCl and EDTA in the spring season 2020 of soil S1.

Extractants / ETM	Cd	Cu	Pb	Co	Ni	Mn	Fe	Cr
EDTA	0.75	9.94	14.56	0.55	4.94	20.79	101.22	6.85
HCl	00	0.76	4.58	0.23	0.56	7	59.42	2.78
CaCl₂	0.60	5.79	10.93	0.48	5.91	18.70	111.32	5.27
NH₄OAC	0.41	7.68	10.61	0.40	1.57	13.10	91.43	6.46
NH₄NO₃	0.29	6.45	11.50	0.35	2.50	15.32	75	5.78
Na NO₃	0.25	6.27	12.85	0.64	2	11.50	108.12	5

Table 5. The contents of heavy metals (mg / kg of MS) extracted by saline solutions, HCl and EDTA in the summer season of the year 2020 of the soil S1.

Extractants / ETM	Cd	Cu	Pb	Co	Ni	Mn	Fe	Cr
EDTA	0.85	10	15.50	0.55	5.82	21.56	105.11	7
HCl	00	0.81	4.63	0.25	0.61	7.55	65.22	2.83
CaCl₂	0.61	5.85	11.52	0.53	6.95	19.49	120	5.44
NH₄OAC	0.42	7.74	11	0.45	1.70	13.16	94.34	6.55
NH₄NO₃	0.31	6.25	11.81	0.39	2.64	17	78	5.95
Na NO₃	0.28	6.33	13.20	0.67	2.27	11.24	111.33	5.15

Fig. 1: The heavy metal contents (mg/kg of MS) extracted by the saline solutions, HCl and EDTA in the winter season of the year 2020 of the soil S1.
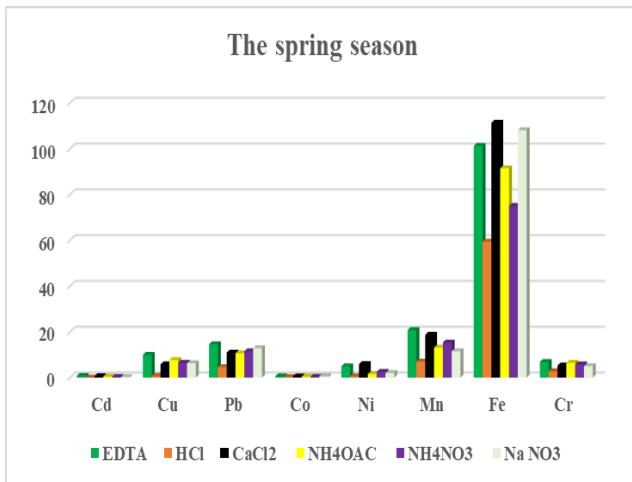
Fig. 2: The heavy metal contents (mg / kg of MS) extracted by saline solutions, HCl and EDTA in the spring season 2010 of soil S1.
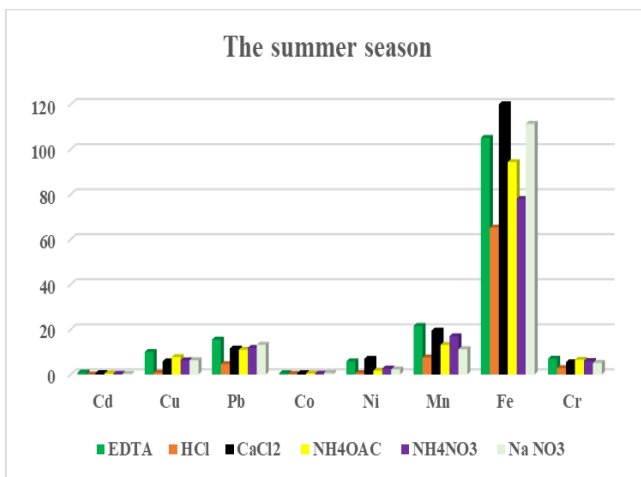

Fig. 3: The contents of heavy metals (mg / kg of MS) extracted by saline solutions, HCl and EDTA in the summer season of the year 2010 of the soil S1.

An extraction of heavy metals by aqua regia at the roots and aerial parts was carried out. This assay was carried out on these samples of plants taken. The results of these extractions are listed in Tables (6-9) and shown as histograms in Figures (4-7).

Table 6. The levels of heavy metals (mg / kg of MS) in the roots of durum wheat during the different seasons of the year 2020 (extracted by aqua regia).

