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TOTAL CONTENTS OF CADMIUM, COPPER, MANGANESE AND ZINC IN AGRICULTURAL SOILS IRRIGATED WITH WASTEWATER FROM HIDALGO, MEXICO

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ABSTRACT

This study analyzes the levels of heavy metals (Cd, Cu, Mn and Zn) present in five soil profiles from the state of Hidalgo and which, for over 40 years, have been irrigated with wastewater coming out of the basin of Mexico. These soil profiles are compared to others from a nearby area which are free from effluent irrigation. It was observed that in sites which have been irrigated with sewage effluents the averages of metal concentrations in Ap horizons were consistently higher in comparison with the lower horizons. The average content of Cu in Ap horizons was highly significant which indicates high accumulation in the superficial soil layers. With respect to Cd and Zn, it was noted that highly significant accumulations embrace the two most superficial soil horizons. No significant accumulations of Mn were present in the superficial soil horizons. It was possible to observe the influence of irrigation when comparisons were made between total contents of the above mentioned elements in areas irrigated with wastewater and those not receiving these effluents. In this last case heavy metal contents were lower and the difference between both areas was highly significant. Contents of organic matter and silt seem to be the soil properties most associated to the presence of Cu, Mn and Zn in soils irrigated with sewage effluents, while $CaCO_3$ contents in soils is the characteristic most associated to Cd.

RESUMEN

Este estudio analiza los niveles de metales pesados (Cd, Cu, Mn y Zn) presentes en cinco perfiles de suelo del estado de Hidalgo que han sido regados, por más de 40 años, con aguas residuales provenientes del Valle de México. Estos perfiles de suelo son comparados con otros de un área cercana que no ha estado sujeta a este tipo de riego. En los sitios que han estado regados con aguas residuales se observó que las concentraciones medias de los metales en los horizontes Ap, fueron consistentemente más altas en comparación con los horizontes de abajo. El contenido medio de Cu en los horizontes Ap fue altamente significativo, lo cual indicó una gran acumulación del elemento en esta capa superficial del suelo. En el caso de Cd y Zn, sus concentraciones significativas abarcaron los 2 horizontes superficiales de los perfiles de suelo. Las concentraciones de Mn fueron estadísticamente iguales a lo largo del perfil. Se logra observar la influencia del riego, al comparar los contenidos totales de los mismos elementos en la zona que no recibe aguas residuales, los cuales son más bajos, y esta diferencia es altamente significativa. La materia orgánica y el limo parecen ser las propiedades que están más asociadas al Cu, Mn y Zn en los suelos sujetos al riego con aguas residuales, mientras que el $CaCO_3$, de estos mismos suelos, es la característica más asociada al Cd.

INTRODUCTION

Domestic and industrial wastewaters have been used for irrigation and thus they have served as a source of nutrients for crops. Heavy metals borne by these waters, even if they are usually in low concentrations, tend to accumulate in soil, where crops can take them up. Also heavy metals can leach into underground waters (CAST 1976, Elliot and Stevenson 1977, Brown *et al.* 1983). Some heavy metals are not essential for plants and they can affect growth and quality as is the case for Cd. Other elements such as Cu and Zn, which are necessary for plants, can become toxic when concentrations are high (CAST 1976). King (1982) carried out a study to determine if untreated industrial wastewater could be applied to soil without having adverse effects on crop growth, soil properties or underground water since they can be endangered by soil contamination. He found that fodder production was greater when untreated wastewater was applied in places where inorganic fertilizers were used, instead of untreated wastewater.

Schirado *et al.* (1986) studied a vertisol irrigated for over 50 years with untreated municipal wastewaters. They found high levels of Cd, Co, Cu, Mn, Ni and Zn when extracted with DTPA on soil from the cultivated layer; but with regards to total concentrations of Cd, Co, Cr, Cu, Ni and Zn the authors suggested that there is a downward movement of metals so that they can be distributed throughout the whole profile.

This research was carried out to: i) characterize total Cd, Cu, Mn and Zn distribution with respect to soil depth from different profiles at sites with a semi-arid climate where there has been irrigation with untreated wastewater, ii) compare these sites with others that have not been irrigated with wastewater.

