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Uptake of metals in maize as affected by irrigation water quality and clay content of the soil

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INTRODUCTION. – Agricultural expansion depends largely on water availability. Water availability is a major limiting factor in most developing countries (SALEM *et al.,* 1990). In view of the scarcity of natural fresh water resources, municipal sewage water might be an important substitution for fresh water for irrigation purposes in arid and semi-arid countries. Heavy metals and organic matter are often the main contaminants.

The soil environment is an appropriate site for the treatment of many municipal and industrial waste waters (TAYLOR and NEAL, 1982). The oxygen demand found in industrial wastewater can be many times greater than that in municipal sewage water. The ability of a land treatment system to remove the oxygen demand depends on the transfer of oxygen into the soil zone where the waste loading induces microbial activity (COODY *et al.*, 1984). Regular application of contaminated municipal sewage water on arable land for irrigation purposes may lead to an accumulation of heavy metals in the surface soil layer. Depending on the pH and texture of the soil, these metals may become plant available and be incorporated into the plant tissues. The fraction of the total metal content that is available for uptake by biota depends strongly on the chemical form in which metals are present and where they are located in the soil system (BERNHARD *et al.*, 1986; NEDERLOF *et al.*, 1993).

The objective of the present study was to quantify the effect of increasing chemical oxygen demand (C.O.D.) and heavy metal concentration in irrigation water on the uptake of various metals by maize. An acidic sandy soil was used for the experiments. The influence of soil properties was studied by repeating the experiment with the same soil, amended with 5% polder clay.

MATERIALS AND METHODS. – An acidic sandy soil (LEMBEKE, Belgium) sampled from the surface layer (0-20 cm) was used for this pot experiment. The soil was dried and passed through a 2-mm sieve. A second soil was prepared by adding 5% polder clay. Initial physico-chemical characteristics of these soils are shown in Table 1. Soil pH was measured in the 1:5 (solid:liquid) suspension after an equilibrium period of 18 hours while pH-KCl was determined in a 1M KCl suspension (1:2.5 solid:liquid) after 10 min. Electrical conductivity was measured in the saturation extract. Organic matter was estimated by the Walkley & Black method. Cation exchange capacity (C.E.C) was determined by saturating the adsorption complex with NH_4^+, washing the excess NH_4^+ with ethanol and determining the adsorbed NH_4^+ after quantitative removal by K^+ ions (COTTENIE *et al.*, 1982). In black plastic pots (diameter 15 cm, height 12 cm) one kg of the soil was mixed with 200 ml of demineralized water. For each soil, nine treatments were triplicated in a completely randomized block design. The demineralized water added corresponded with 70% of the water-holding capacity of the soil. During eight weeks, these soils were irrigated daily with 30 ml of artificially prepared waste water, containing different levels of C.O.D. (C.O.D. = 0, 300, and 600 mg oxygen L^{-1}) and heavy metal concentrations (Cd = 0, 0.1, and 0.3 mg L^{-1}, Cu = 0,1, and 3 mg L^{-1}; Pb = 0, 2.5, and 7.5 mg L^{-1}; Ni = 0, 1, and 3 mg L^{-1}; and Zn = 0, 2.5, and 7.5 mg L^{-1}). The total volume added was 1800 ml. The soils of the individual pots were dried individually, mixed and analyzed for total metal contents (Table 2). Water was again added to bring the moisture content to 70%, of the water-holding capacity before growing the maize. After an equilibrium period of two weeks, maize *(Zea Mays L.)* was sown at a rate of 7 seeds per pot and after emergence five uniform plants were maintained. During growth, the plants were irrigated every day with 30 ml of artificially prepared waste water in equal amounts to all pots. The total volume added during the growth was 900 ml per pot.

TABLE 1. – *Initial soil characteristics.*

Characteristics	Acidic sandy soil	Clay-amended soil
pH (H_2O)	4.02	6.70
pH (KCl)	3.40	6.00
EC ($dS.m^{-1}$)	0.40	0.70
CEC ($cmoles.kg^{-1}$)	5.46	6.52
Base saturation (%)	38.5	66.3
Organic carbon (%)	1.02	0.99

Three levels of C.O.D. (C.O.D. = 0, 300, and 600 mg oxygen L^{-1}) were prepared by dissolving 0, 300 and 600 mg of glucose per liter. Cadmium, Cu, Ni and Zn were added as hydrated sulfates and Pb as hydrated nitrate. To simulate the effects of detergents in the sewage water 200 mg L^{-1} of sodium carbonate was added to the synthetic irrigation water. The day length was artificially adjusted to 16 hours. After one week of germination, 25 ml of nutrient solution containing 5 g of NH_4NO_3, 2.5 g of $Ca(H_2PO_4)_2.H_2O$, 2.5 g of K_2SO_4, and 2.5 g of $MgSO_4$ per liter, was applied per pot. After two weeks of growth, another 25 ml of the same solution was added.