Seasons /ETM	Cd	Cu	Fe	Pb	Mn	Ni	Co	Cr
Winter	2.88	21.75	2595.93	40.19	74,83	11.13	2.27	22.57
Spring	2.70	19.12	2522.18	58.22	55.79	20.44	3.89	34.58
Summer	2.41	18.36	2418.33	48.99	48.76	26.39	1.43	47.90

Table 7. The heavy metal contents (mg / kg MS) in durum wheat stalks (extracted by aqua regia) during different seasons of the year 2020.

Seasons /ETM	Cd	Cu	Fe	Pb	Mn	Ni	Co	Cr
Winter	6.80	16.77	369.33	38.54	62.43	20.32	4.31	16.43
Spring	4.11	15,11	100.28	30,77	36.68	14.50	2.22	11.92
Summer	4.34	13.72	110.86	36.62	42.32	14,97	2.86	12.57

Table 8. The levels of heavy metals (mg / kg of MS) in the leaves of durum wheat (extracted by aqua regia) during the different years of 2020.

Seasons /ETM	Cd	Cu	Fe	Pb	Mn	Ni	Co	Cr
Winter	0,98	12	127.90	5.50	17.44	10.90	5.68	8.90
Spring	1.48	19.75	225	5.64	24.33	9.88	4.87	8,98
Summer	1.63	17.93	269.44	5.82	31.44	16.25	4.75	8.55

Table 9. The levels of heavy metals (mg / kg of MS) in the seeds of durum wheat (extracted by aqua regia) during the different seasons of the year 2020.

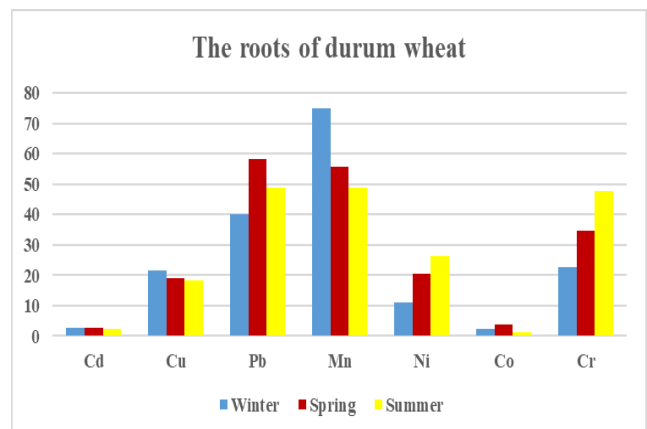| Seasons /ETM	Cd	Cu	Fe	Pb	Mn	Ni	Co	Cr
Spring	4.88	63.75	89.90	27.11	29.77	10.77	6.21	6.74
Summer	5.23	82.69	98.78	29.67	41.39	13.40	4,23	7.23

Fig. 4: The heavy metal contents (mg / kg of MS) in the roots of durum wheat during the different seasons of the year 2020 (extracted by aqua regia).
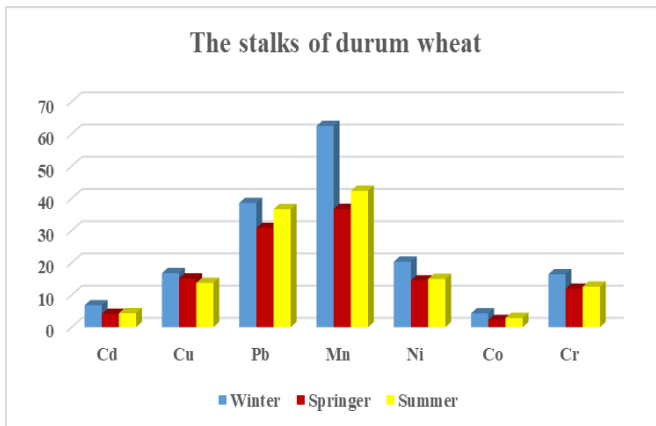
Fig. 5: The heavy metal contents (mg / kg MS) in durum wheat stalks (extracted by aqua regia) during different seasons of the year 2020.
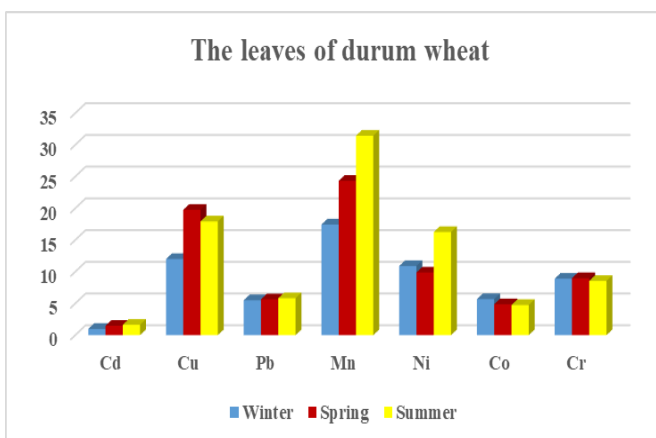

