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Effect of Fertilizer Application on the Uptake of Heavy Metals by Corn Plant Grown In Different Soils

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ABSTRACT

Intensive farming systems are mainly associated by using enormous amounts of N. P and K fertilizers which unfortunately contain significant concentrations of heavy metals as impurities. Therefore, the objective of the present study was to evaluate the effect of fertilization on the mobility and uptake of Pb. Ni. Cr and Cd by corn plants.

Three types of soils (namely, Torrifluvents, Calciorthids and Torripssaments) were received the fertilizer treatments such as control, N, NP, and NPK in recommended rates for corn plant without and with external addition of heavy metals.

The addition of small amount of heavy metals in association with fertilizer treatment increased the dry matter of corn. However, increasing the amount of added Cd, Ni, Pb and Cr decreased the dry matter production of corn plant. The reduction in dry matter was associated with an increase in heavy metal concentrations in both shoots and roots of corn plant. The increase in heavy metal concentrations in roots were much higher than that in shoots. Therefore, the tolerance index and mobility index of heavy metals for corn plants were calculated and discussed.

Key words: Corn, intensive farming, NPK, heavy metals, soil, fertilization, mobility

Introduction

Chemical fertilizers have been widely used but it is difficult to achieve sustainable high-yielding peanut crops because the supply of macronutrients such as nitrogen (N), P, and K is often unbalanced and micronutrients can also be deficient. Soil fertility can deteriorate with the long-term use of NPK fertilizers, resulting in soil acidification, poor soil aggregate stability, and low levels of essential micronutrients. Although farmers typically prefer mineral fertilizers to organic amendments, the importance of using organic fertilizers to improve crop quality and restore soil fertility is recognized (Biau *et al*., 2012; Ghosh *et al*., 2012). Application of mineral and organic fertilizers can introduce potentially toxic heavy metals into the soil–plant system. Phosphate rock fertilizers often contain potentially toxic trace elements including copper (Cu), zinc (Zn), manganese (Mn), lead (Pb), and cadmium (Cd) (Zaccone *et al*., 2010).

Intensive farming systems deserve the use of enormous amounts of N, P and K fertilizers which unfortunately associated with significant amounts of some heavy metals as impurities. However, the chemical parameters of the soil such as pH, ion sorption sites, ionic strength, and ligands which may form sparing soluble precipitates affect the concentration of metals in soil solution (Mühlbachová *et al*., 2005; Zhao *et al*., 2010). The processes moderate the reaction of heavy metals such as precipitation dissolution, adsorption-desorption, complex and ion pair formation may influence the distribution of the metal species in the solid phase of the soil and the soil solution. Usman *et al*., (2008) found that the concentration and uptake of Cd was greater when the metal was applied to the soil as nitrate than when applied as the sulphate salt. Excessive N fertilizer supply and overdosing of soil with phosphate causes undesirable additions of Cd in P-fertilizers.

The results of some investigators indicated that there are beneficial effects of some heavy metals at their lower doses and toxicity at higher levels. Abnormal increase of the concentration of heavy metals in plant is often accompanied by a significant decrease in the activity of several plant enzymes and consequently the plant growth (Van Assche *et al*. 1985).

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Tnvalent chromium compounds are extremely insoluble and regarded as biologically insignificant. Whereas hexavalent compounds have a potential hazard, being toxic and cancirogenic (Taylor, 1983). The Cr content of plants has received much attention since discovery that Cr participates in glucose and cholesterol metabolism and therefore is essential to man and animals (Schroeder *et al*., 1962).

Mishra and Kar (1974) stated that low concentration of nickel improved the growth of several higher plants, but the reasons for its stimulating effects are not clear. Bazzoz *et al*. (1974) found that both photosynthesis and transpiration are inhibited by the presence of high lead levels in plants.

The objective of the present study was to evaluate the effect of fertilization on the mobility and uptake of Pb. Ni, Cr and Cd by corn plants.

Materials and Methods

Column experiment was performed using PVC columns of 15 cm -inner diameter and 70 cm length. Each column was divided into 4 sections corresponding to 0 - 5, 5 - 15, 15 - 30 and 30 - 60 cm after leaving the uppermost 10 cm of the column for irrigation. Three soil materials representing the most important types of Egyptian soils were collected from plough depth (0-30 cm). Some chemical properties of these soils are presented in Table (1).

Table 1: Some characteristics of the investigated soil materials.