Physical environment of study area

The lower part of the Mezquital Valley is occupied by irrigation district 063 notable for the use of wastewater. This area is located 109 km north of Mexico City in southwestern Hidalgo State. It covers gently rolling land with a mean height of 2,000 meters above sea level and it includes several intercommunicating valleys, naturally drained by the Tula river and its tributaries, as part of the Panuco river system (Fig. 1).

Local geology includes limestone from the Cretacic period with intrusions of igneous rocks from the end of the Tertiary era, thus favoring mineralization and metamorphism along some places. Most of the surface of this area was covered by volcanic ashes and alluvium from the Quaternary era (MMAJ 1981). Soils from this area reflect local geology and topography. They originate from colluvial and alluvial materials transported from the hills to the valleys, resulting in profiles of varied depth, where thin soils predominate. On the other hand, upland areas have soils formed *in situ* with a scant depth of less than 25 cm. The climate is dry temperate with a mean annual rainfall of 502 mm, highly variable from one year to another and falling mainly in summer and autumn. The mean annual temperature is 17.4°C (García 1988). Such a climate favors natural vegetation of xerophytic scrubland of different types, predominantly grassland, cactus, agaves, Joshua palms (*Yucca* sp) creosote bush (*Larrea* sp). This last one bush grows in the driest northern part of the area, while mezquites are so common that they gave the name to the whole zone (González 1968). Natural vegetation is now only present on hills, while most of the lowlands are under irrigated crops.

Historic and socio-economic background of study area

In this zone untreated urban wastewater was introduced gradually. It started at the beginning of this century, but in the greater part of the valley irrigation appeared between 1925 and 1938. This wastewater originates in the metropolitan zone of Mexico City, an urban centre localized within a closed basin. Therefore, water used by the city must be immediately pumped out of the basin in order to prevent floods, particularly during the rainy period. Here, human beings have been combatting floods for centuries. Prehispanic people lived in harmony with their aquatic environment and protected themselves by constructing dikes and channels, in order to control overspills from Texcoco lake. Spaniards, who appeared during the XVI century, dealt with this problem differently. They filled most of the channels with rock material from the surrounding mountains and opened the basin of Mexico in 1607 by changing the course of Cuautitlan river, deviating it from this basin into the Mezquital Valley. This was done through the construction of a tunnel, which collapsed and was turned into an open trench known as "El Tajo de Nochistongo", a hydraulic work which was finished in 1789. Nevertheless, the floods in Mexico City continued and new attempts to solve this problem were carried out by means of the first tunnel of Tequisquiac built in 1886 and the second tunnel in 1937. The forth and largest water outlet was opened in