Fig. 6: The levels of heavy metals (mg / kg of MS) in the leaves of durum wheat (extracted by aqua regia) during the different years of 2020.
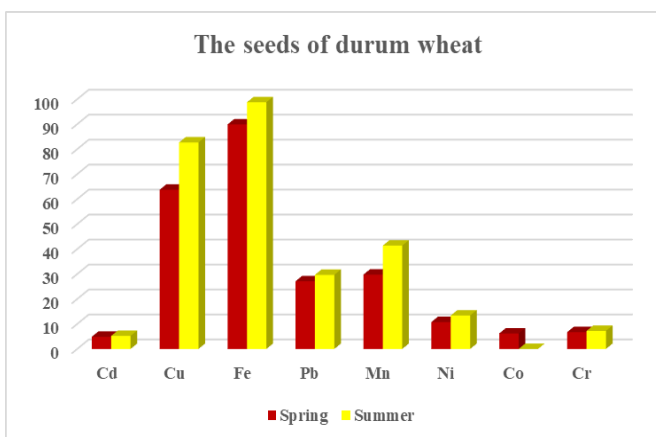

Fig. 7: The levels of heavy metals (mg / kg of MS) in the seeds of durum wheat (extracted by aqua regia) during the different seasons of the year 2020.

4 Discussion

4.1 Chemical Characterization

The pH-water measured for the two soils shows an alkaline character. This coincides with the high carbonate content in these soils. There are no significant changes in pH over time. Changes in pH could in particular result from biological activity and increased CO_2 content.

The values of the cation exchange capacity are quite low compared to the average values announced by [16]: 60 meq / 100g for a mineral soil and 200 meq / 100g for an organic soil. These values vary little over time, however, there is an increase in the cation exchange capacity with increasing pH.

The higher the CEC, the more the metal cations (Cd, Cu, Pb, Co, Ni, Cr, Mn) are adsorbed or complexed by organic matter and oxides, and therefore less assimilable by plants.

The levels of total limestone recorded in the two soils are significant, they are limestone soils. Among other things, limestone blocks certain elements essential to plants such as iron and various trace elements (in particular manganese, copper), it then causes deficiencies (which manifest for example chlorosis in plants) [17].

Both soils are not rich in organic matter. It is also noted that a slight increase in pH leads to a decrease in the rate of organic matter, at the same time leading to an increase in the CEC of the soils.

4.2 Extraction of Heavy Metals with Saline Solutions (NH₄OAC, NaNO₃, CaCl₂ and NH₄NO₃, the Complex (EDTA) and acid (dilute HCl).

The highest levels are recorded during the summer season. By comparing the results obtained by the different extractants HCl, EDTA, NH₄OAC, NaNO₃, CaCl₂ and NH₄NO₃, we can deduce that:
• HCl hardly extracts the heavy metals studied.
• Cd is best extracted by EDTA and CaCl₂, then by NH₄OAC.
• Cu is better extracted by EDTA then NH₄OAC.
• Pb is better extracted by EDTA then NaNO₃.
• Co is better extracted by NaNO₃ then EDTA.
• Ni is better extracted by CaCl2 then EDTA.
• Mn is better extracted with EDTA then CaCl₂, then NH₄NO₃.
• Cr is better extracted by EDTA then NH4OAC.
• Fe is better extracted by CaCl₂ then NaNO₃

So, the ranking scale of the best extractant in descending order is as follows:
EDTA> CaCl₂> NaNO₃> NH₄OAC> NH₄NO₃> HCl
Numerous studies confirm the effectiveness of ETDTA for the extraction of cationic species such as lead, zinc, copper and cadmium, present in contaminated soils [18].

In the soil, the values of the contents of the eight heavy metals given by the various extractants HCl, EDTA, NH_4OAC, $NaNO_3$, $CaCl_2$ and NH_4NO_3 are relatively low compared to the total contents obtained by the aqua regia extraction.

However, according to these results, it can be seen that Cd, Pb and Cr are the most bioavailable elements followed by Ni then by Co.

On the other hand, Cu has very low bioavailability as does Mn.

Thus, we can classify these elements in the order of decreasing bioavailability:

• For soil: Pb > Cd > Cr > Ni > Co > Cu.