Soil type		Alluvial	Calcareous	Sandy
Soil order		Torrifluvents	Calciorthids	Torripssamments
Texture		SCL	Clay	S.L.
pHs		7.56	7.73	8.10
EC (dS/m)		2.27	0.93	2.94
O.M. %		1.88	1.73	0.20
CaCO3 %		1.2	15.1	0.10
CEC (cmol/Kg)		35	38	12
Soluble ions (me/L)				
Na+		4.7	1.86	20.70
K+		0.86	0.42	0.57
Ca++		13.5	5.50	3.10
Mg++		1.50	2.10	6.51
HCO3-		2.12.	0.85	2.73
Cl-		9.50	4.36	19.31
SO4--		10.22	3.77	6.98
Ni	Total	115	62	25
(ppm)	DTPA	0.80	1.4	0.4
Pb	Total	33	18.7	6.2
(ppm)	DTPA	1.20	1.0	0.8
Cd	Total	1.08	1.80	1.00
(ppm)	DTPA	0.10	0.04	0.04
Cr	Total	64.0	32.0	16.0
(ppm)	DTPA	0.30	0.20	0.30

Columns were packed with soil material which ranged from 12 to 15 Kg according to the bulk density of each soil type and divided into two groups. One group (4 columns) received 0, N, NP and NPK fertilization treatments in rates correspondent to the highest fertilization rate that applied to corn in sandy soils (i.e. 450, 450 and 170 Kg/Acre of superphosphate, ammonium sulphate and potassium sulphate, respectively). The second group (4 columns) received the same fertilization treatments with supplemental amounts of heavy metals. The amount of applied heavy metals to each treatment was added in the form of chlorides and sulphates in different levels, that normally existed in NPK fertilizer as presented in Table (2).

Five com seeds were sown in each column and covered with 2 cm layer of the soil material. The seedling were thinned to three plants at 10 days after sowing for the bioassay. Columns were maintained at 70 % of field capacity throughout the experiments with distilled water. Columns were harvested 3 times at plant ages of 30, 45 and 60 days after sowing. At the end of the experiment, the plant roots were extracted from the soil. Harvested shoots and roots were washed, dried at 70 °C and weighed. Pb, Ni, Cr and Cd were determined in soil extracts and plant materials digestions using flamless atomic absorption.

Table 2: Supplemental heavy metals addition to the fertilizer treatments (mg/Kg).

Treatment	Cd	Ni	Pb	Cr
Control	0	0	0	0
N-fertilizer	0.05	0.86	0	0
NP-fertilizer	0.54	3.42	2.60	6.33
NPK-fertilizer	0.59	3.89	2.70	7.00.

Results and Discussion

Dry weight of com plants

The mean dry weight of corn shoots in different treatments of corn at three plant ages (30; 45 and 60 days) were represented in Fig. (1). The data showed that the dry weight of shoots have depended upon soil type, fertilizers type and its combination and the amount of applied heavy metals. The dry weight of shoots was affected by soil type and decrease in the following order: clay soil > calcareous soil > sandy soil, at all fertilizer treatments with and without heavy metals (Fig. 1). The dry weight production of clay soil was 3.5 to 6.5 times more than that of sandy soil.

The dry weight of com shoots varied for the different fertilizers treatments; it increase in the following order: N < NP < NPK under all soil conditions, clay, calcareous and sandy (Fig. 1). It is noticed also that the application of small amount of heavy metals associated with nitrogen fertilizers stimulated the growth of corn plants at all studied ages of growth and under the conditions of the three soils. This is in agreement with the finding of Yousef, *et al*. (1993) and Mishra and Kar (1994). However, growth reductions were found when the higher amounts of heavy metals applied with NP and NPK fertilizers for the three soils at all plant ages (Fig. 1). The synergetic effect was postulated to some degree to the presence of heavy metals in soil which may influenced the uptake of other elements (Allinson and Dzielo, 1981 and Yousef, *et al*., 1993). The percentages of increments or reductions of shoot dry matter relative to the control of each fertilizer treatments, as a result of the application of heavy metals are listed in Table (3). The presented data showed the effect of high amount of heavy metals on the reduction of dry weight of corn plant was greater in sandy than in clay and calcareous soils. This could be rendered to the very low buffering capacity of the sandy soil which help in the direct deleterious effect on plant growth.

According to Camerlynck and Velghe (1979), the criteria for evaluation the effect of heavy metals on plant growth are provided by the following index which is considered as "Tolerance Index" (T):

$$T = \frac{Dry\ weight\ in\ enriched\ soil}{Dry\ weight\ in\ normal\ soil}$$

where : T has a value of 1, the element had no effect:
T > 1 when the effect was favorable :
T < 1 when the effect was unfavorable.