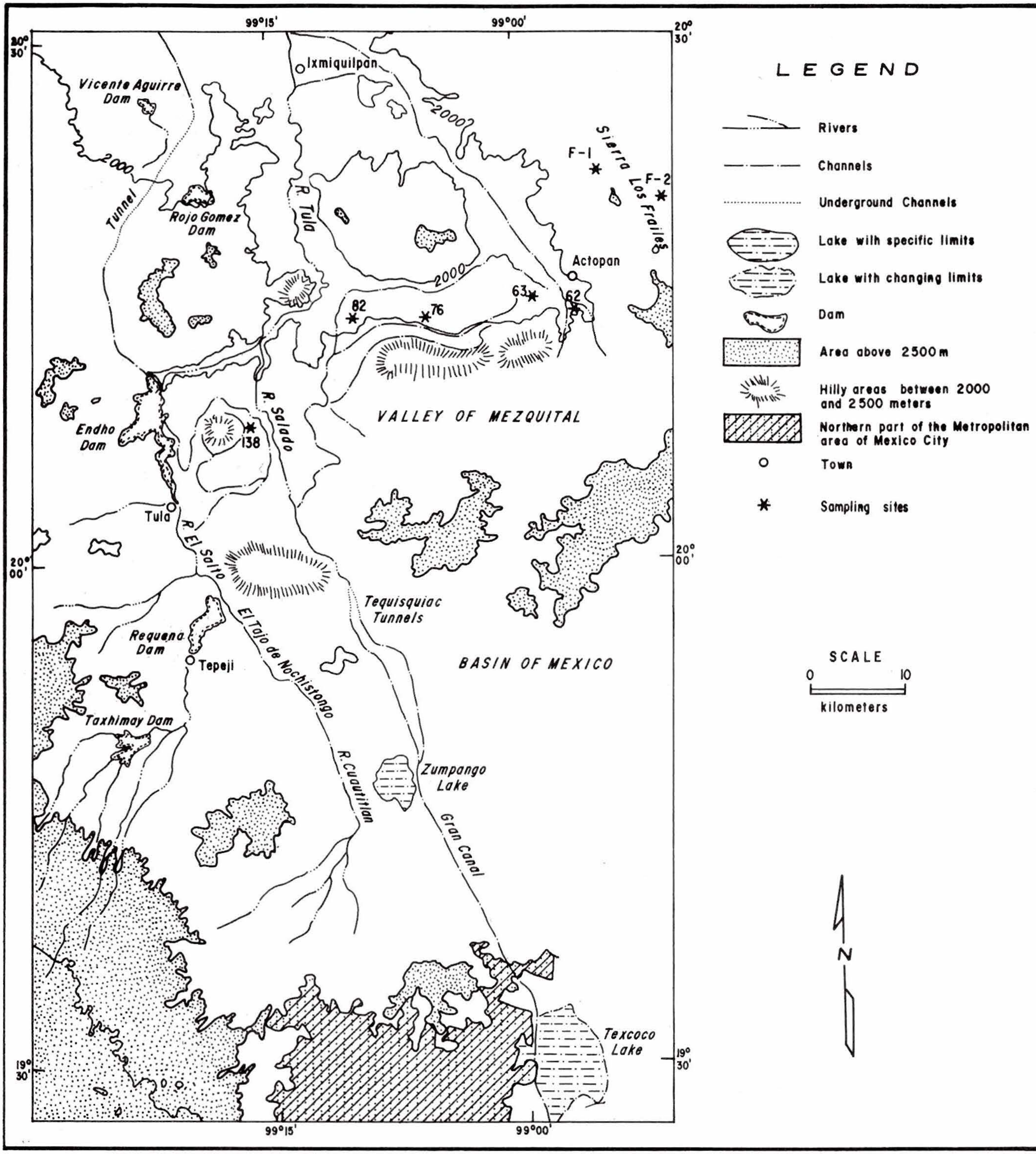

Fig. 1. The hydrological system of The Mezquital Valley and sampling sites in irrigation district 063

1975. This is the underground waterway known as "El Emisor Central". It has a length of 68 km and a capacity of 220 m^3 per second. Wastewater entered the Mezquital Valley for the first time when the old Tequisquiac tunnel was opened in 1900. Previously, irrigation had existed in this area but only in a few places and by using clean water. Irrigation was first along main channels constructed by a private company and local wealthy landowners. Irrigation expanded together with each new waterway constructed and also due to the increase in water coming out of Mexico City, this was a consequence of population explosion accompanied by industrialization in this city which brought a correspondingly greater need of water, a fact that obliged authorities to bring water into the basin of Mexico from other river catchments such as the Lerma and Cutzamala. Thus, between 1914 and 1926 there were 14,000 ha of irrigated land which between 1926 and 1950 had increased to 28,000 ha and by 1965 had reached 42,460 ha. At present the irrigation district 063 has approximately 100,000 ha (Dirección de Hidrología 1977).

Several dams are regulating the water of this district. The most important ones are Taxhimay and Requena both of which impound clear water, although they do have some pollution from local settlements such as Tepeji. The other important dams control wastewater, such as the Endho, Vicente Guerrero and Rojo Gomez dams, all of which act as stabilizing lagoons for microorganisms and also control irrigation. The whole area has a complex and old hydraulic network made empirically by local farmers and later improved by professional engineers. It is a water network which has always been adjusted to the water usage of Mexico City.