In the light of these results, we can deduce that saline solutions seem exclusively reserved for monitoring polluted soils and most often for monitoring acidic or neutral soils. On the other hand, the small quantities extracted would prevent this method from being applied to soils where the origin of trace elements is geochemical. In addition, the main criticism leveled against the use of saline solutions concerns various analytical problems that they cause.

The choice of an extraction method can be based on two criteria: on the one hand the scope of the field of application of the method (number of trace elements, nature of the soils and plants) and on the other apart from the analytical limits of its use. For example, Pb is bound to carbonates in dry Mediterranean regions with carbonate-rich soils, while it is more bound to iron and aluminum oxides in regions with wetter soils.

It turned out that the extracted part is not very representative of the fraction actually bioavailable in the soil.

Thus EDTA is the extractant which best extracts heavy metals. In general, it is a chelating agent with a maximum extraction capacity of metals present in the phases not bound to silica, including metals complexed with organic ligands, but it does not make it possible to estimate phytoavailability.

4.3 Metal Content in the Plant

- Variation in heavy metal content in the roots of durum wheat

Cd, Cu, Fe, Pb and Mn contents are higher in winter than in spring and summer, while Ni, Co and Cr contents are higher in spring.

Whether in the aerial part or in the roots, iron has the highest levels.

They are higher in the roots than those detected in the aerial part.

On the other hand, Ni and Pb present slightly higher contents in the roots than in the aerial part, respectively in winter and in spring.

Manganese is concentrated more in the aerial parts than in the roots. In addition, manganese levels are below normal plant thresholds. So we notice manganese deficiencies in the roots.

According to the contents, metals can be classified in decreasing order of absorption:

Fe >> Mn > Pb > Cr > Cu > Ni > Co > Cd.

Examination of all these results makes it possible to distinguish the following facts:

The different values obtained in Cd, Pb, Cr are within the range of critical heavy metal contents in plants [19].

Thus the increasing order of accumulation is as follows: Cd < Ni < Pb < Cr < Fe.

- Variation in heavy metal content in the stems and leaves of durum wheat

a. Cadmium and Lead

The Cd and Pb contents are 4 to 7 times higher in the stems than in the leaves, thus the Cd and Pb contents slightly exceed the plant toxicity threshold in the stems and greatly exceed the threshold of normal plants [20] in the leaves.

A strong accumulation of cadmium and lead is observed in the stems to a lesser extent in the leaves.

b. Copper

The copper contents are almost similar in the leaves and in the stems, with spring and summer contents in the leaves slightly higher, these contents are within the norms of the plants. Thus, durum wheat does not accumulate copper in the stems and leaves.

c. Chromium

The chromium contents are 1 to 2 times higher in the stems of durum wheat than in the leaves.

The values found greatly exceed the plant toxicity threshold. There is a significant accumulation of chromium in the stems and leaves.

d. Nickel

However, the nickel contents are higher in the stems than in the leaves and these contents slightly exceed the minimum toxicity threshold for plants. Thus, durum wheat accumulates nickel in the leaves and stems.

e. Cobalt

On the other hand, the cobalt levels exceed the normal threshold for plants. these contents are within the standards.

f. The major elements

• Manganese

However, the manganese contents are higher in the stems than in the leaves.

These levels are within the plant deficiency threshold. Manganese deficiencies are observed in stems and leaves.

The iron
The iron contents are higher in the leaves than in the stems and are within the standards.
- Grains
The contents of Cd, Cu, Pb, Ni, Cr, Mn and Fe in the grains are higher in summer than in the spring season, with the exception of the cobalt contents, they are more concentrated in the spring than in the season of summer.

a. Cadmium
The cadmium levels greatly exceed the normal thresholds for plants in the spring season and slightly exceed the toxicity threshold for plants.
According to the results obtained, a significant accumulation of cadmium is observed in the grains of durum wheat.

b. Copper
Copper contents are four times higher in the grains than in the stems and leaves.
The copper levels in the grains exceed the minimum threshold of plant toxicity. Therefore, durum wheat strongly accumulate copper in the grains.

c. Nickel
Ni levels are slightly above the minimum toxicity threshold for plants. So, we notice an accumulation of nickel in the grains of durum wheat.

d. Lead
Lead levels are higher in the grains than in the leaves. these levels are above the minimum toxicity threshold for plants. Consequently, durum wheat accumulates lead quite strongly in the grains.

e. Chromium
The chromium contents in the grains are lower than those found in the stems.
These levels greatly exceed the toxicity threshold of plants. Deduces a strong accumulation of chromium in the grains.

f. Cobalt
The cobalt contents in the grains are similar to those found in the stems and leaves. These contents are within the standards.

g.The major elements
•The iron
Iron levels are much lower in the grains than those found in the stems and leaves. Moreover, these contents are within the standards.