TABLE 2. – *Aqua regia extractable metal concentrations in the soils (mg.kg^{-1} dry matter) after eight weeks of irrigation and before the sowing of maize, as a function of the metal level applied with the irrigation water.*

Metal	Acidic sandy soil			Clay-amended soil		
	Level 0	Level 1	Level 2	Level 0	Level 1	Level 2
Cadmium	0.43	0.43	0.88	0.32	0.67	0.88
Copper	2.17	3.20	6.37	2.18	3.89	6.36
Nickel	4.50	7.26	7.25	5.50	7.34	11.02
Lead	5.71	16.38	29.50	8.36	13.70	25.50
Zinc	16.25	20.70	28.05	22.10	27.66	32.75

The plants were grown during 30 days. After harvesting, the plants were dried at 70°C to constant weight and the dry matter yield was recorded. The plant material was dry-ashed at 450°C and analyzed for the heavy metals Cd, Cu, Ni, Pb and Zn using flame atomic absorption (COTTENIE *et al.*, 1982).

The significance of differences between means of treatments was evaluated using one way analysis of variance (ANOVA) on the untransformed data, followed by means separation using the L.S.D. multiple range test, at the 5% level of significance.

RESULTS AND DISCUSSION. – *Dry matter yield of maize* - The data that pertain to the dry matter yield of maize are presented in table 3. The dry matter yield was 2-3 times higher on the clay-amended soil than on the acidic sandy soil. Plant growth on the clay-amended soil was favoured by the higher pH and the higher nutrient content of the clay-amended soil. Acidic conditions may reduce plant growth through plant toxicity by elements that become more available to plants at low pH and through restriction of root growth in acidic soil (TAYLOR *et al.*, 1992). It was observed that root development in the acidic sandy soil was poor and limited to a few centimeter depth.

On the contrary, root development in the clay-amended soil was homogeneous throughout the pot.

At metal level 1, the yield was slightly higher compared to the control and to the highest metal level. This may be attributed to an improvement of the micro-nutrient status in the acidic sandy soil after application of the irrigation water that contained the intermediate metal level. The decrease at the highest metal level may suggest beginning metal toxicity. In the clay-amended soil, the maize yield was unaffected. The metal concentrations in the irrigation water did not affect the dry matter percentage of the corn in any soil.

TABLE 3. – *Dry matter yield (g per pot) and heavy metal concentration in maize ($mg.kg^{-1}$ of dry matter) as a function of the metal and C.O.D. levels applied with the irrigation water.*

Treatment	Yield	D.M. %	Cd	Cu	Pb	Ni	Zn
			Acidic Sandy Soil				
HML 0 + COD 0	1.37 ab	9.1 a	0.9 a	1.6 a	3.9 ab	2.7 a	279 a
HML 0 + COD 1	1.40 abc	9.3 ab	1.1 a	2.6 a	3.2 a	2.8 a	369 ab
HML 0 + COD 2	1.55 abc	9.6 abc	1.1 a	2.7 a	2.8 a	3.8 a	373 abc
HML 1 + COD 0	1.50 abc	9.1 ab	3.9 b	9.1 b	6.7 abc	9.3 b	440 abc
HML 1 + COD 1	1.67 bc	9.3 ab	4.0 b	15.4 c	8.3 c	14.0 c	481 bc
HML 1 + COD 2	1.73 c	9.5 abc	4.7 b	14.6 c	7.6 bc	12.3 c	512 cd
HML 2 + COD 0	1.20 a	8.5 a	11.2 c	20.3 d	25.2 d	36.2 d	661 de
HML 2 + COD I	1.23 a	8.8 a	11.8 c	22.5 d	26.3 d	42.3 e	691 de
HML 2 + COD 2	1.33 ab	9.2 ab	12.8 c	26.1 e	24.6 d	40.3 e	721 dc
			Acidic Sandy Soil Amended With 5% Polder Clay				
HML 0 + COD 0	2.53 a	9.8 d	0.7 a	2.3 a	2.5 a	3.2 a	22.3 a
HML 0 + COD 1	2.63 ab	9.5 a	0.8 a	2.5 a	2.8 a	3.7 a	24.5 a
HML 0 + COD 2	2.53 a	9.6 a	0.8 a	2.6 ab	2.4 a	3.0 a	31.8 ab
HML 1 + COD 0	2.57 a	9.5 a	1.1 b	5.3 c	4.9 b	4.7 b	36.9 ab
HML 1 + COD 1	2.70 ab	9.6 a	1.2 bc	4.8 bc	4.8 b	5.2 bc	40.0 b
HML 1 + COD 2	2.90 ab	9.9 a	1.4 c	5.7 c	5.8 b	4.8 bc	38.9 b
HML 2 + COD 0	2.93 ab	9.6 a	1.8 d	10.9 d	5.5 b	5.3 bcd	60.5 c
HML 2 + COD 1	2.86 ab	9.7 a	1.8 d	9.9 d	4.6 b	5.5 cd	60.9 c
HML 2 + COD 2	3.13 b	9.8 a	1.8 d	11.8 d	5.1 b	6.0 d	63.8 c