The main crops in this area are corn and lucerne (alfalfa). These crops cover approximately 80% of the whole area. Other important crops are oats, chili and tomatoes. There are also several crops whose cultivation is forbidden due to dangers for human health, as part of the plant consumed is in close contact with water and soil, or else because the products are eaten without cooking. Examples of such plants are potatoes, beets, turnips, onions, garlic, lettuce and other vegetables, yet this sanitary disposition is not always kept. This represents a danger not only to the local population, which is approximately 600,000 inhabitants, but also to the people of Mexico City who are the nearest largest market for this area.

During the first half of the century wastewater was mostly of domestic origin, but since the decade of the 50's industrialization has added to it chemical compounds which include heavy metals that are more dangerous and more difficult to deal with than the former organic pollution which was free of industrial contaminants.

MATERIALS AND METHODS

Sampling sites

The selected sampling sites were chosen at random. Five sites were located within the area irrigated by wastewater from Mexico City and its metropolitan zone, and the other two sites came from control points 300 to 400 meters above the irrigated zone and at a distance of 2 km within an area without influence from wastewater. The irrigated sites have an average height of 2,000 meters above sea level. They are coded as: 62, 63, 76, 82, 138, and belong to two soil series Lagunilla and Tepatepec, while the control sites belong to the soil series Los Frailes and are coded as F-1 and F-2.

At each site a pit was made and samples were taken from each soil horizon. The soils sampled were air dried, ground and sieved using a 2 mm (10-mesh) stainless steel sieve and stored in polyethylene bags.

The laboratory determinations made were: a) soil pH using a glass electrode with soil water ratios of 1:2.5 and a 30 min equilibration period, b) particle-size distribution was measured by the hydrometer method (Day 1965), c) cation exchange capacity (CEC) was determined by saturating the soils with sodium acetate, and replacing sodium with ammonium acetate (Chapman 1961). Methanol instead of isopropyl alcohol was used to wash excess sodium from the soil. The exchanged sodium was subsequently measured with a flame photometer, d) organic matter was determined by the Walkley-Black procedure (Jackson 1958), e) determination of calcium carbonate equivalent was done by acid neutralization (Richards 1969), f) soluble cations and anions and electrical conductivity were analyzed in saturated soil extract (Richards 1969), g) concentrations of Cd, Cu, Mn and Zn in soils were determined by atomic absorption spectrophotometry after a $HClO_4$ —HF digestion (Linn and Jackson 1982). This was done in order to destroy organic matter and also to dissolve inorganic materials. Due to the fact that the Cd extracted was found in very small quantities it was necessary to concentrate the acid solution five times its original volume. The analyses of heavy metals were made in three replicas.

It was possible to make an analysis of variance by using soil depth as a main effect. A multiple range test was also performed to determine if the amounts of Cd, Cu, Mn and Zn in soil profiles irrigated with wastewater were significantly different from those not irrigated with wastewater and this was performed for all soil depths. A linear regression analysis was utilized to determine significant relationships between metal concentrations and soil properties by using all soil properties above mentioned as independent variables and total Cd, Cu, Mn and Zn as the dependent variable.

RESULTS AND DISCUSSION

Table I shows the total contents of heavy metals in sites where irrigation was done with wastewater. When this information is compared with the data presented by Bohn (1985), only two sites (62 and 76) have average concentrations of Cd in the Ap horizon, which are slightly above normal range. Copper, Mn and Zn were within normal range in all sites and in all horizons. The average concentrations of metals in the Ap horizon were consistently higher in comparison to other horizons. The differences found for the average contents of Cu and Zn between Ap horizons and subjacent horizons were significant ($P < 0.05$). In the case of Cd and Mn, there were only significant differences between Ap horizons and the third depth (considering the Ap horizon as the first depth). With respect to Cu, the differences between Ap horizon and the lower horizons was highly significant, a fact which points out the existence of a great accumulation of this element in the Ap horizons. Highly significant accumulations ($P < 0.01$) of Cd and Zn were found in the two most superficial horizons. As for Mn no highly significant differences were noticed in any of the horizons compared.