•The manganese

The manganese levels in durum wheat grains are lower than those found in the stems and leaves, these levels are below the standards. As well as stems and leaves, there are manganese deficiencies in the grains.
According to the contents, we can classify the metals in decreasing order of absorption:
The roots: Fe > Mn > Pb > Cr > Ni > Cu > Cd ≥ Co.
The stalks: Fe>Mn>Pb >Ni > Cu ≥ Cr> Pb > Co> Cd.
The leaves: Fe> Mn> Cu > Ni > Cr > Pb > Co > Cd.
The grains :: Fe > Cu> Mn > Pb> Ni > Cr > Co> Cd.
Like the roots, there is a seasonal effect on the contents of Cd, Cu, Pb, Ni, Co, Cr, Mn and Fe. Our results show that durum wheat is extremely tolerant of chromium, copper, cadmium and lead, particularly in the grains, and to a lesser extent of nickel.
Consequently lead, chromium and then cadmium accumulate quite strongly in the aerial parts and roots of durum wheat and to a lesser extent nickel and copper.
Iron and cobalt are therefore within the standards. On the other hand, there are manganese deficiencies in the roots and aerial parts.

5 Conclusion
In conclusion, there is no universal chemical extraction method that allows simultaneous evaluation and without analytical difficulties of the absorption of any trace element by any plant grown on any type of soil.
However, the extraction with the solution of calcium chloride aims to quantify the mobile fraction, that is to say the fraction of elements bioavailable and easily leachable with water.
This extraction best represents the intrinsic conditions of the equilibrium soil solution in terms of ionic strength. It is often used to establish soil-plant correlations and thus define the bioavailable fraction of pollution.
EDTA extraction aims to measure the mobilizable fraction, comprising both the mobile part of the pollution but also a potentially active part.
This fraction can thus be considered to some extent as the maximum extractable fraction from the soil. This is because EDTA is a chelating agent with maximum extraction capacity for metals present in phases unrelated to silica, including metals complexed with organic ligands.
The choice of pH 7.5 constitutes a compromise between the maximum solubility of many anions in

acidic medium and the increase in optimal cation chelation in basic medium, which makes this type of extraction a procedure applicable as well. to species forming oxyanions (As, Cr, Mn,…) than to cations (Cd, Pb, Zn). The total content is therefore similar to the fraction of elements of the mobilizable soil added to the immobile fraction.

The quantities extracted by the solutions of chelating molecules are generally not or only slightly correlated with those extracted by cultivated plants. On the other hand, we can say that by considering the alkaline pH of these soils, it is possible that the metallic elements are naturally found in very little mobile forms and therefore less extractable by the selected extractants.

By comparing the results obtained between the roots and the aerial parts of our plants, we can notice that for durum wheat the Cr and Ni are well transferred into the roots, continue to migrate to the aerial parts and are therefore enriched in the aerial parts.

By comparing the results obtained between the roots and the aerial parts, it can be seen that chromium, copper, lead and nickel are indeed transferred to the roots and continue to migrate towards the aerial parts and are therefore enriched in the parts. aerial.

Moreover, the cadmium which is little transferred in the roots accumulates well in the aerial parts.

On the other hand, the iron is initially well absorbed by the roots, it remains blocked in the roots and it is little transferred in the stalks and the leaves.

There is thus a very marked "organ" effect.

However, some chemical elements show a similar behavior whether at the level of diffusion in plants or their migration in tissues. This similarity is called synergistic or antagonistic relationships. In our case, this similarity in behavior was observed for lead and chromium (are translocated in the different organs of the plant).

This result confirms that the type of plant is a determining factor in the transfer and accumulation of heavy metals and depends on the age of the plant and the time of exposure to wastewater.

All the results obtained constitute a first step towards understanding the effects affecting the soils irrigated by wastewater, the waters of the Tafna River and the Hammam Boughrara dam.

During this work, we studied a real case of the fate of heavy metals in agricultural soils and in a food plant (durum wheat).

6 Recommendations

The future prospects of our research are based on three axes to be further explored given the locations of heavy metals in the microstructures specific to a type of land use:

-Study other sites with slingers from different soils, other grain size fractions and test a statistical approach.

-Studies of the biological and microbiological compartments would make it possible to better define their influence on the mobility of heavy metals reasoned in terms of localization.

-Finally, a study and modeling of flows on plants and soils would make it possible to quantify and qualify the entry and exit of heavy metals from the systems as well as those transported in the soil solution. These data are essential when modeling the mobility and transfers of heavy metals in soils and lead to the prediction of environmental and health risks.

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