Abbreviation: * COD = Chemical oxygen demand - ** HML = Heavy metal level.
Values followed by the same letter are not significantly different at the 5% level of significance.

Concentrations of heavy metals in maize plants - The average concentrations of Cd, Cu, Ni, Pb and Zn in maize are reported in table 3. The metal concentrations in the plant increased significantly with increasing metal levels in the irrigation water. The distribution and accumulation pattern varied considerably among elements. All elements accumulated more strongly in the maize grown on the acidic sandy soil than in the clay-amended soil.

Both the higher C.E.C. and the higher pH of the clay-amended soil, compared to the acidic sandy soil, account for the lower metal concentrations in the maize. Heavy metals added through the contaminated irrigation water were effectively adsorbed on the clay complex and therefore less available for plant uptake (GONZALEZ *et al.*, 1992). According to DE HAAN *et al.* (1985) and VERLOO *et al.* (1987) the uptake of Zn and Cd is mainly controlled by soil pH and to a lesser extent by the C.E.C. of the soil. For Cu and Ni, however, interactions with C.E.C. and eventually other soil characteristics may be more pronounced. Metal availability increases with decreasing soil pH (BRADY, 1974; ADRIANO, 1986; ALLOWAY and JACKSON, 1991). Moreover, their speciation is affected (BERNHARD *et al.*, 1986). For example, Ni and Zn occur mostly as free metals below pH 6 (SANDERS and MCADAMS, 1987).

A significant increase in Cu and Ni concentration was observed with increasing C.O.D.-level in the irrigation water. For Cd, Pb, and Zn, an increasing trend was also apparent, but was not significant at the 95% level. The use of organic matter contaminated water for irrigation may have resulted in a higher soil microbial activity. Soluble low molecular weight organic molecules, produced during the microbial decomposition of soil organic matter, form soluble complexes with the heavy metals. These complexes are more mobile, less readily adsorbed and, possibly, more readily taken up by plants than free metal ions (NEAL and SPOSITO, 1986; ALLOWAY and JACKSON, 1991).

CONCLUSION. – A pot experiment was designed under green house conditions to investigate the effects of C.O.D. and heavy metal contaminated irrigation water on the uptake of metals by maize, grown on an acidic sandy soil and on the same soil amended with 5% polder clay. Metal uptake mainly depended upon soil characteristics and metal levels in the irrigation water. Heavy metal concentrations in the plant increased slightly with increasing C.O.D level in the irrigation water. This increase was statistically significant ($p = 0.05$) for Cu and Ni in the plant grown on the acidic sandy soil.

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SUMMARY. – A pot experiment was carried out under controlled conditions to evaluate the combined effects of chemical oxygen demand (C.O.D.) and heavy metal content in synthetic irrigation water and clay content of the soil on the metal uptake by maize plants. Maize (*Zea Mays L.*) was grown during 30 days on two soils, an acidic sandy soil and the same soil amended with 5% polder clay. These soils were continuously irrigated with synthetic irrigation water before and during plant growth. The dry matter yield of maize decreased and heavy metal concentrations in the plant tissue increased with increasing heavy metal concentration in the irrigation water. A higher C.O.D. concentration in the irrigation water also resulted in an overall increase of the dry matter yield and metal concentrations in the plant tissue. Addition of 5% clay to the acidic soil reduced these effects. The clay content of the soil was by far the most important factor in controlling plant growth and metal uptake.