Table II presents the total contents of heavy metals in sites which do not receive irrigation from wastewater. The A_1 horizon of profile F-1 presents the highest concentrations of metals, in comparison with deeper horizons as a result of different reactions of intemperism within these superficial horizons which have the

TABLE I. TOTAL CONTENTS OF HEAVY METALS IN SOIL PROFILES IRRIGATED WITH UNTREATED SEWAGE EFFLUENTS*

Sites	Horizon	Depth cm	*Cd*	*Cu*	*Mn*	*Zn*
			mg kg⁻¹			
	Ap	0-14	7.9 (0.34)	80 (6)	775 (69)	216.9 (15.2)
62	C_1	14-27	6.8 (0.29)	65 (5)	690 (60)	198.0 (12.4)
	C_2	27-70	5.1 (0.22)	45 (3)	645 (58)	181.2 (12.0)
	C_3	70-125	3.9 (0.20)	45 (3)	620 (56)	88.5 (6.2)
	Ap	0-25	5.1 (0.23)	70 (5)	675 (60)	257.0 (20.1)
63	A_1	25-33	5.7 (0.23)	60 (4)	645 (58)	158.0 (12.3)
	B_1	33-120	4.0 (0.18)	45 (3)	605 (51)	99.0 (8.0)
	B_2	120-170	4.0 (0.20)	40 (2)	630 (50)	94.6 (7.5)
	Ap	0-17	7.9 (0.38)	70 (6)	690 (61)	240.2 (12.7)
76	B_1	17-45	5.7 (0.31)	60 (4)	645 (55)	195.2 (10.4)
	BC	45-76	5.1 (0.29)	60 (3)	665 (57)	122.2 (8.0)
	Ap	0-25	6.8 (0.30)	70 (4)	735 (71)	229.6 (17.6)
82	B_1	25-52	5.1 (0.25)	45 (4)	715 (62)	130.6 (9.3)
	BC	52-70	5.7 (0.25)	40 (3)	635 (51)	101.1 (7.8)
	Ap	0-15	5.1 (0.26)	95 (7)	605 (53)	136.9 (9.1)
138	A_1	15-33	4.8 (0.26)	70 (6)	580 (40)	134.0 (9.0)
	A_{12}	33-68	4.0 (0.28)	60 (4)	575 (41)	80.0 (5.4)

* Values in parentheses represent standard deviations of the mean

TABLE II. TOTAL CONTENTS OF HEAVY METALS IN SOIL PROFILES NOT IRRIGATED WITH UNTREATED SEWAGE EFFLUENTS*

Sites	*Horizon*	*Depth* cm	*Cd*	*Cu*	*Mn*	*Zn*
			mg kg^{-1}			
	A_1	0-5	2.4 (0.10)	43 (1.8)	471 (20)	140.3 (6.1)
F-1	A_2	5-27	1.9 (0.08)	30 (1.3)	150 (6)	76.4 (3.0)
	C	27-90	2.0 (0.08)	22 (0.9)	93 (4)	71.3 (3.0)
	A	0-5	2.6 (0.10)	45 (1.8)	670 (29)	109.1 (4.5)
F-2	B	5-30	2.3 (0.10)	37 (1.5)	1437 (66)	99.2 (4.2)
	BC	30-60	2.7 (0.11)	23 (0.9)	728 (31)	93.3 (4.0)