Data in Table (4) show the tolerance index of corn plant grown on different soils and fertilizer treatments at three plant ages. Data indicate that there is a favorable effect for small amounts of heavy metals with nitrogen fertilizer treatments. On the other hand, there is unfavorable effect for the relatively high amounts of heavy metals with NP and NPK fertilizer treatments.

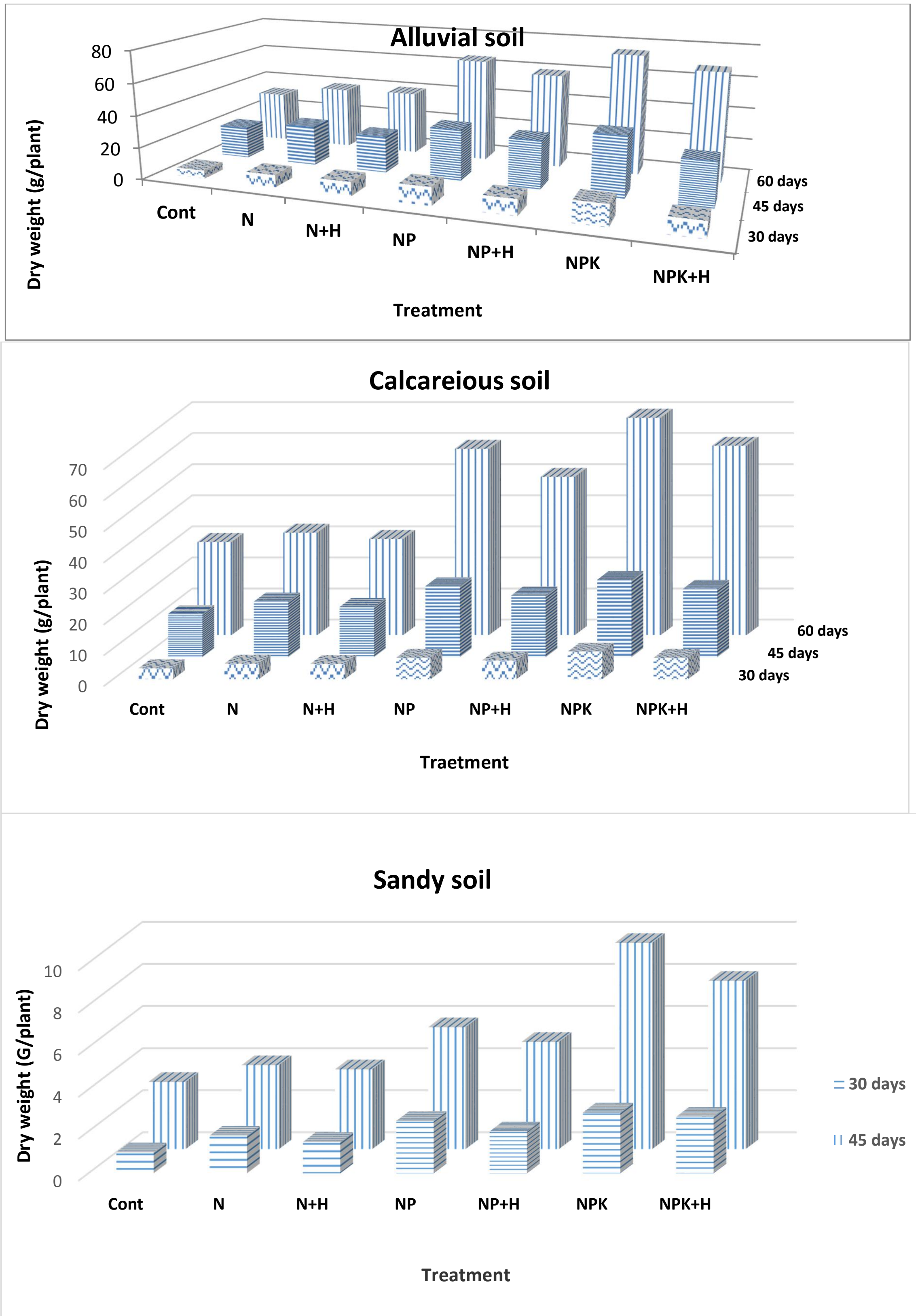

Fig. 1: Dry weight of corn plants as affected by fertilization and heavy metals application in different soils

Table 3: Relative changes of dry matter of corn shoots upon the addition of heavy metals as a percent of control for each fertilizer treatment.