* Values in parentheses represent standard deviations of the mean

greatest physical, chemical and biological activity. This same fact can also be seen in profile F-2 but only with respect to Cu and Zn. The influence of irrigation appears to be very clear when statistical comparisons are made between average metal contents of soil profiles irrigated with wastewater and those irrigated with water free of wastes. The differences found were highly significant ($P < 0.01$) for Cd and Cu in all horizons; while differences in Zn were only significant ($P < 0.05$) between Ap horizons (sites 62, 63, 82, 76, 138) and A horizons (sites F-1 and F-2). This shows significant settling of Cd, Cu and Zn as a result of wastewater usage. When profile F-1 was compared with other profiles under irrigation, Mn values, showed highly significant differences in the deeper horizons. While in profile F-2 an accumulation of Mn is present in the B horizon found at a depth of 5 to 30 cm. This last result can be explained by the fact that the area is highly mineralized and heavy metals, particularly Mn, present themselves naturally within this region's geologic material. All of these results show that even after 40 years or more of irrigation with wastewater, the accumulation of most of the metals under study were restricted to a layer in the soil's uppermost horizons. If we consider the data from table II as values that are "normal" for this region, the depth of normal metal concentrations in the case of Cu and Zn could be in the second or even the third layer, for sites within the area irrigated with wastewater. But concerning Cd, those concentrations considered as normal are not found at any depth, at the sites irrigated with sewage water, since the highest normal value is 2.7 mg kg^{-1}, a value which is not obtained even in the deepest horizons of the profiles irrigated with wastewater (Table I). This can also indicate that this element has moved towards deeper horizons in the soil profiles irrigated with sewage effluents as was also observed by Schirado *et al.* (1986).

Most researchers have studied the effect of sewage sludge applied to soils for its amendment. But there are also other researchers who have studied the effect of wastewater on soils. However, many of them observed a scant downward movement of heavy metals in soils. Banin *et al.* (1981) reported accumulation of heavy metals in superficial soil layers of arid zones submitted to prolongued irrigation with treated wastewater. Emmerich *et al.* (1982) studied the different fractions of Cd, Cu, Ni and Zn in soils treated with sewage sludges and they observed that the metals added to a soil which had been set up in a column did not move from the sludge soil layer. Baxter *et al.* (1983) studied heavy metals and persistent organics at a site which was a sewage sludge deposit. They observed that heavy metals stayed within the depth to which the sewage sludge had been incorporated. Miller and McFee (1983) concluded that the movement of metals in soil profiles of a highly industrialized region was minimum; the effective retention of metals is limited to a layer of litter and 2.5 cm of soil. Williams *et al.* (1984) also observed that the descendent movement of metals was limited to 5 or 10 cm below the zone of sludge incorporation and this was true for both acid and neutral soils. Rappaport *et al.* (1987) observed that metals extracted with DTPA in a soil profile did not show downward movement. Welch and Lund (1989) studied the movement of Zn in soils treated with sewage sludges and they observed that most of the Zn applied remained in the soil strata where sludges had been incorporated. The relative immobility of metals added to soils by means of sludges and wastewaters, show several chemical reactions which take place particularly in the surface of soils which is the zone of incorporation.

Some properties of soil profiles irrigated with wastewater are shown in table III. The clay and silt con-