	Clay			Calcareous			Sandy	
Fertilizer treatments	Period per days							
	30	45	60	30	45	60	30	45
N+H.M	2.7	6.0	5.5	6.6	3.8	4.0	8.5	6.0
NP+H.M	- 9.3	-7.1	-11.3	-25.7	-12.4	-12.8 -	-16.0 -	- 26.0 -
NPK+H.M	-14.3	-20.9	- 7.2	-27.2	-26.5	10.1	28.0	32.1

H. M. = Heavy metals
*negative value correspondent to reduction

Table 4: Tolerance index of corn plants in different soils and fertilizer treatments with heavy metals.

	Clay			Calcareous			Sandy	
Fertilizer treatments			Period	per	days			
	30	45	60	30	45	60	30	45
N+H.M	1.03	1.06	1.05	1.06	1.04	1.04	1.08	1.07
NP+H.M	0.91	0.93	0.89	0.74	0.88	0.87	0.84	0.74
NPK+H.M	0.86	0.79	0.93	0.73	0.73	0.89	0.72	0.68

H. M. = Heavy metals

Concentrations of heavy metals in shoot tissues of corn plants:

Depression of corn dry matter are often accompanied by a concomitant increase in the concentration of heavy metals in the plant tissues. However, the degree of dry weight depression and final metal concentrations in plant tissues both vary considerably depending on soil type, amount of heavy metals associated with fertilizers, type of fertilizers in the mixture and plant age. The data in Table (5) showed the consistent reduction in heavy metal concentrations with increasing plant age in all the studied treatments and soils. This reduction in concentrations of heavy metals with increment of plant aging may be due to the differences between rate of absorption of heavy metals and the rate of growth, which is well known as 'dilution effect". However this has a significant merit when the shoots is used as animal fodder. It is, thus, preferable to cut the plant after 60 days rather than at 30 days, for animal feeding. Therefore, the concentration of heavy metals in corn plant decrease with age. In addition, the concentration of heavy metals in corn were enhanced with increasing the amounts of applied Pb. Ni, Cd and Cr. These results are in harmony with the results obtained by Taylor and Allinson (1981), Allinson and Dzielo (1981) and Khan and Frankland (1983).

Concentration of heavy metals in root tissues:

The presence of heavy metals in the soil influenced their concentrations in root tissues. Data in Table (6) showed that in the presence of additive heavy metals in the soil, the NP and NPK fertilization significantly increased their concentrations in the roots of corn. The relative increase percent was 65-88% for Pb, 137-240% for Ni, 83-140% for Cr and 85-194% for Cd.

Therefore, it could be noticed that the highest increase in concentration in root tissue was accounted for Ni followed by Cd. This may draw the attention to avoid the cultivation of tuber crops in the soils polluted with Ni and Cd. It was found in the present study that the concentrations of Pb, Ni, Cd or Cr in roots followed the same manner of those in shoots, but their levels were higher in roots than their corresponding in shoot and in root varied from one metal to another and from one soil to the another. The relative changes of a heavy metal concentration in roots compared to shoots could be taken to Judge the mobility of such element inside the plant. So, a "mobility index" (MI) may be calculated as follows: Mobility index (MI)= Coc. of heavy metal in shoots at 60 days/Conc. of the same metal in roots

Table 5: Concentration of heavy metals (ug/g) in corn shoots at different under fertilizer and heavy metals application treatments in different.

Treatments		Alluvial				Calcareous				Sandy			
	Days	Pb	Ni	Cr	Cd	Pb	Ni	Cr	Cd	Pb	Ni	Cr	Cd
Control	30	17.0	10.5	6.6	1.2	11.1	10.0	6.6	1.3	20.2	14.0	6.6	1.4
	45	7.0	5.1	5.3	1.0	8.8	6.1	6.1	1.0	9.2	6.3	4.1	1.3
	60	7.0	1.4	4.1	0.5	8.3	1.3	5.4	0.4	-	-	-	-
N	30	17.6	10.0	8.0	1.3	12.0	9.3	6.6	1.3	21.0	13.2	10.6	1.5
	45	8.8	5.1	6.1	1.0	10.1	7.1	6.0	1.0	9.5	6.6	4.1	0.9
	60	6.3	1.5 i	4.0	0.6	8.5	1.7	5.0	0.6	-	-	-	-
N + H	30	17.5	14.2	9.3	1.4	13.1	17.2	6.7	1.2	23.2	18.3	11.7	1.3
	45	8.8	6.3	6.0	1.1	11.0	8.3	5.9	1.2	13.0	10.7	4.0	1.5
	60	6.4	1.9	4.0	0.9	9.5	2.0	5.3	0.7	-	-	-	-
NP	30	18.2	13.0	8.0	1.2	16.2	12.1	10.2	1.4	23.0	14.5	11.6	1.4
	45	13.2	5.2	7.1	1.2	14.0	5.9	7.3	1.1	16.3	7.2	4.2	0.5
	60	8.8	1.8	2.7	0.7	9.9	2.0	4.1	0.7	-	-	-	-
NP + H	30	30.3	31.6	14.6	1.5	22.1	30.2	27.9	1.8	30.9	35.5	30.4	2.9
	45	22.1	8.4	11.9	1.4	20.3	9.5	11.9	1.6	30.9	13.3	10.2	2.0
	60	12.4	4.1	5.3	1.3	16.3	4.0	7.3	0.9	-	-	-	-
NPK	30	17.6	13.5	9.1	9.2	17.8	14.1	12.3	1.5	26.3	17.0	13.0	1.9
	45	17.6	4.1	7.5	1.2	15.4	5.3	8.1	1.2	18.0	7.0	4.4	1.3
	60	9.3	1.3	3.1	0.7	10.0	1.2	4.0	0.1	-	-	-	-
NPK + H	30	32.3	35.3	17.3	9.8	30.9	33.1	26.5	2.1	33.5	36.5	30.1	2.6
	45	22.1	7.1	11.9	1.5	25.0	9.0	20.2	1.8	33.3	12.1	13.3	2.0
	60	15.2	3.2	5.1	1.3	15.0	3.9	10.0	1.2		-	-	-

H= Heavy metals

Table 6: Concentration of heavy metals (ug/g) in corn roots under different fertilizer treatments with or without heavy metals and soil types.

Treatments	Clay soil				Calcareous soil			
	Pb	Ni	Cr	Cd	Pb	Ni	Cr	Cd
Control	9.1	8.0	5.0	1.3	8.8	5.0	5.3	1.1
N	8.9	8.0	5.2	1.4	8.0	4.2	4.0	1.2
N + H.M	10.3	7.9	6.5	1.9	7.1	9.2	5.6	1.3
NP	8.0	7.9	7.2	1.5	8.5	5.3	9.3	1.7
NP + H.M	13.2	18.7	17.3	4.3	16.0	18.0	18.1	5.0
NPK	9.2	6.2	8.2	2.0	8.0	6.1	9.3	1.8
NPK + H.M	16.1	16.6	14.6	3.2	14.4	17.1	20.0	4.0

Table (7) present the mobility index values for the studied heavy metals in the alluvial and calcareous soils under different fertilization and heavy metal treatments. It is found that the mobility index of heavy metals ranged from 0.62 to 1.34 for Pb, from 0.31 to 1.25 for Cr, from 0.14 to 0.54 for Cd and from 0.18 to 0.41 for Ni. Data generally indicated that the mobility of heavy metals was dependent upon metal type, fertilizers mixture and amount of the applied heavy metals. However, it is clear that Pb and Cr have greater mobility from root to shoot than Cd or Ni, and the mobility sequence from root to shoot could be in the following order:

Pb > Cr > Cd > Ni

The mobility index of heavy metals in plants treated with only fertilizers were higher than those for fertilizers mixed with heavy metals (Table 7). This means that the application of heavy metal with fertilizers have increased their concentration in shoots than that in roots. It was also found that the fertilizer treatment influenced the mobility index of the studied heavy metals in different manner (Table 7).

The mobility index for Pb increased in the following order for fertilizers mixture: N < NP < NPK. on the other hand, mobility index for Cd decreased in the following order for fertilizers mixture: N > NP > NPK.

Table 7: Mobility index of some heavy metals in corn plants for different treatments.

Treatments	Clay soil				Calcareous soil			
	Pb	Ni	Cr	Cd	Pb	Ni	Cr	Cd
Control	O78	0J8	0.82	0.38	0.94	0.26	1.02	0.36
N	0.71	0.19	0.77	0.43	1.06	0.40	1.25	0.50
N +H.M	0.62	0.24	0.62	0.47	1.34	0.22	0.95	0.54
NP	1.10	0.23	0.38	0.47	1.17	0.38	0.44	0.41
NP + H.M	0.94	0.22	0.31	0.30	1.02	0.22	0.40	0.18
NPK	1.01	0.21	0.39	0.35	1.25	0.20	0.43	0.06
NPK + H.M	0.94	0.19	0.35	0.41	1.04	0.23	0.50	0.30

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