TABLE III. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL PROFILES IRRIGATED WITH UNTREATED SEWAGE EFFLUENTS

Sites	*Series*	*Horizon*	*Depth* *cm*	*pH*	*OM* %	*CEC* *me* $100g^{-1}$	$CaCO_3$ %	*Clay* %	*Silt* %	*Soil* *texture*	*EC* *mmhos* cm^{-1}	Soluble ions (*me* L^{-1}) *Ca*	*Mg*	*Na*	*K*	CO_3	HCO_3	*Cl*	SO_4
62	Lagunilla	Ap	0-14	8.1	3.35	32.6	1.06	22.4	36.6	loam	1.9	4.8	0.4	14.4	1.0	2.0	7.0	10.0	1.6
		C_1	14-27	8.2	2.01	33.7	1.09	19.6	40.0	loam	1.4	3.6	0.4	10.2	0.7	0.8	4.8	7.0	1.4
		C_2	27-70	8.1	1.88	35.6	1.23	29.8	57.2	silty clay loam	1.1	3.6	N.D.	9.0	0.5	0.4	3.6	6.0	1.4
		C_3	70-125	8.1	1.74	34.8	1.58	30.4	57.6	silty clay loam	1.9	3.2	1.6	11.8	0.7	0.6	3.5	9.0	1.2
63	Lagunilla	Ap	0-25	8.2	2.68	33.5	1.01	33.8	39.0	clay loam	1.7	3.2	1.6	12.1	1.0	1.0	5.8	8.5	1.7
		A_1	25-33	8.3	1.61	32.6	1.05	31.2	41.6	clay loam	1.3	3.2	0.8	11.0	0.7	1.2	4.3	7.0	1.4
		B_1	33-120	8.2	1.47	30.4	1.08	23.8	46.8	loam	1.6	3.6	1.2	12.1	0.7	0.8	3.1	1.1	1.2
		B_2	120-170	8.2	0.54	29.8	1.19	19.0	37.6	loam	1.0	2.0	1.2	9.6	0.4	0.2	2.6	7.0	1.2
76	Tepatepec	Ap	0-17	8.3	2.28	33.5	1.82	28.2	44.8	clay loam	1.3	2.4	0.4	9.4	0.9	0.8	5.2	4.5	1.9
		B_1	17-45	8.5	1.61	35.6	2.39	30.2	45.4	clay loam	0.9	2.4	1.2	8.4	0.5	0.8	5.1	5.0	1.7
		BC	45-76	8.3	1.07	35.6	2.81	33.2	49.3	silty clay loam	1.3	1.6	0.8	13.0	0.5	1.2	4.6	7.5	1.2
82	Tepatepec	Ap	0-25	8.1	2.41	43.5	2.21	32.6	43.0	clay loam	1.6	3.6	0.4	13.1	1.1	1.4	5.4	8.0	1.8
		B_1	25-52	8.4	1.21	38.3	1.63	29.6	42.8	clay loam	1.2	2.4	0.4	12.1	0.7	1.2	4.2	6.0	1.6
		BC	52-70	8.6	0.80	42.6	3.86	21.4	48.4	loam	1.4	2.4	1.2	12.5	0.7	0.8	4.4	7.0	1.4
138	Lagunilla	Ap	0-15	8.4	4.15	38.3	2.09	25.0	32.5	loam	1.8	5.2	3.6	13.4	0.7	1.6	5.8	10.0	2.0
		A_1	15-33	8.0	3.35	40.0	2.99	19.0	41.0	loam	1.5	3.6	2.8	11.0	0.6	1.6	4.4	7.0	1.6
		A_{12}	33-68	8.3	1.47	41.8	1.01	22.5	28.3	loam	1.8	4.4	2.4	10.0	0.6	0.8	3.1	9.5	2.0

N.D. Not detected

TABLE IV. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL PROFILES NOT IRRIGATED WITH UNTREATED SEWAGE EFFLUENTS

Sites	Horizon	Depth cm	pH	OM %	CEC me $100g^{-1}$	Clay %	Silt %	Soil texture	$CaCO_3$ %
	A_1	0-5	7.0	2.50	32.4	16	46	loam	3.21
F-1	A_2	5-27	7.2	0.44	27.2	16	40	loam	0.83
	C	27-90	7.0	0.25	35.3	36	32	clay loam	1.10
	A	0-5	7.1	5.61	42.7	33	37	clay loam	1.91
F-2	B	5-30	7.6	1.65	35.3	37	27	clay loam	1.25
	BC	30-60	7.2	0.99	39.3	28	32	clay loam	0.80

tents show medium values ranging from 19.0 to 33.0% and from 28.3 to 57.6%, respectively. The pH values were rather constant with respect to depth when examined from top to bottom in soil profiles of all sites; the cation exchange capacity values are relatively high and sufficiently homogeneous. The only property which differed significantly between sites was organic matter. The contents of soluble ions are considered as normal for soils of arid zones. The salts carried by irrigation water, as well as those originated by intemperism of parental material, apparently suffer an adequate process of lixiviation. Table IV gives us the values of soil profiles not irrigated with sewage effluents. In a general way we can observe that these soils have very similar characteristics to the soils subjected to irrigation with wastewater. The only soil property which differs between the two zones is pH, this also reflects the influence of the use of wastewater.

The relationships between total metal contents at different depth and soil properties were determined by means of lineal regression analysis resulting in the equations presented in table V. Organic matter and silt contents are the variables which have the greatest influence in the concentrations of Cu, Mn and Zn.

Possibly the low absorption capacity which has the fine fraction of silt was important in the retention of metals in these soils. On the other hand, perhaps there are some processes of heavy metal deposition over this fraction of mineral particles. The $CaCO_3$ content is the variable that appears to have influence in Cd concentrations. The absence of significant relationship between metals and the values of pH, cation exchange capacity and clay, suggest that these soil properties do not have a significant contribution in metal concentrations due to the fact that these properties show a varia-

TABLE V. REGRESSION EQUATIONS FOR THE RELATIONSHIP OF SOIL PROPERTIES AND TOTAL HEAVY METALS

Dependent variable	Independent variables[a]	R^2
Cd depth 2	$y = 7.02 - 0.69\ CaCO_3$	0.66*
Cd depth 3	$y = 3.79 + 0.49\ CaCO_3$	0.69*
Cu depth 1	$y = 36.08 + 13.75$ O.M.	0.95***
Cu depth 1	$y = 150.4 - 1.88$ Silt	0.73*
Cu depth 2	$y = 41.86 + 9.26$ O.M.	0.67*
Mn depth 2	$y = 755.3 - 51.23$ O.M.	0.67*
Mn depth 3	$y = 499.0 + 2.73$ Silt	0.68*
Zn depth 1	$y = 375.5 - 53.59$ O.M.	0.80**
Zn depth 3	$y = -18.32 + 2.93$ Silt	0.64*

[a] y = best fit equation by F-Test
* significant at $P < 0.1$
** significant at $P < 0.05$
*** significant at $P < 0.01$

tion which is not significant between and within each site and that lineal regression analysis does not detect their influence for metal contents.

There are many researchers that have reported properties such as pH, texture, cation exchange capacity and presence of organic matter as soil characteristics which can be considered as the main influence on the soil's capacity for heavy metal retention. Scokart *et al.* (1983) reported that organic matter is the main soil component responsible for immobility of heavy metals, both in acid and neutral soils. They also reported that there are many possible interactions between trace metals and soil constituents which increase the capacity of soil for heavy metal accumulation, particularly for Cd and Zn in loamy soils rather than in sandy soils. Valdares *et al.* (1983) showed that it was possible to use high doses of sewage sludges containing high heavy metal concentrations in calcareous soils. They also observed that plant absorption of Ni and Zn was significantly greater in acid soils than in calcareous soils; furthermore, Ni and Cd concentrations in extracts of a mixture of sludges and calcareous soils were significantly lower than acid soils. King in 1988, when studying the retention of metals for several soils of the southeastern United States, found the following sequence: Pb > Sb > Cu > Cr > Zn > Ni > Co > Cd, considering pH, Fe oxides and clay contents as the principal parameters responsible for this retention.

Several other studies have been carried out in irrigation district 063. The results obtained in this work were similar to those described by Gutiérrez (1982). The maximum values reported by Gutiérrez (1982) for total Cd, Cu, Mn and Zn were 8.0, 95, 600 and 345 ppm, respectively. García *et al.* (1988) studied the degree of contamination by Pb, Cd and Cr in soils and plant tissues and found that the concentrations of Cd and Cr were slightly above the permissible levels. Méndez (1982) made a study of some heavy metals, boron and detergents in this region of the Mezquital Valley. The results of his study on Cu, Mn and Zn were also very similar to the ones determined in this work. All this indicates that the total concentrations of Cd, Cu, Mn and Zn have remained more or less constant in the course of nine years.

CONCLUSIONS

The data obtained from the profiles irrigated with wastewater show that there is an accumulation of Cu, Mn and Zn in the top layers of soils. This process of accumulation appears to be dependent of the organic matter and silt contents. In the case of Cd, due to the fact that it is present in a lesser extent in chelation reactions with humic substances of the soil, this element did not show significant accumulations in the Ap horizons of the profiles studied. Consequently, Cd was more inclined to show a slight movement towards the deepest layers of the profiles. This fact can increase the risk of contamination of underground water.

Not all metals studied here were associated with the same soil properties; however, soil texture and calcium carbonate contents are important factors which favor the capacity of heavy metal accumulation, particularly in the upper layers. This could bring as a consequence a low availability of metals for plants.

Although several research studies on heavy metals have been carried out in this area, there are still many unknown problems which will require further research in the future.

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