Distribution and absorption of lead by maize plants cultivated in biosolid treated soil

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ABSTRACT. Although sewage sludge (biosolid) provides nutrients for plant growth, its successive use may result in the accumulation of heavy metals to levels detrimental to the environment. Pb behaviour in red nitosol with twice-treated contaminated sewage sludge at interval of 18 months was analysed. Soil samples received five different treatments: one with biosolid without Pb (control); two with biosolid with Pb in concentration 2,500; 5,000 $\mu g\ g^{-1}$; two with Pb plus cadmium (Cd) (as interferer) in the same concentration 2,500 + 2,500 and 5,000 + 5,000 $\mu g\ g^{-1}$, respectively. Pots containing the treated soil were cultivated with maize in a green house for 75 days. Pb was extracted by nitric perchloric digestion and analyzed by atomic absorption spectrometry. Soil samples with sewage sludge and contaminated by Pb presented a higher concentration of lead at 0-20 cm deep. Metal concentration remained constant in all treatments at 20-60 cm deep. Low absorption of Pb by plants was detected.

Key words: sewage sludge, heavy metal, lead, environmental pollution.

RESUMO. Distribuição e absorção do chumbo por plantas de milho cultivadas em solo tratado com biossólido. O uso continuado de biossólido no solo pode resultar na acumulação de metais pesados em nível prejudicial ao ambiente. Neste intuito, foi estudado o destino do Pb em um Nitossolo Vermelho, tratado duas vezes com biossólido contaminado, num intervalo de 18 meses. Amostras do solo de 0-80 cm de profundidade foram colocadas em sua posição natural em vasos de PVC. Os solos de 0-20 cm de profundidade de cada tubo receberam cinco tratamentos: um com biossólido sem Pb (controle); dois com biossólido com Pb na concentração 2.500; 5.000 $\mu g\ g^{-1}$; dois, com a mistura de Pb mais cádmio, Cd (interferente) na mesma concentração 2.500 + 2.500 e 5.000 + 5.000 $\mu g\ g^{-1}$; respectivamente. As amostras de solo tratado foram recolocadas nos respectivos vasos e o experimento, com três repetições, foi desenvolvido em casa de vegetação utilizando o milho como planta teste. Após 75 dias do plantio, foram feitas as coletas das plantas e dos solos. Depois da preparação das amostras e respectivas digestões com solução nitro-perclórica, a concentração de Pb foi determinada pela espectrometria de absorção atômica. As amostras de solo de 0-20 cm, tratadas com biossólido contaminado, apresentaram as maiores concentrações de Pb. A concentração do metal permaneceu constante ao longo do restante da coluna de solo (20-80 cm). A concentração de Pb extraída pelas plantas permaneceu abaixo dos níveis fitotóxicos.

Palavras-chave: biossólido, metal pesado, chumbo, poluição ambiental.

The application of sewage sludge in agriculture has become a common practice (Andreoli *et al*., 1999). Home and industrial sludges may have a beneficial effect on plant growth and crop yields when applied to soils due to organic matter and nutrients present. However, the presence of heavy metals in sewage sludge (*e.g.*, Pb, Cd, Cr, Cu Ni and Zn) may be an important factor that limits its usage (Betiol and Camargo, 2000).

Many research projects have evaluated the agronomic and environmental effects of applying biosolids to cropland. Research efforts have emphasized the impact of trace metals of sewage sludge applied to soil and their uptake by plants (Berti and Jacobs. 1996). Sewage sludge may be used in agriculture manure to increase yield. However, as time goes on, metal accumulation may cause serious problems, since high concentrations of Cd, Cu, Ni, Pb and Zn in the sludge may be toxic to plants.

High concentrations of metals may change the plant's biological processes, such as photosynthesis, respiration, enzyme activity and growth, which may result in a lower production (Malavolta, 1994). Other studies have shown a yield increase after sludge application.

Berton *et al.* (1989) have detected a significant increase in the production of dry matter and in N, P, Ca, Mg and Zn absorption by maize in 5 different soils in the state of São Paulo (Brazil) using higher sludge doses (40 and 80.t ha^{-1} of dry matter).

Silva (1995) used sludge doses of 0, 20 and 40 $t.ha^{-1}$, supplemented by N, P and K nutrients, and detected a linear increase in sugar cane production during the first year of crop. No heavy metal was found in the sugar syrup produced in this experiment.

Using 0, 20, 40, 80 and 160 $t.ha^{-1}$ doses, wet base, Da Ros *et al.* (1993) observed a significant increase in dry matter production of millet and oat associated with vetch. This effect was observed in two different ways: immediate effect on millet production and residual effect on production of oat associated with vetch. There was a reasonable increase in N, P and K absorption by millet when sewage sludge was used.

According to report above, it may be perceived that there is no general agreement concerning the exact dose of sewage sludge for each crop. This may be due to great fluctuations in its composition, the difficulty in foreseeing the behavior of metals in different types of soil and distinct nutritional requirements of each crop.

Many researches have been studying the situation of heavy metals due to their mobility and accumulation in the environment (McBride *et al*., 1997; Baveye *et al*., 1999; Illera *et al*., 2000; Ge *et al*., 2000). Several studies have addressed the heavy metal potentiality to leach from a lower layer up subsoil surfaces. Most of these studies concluded that a downward movement of heavy metal either did not occur (Chang *et al*., 1982; Emmerich *et al*., 1982) or was limited to a depth of 10 cm or less below the zone of incorporation (Chang *et al.* 1984; MacGrath and Lane, 1989; Yingming and Corey, 1993). They generally worked with a soil layer containing the highest fertility index widely used for agricultural purposes, i.e., 0-20 cm of deep layer. Lead accumulates at the first centimetres of soil surface and its concentration decreases at greater depths. Such a distribution occurs as a result of recycling of Pb linked to organic material used by plants. As a rule, anthropogenic Pb has the same distribution, even though, in some cases, it may be found at 30-45 cm (Malavolta, 1994). It has been found that 90% of metals remained at the first 15 cm for over 6 year in sewage sludge-treated soil (Chang *et al*., 1984).

Alloway (1990) states that lead accumulates in soils and sediments due to its low solubility and to the fact that it undergoes no microbial degradation. Brady (1989) has mentioned that Pb is almost insoluble in soils, especially in a non-acid environment.

Soil factors such as pH, CTC, organic content, texture and clay composition, redox potential, competition with other metals for absorption and chelation sites as well as temperature and microbial activity control residue degradation processes and, consequently, the solubility and mobility of metals in the soil (Lindsay, 1979).

Heavy metals react with diffusing binders, macromolecules and membrane binders. This fact results in accumulation, bioaccumulation, biomagnification in the food chain and disturbances in the metabolic processes of living organisms. Bioaccumulation and biomagnification transform normal concentrations into toxic concentrations for different biotic species and for man (Tavares and Carvalho, 1992).

Thus, it is necessary to be fully aware of the use of organic fertilizers produced from sewage sludge. There is always the possibility that these products have high concentrations of heavy metals. Once in the environment, metals accumulate in soils and plants and may cause serious damage to health when diffused throughout the different levels of the food chain.

The objective of this work was to study the behavior of the heavy metal Pb in red nitosol treated with sewage sludge contaminated by lead in which maize was cultivated after 18 months from the first treatment.

Material and methods

Soil

Samples of red nitosol ("terra roxa") were collected vertically at 20 cm intervals up to a depth of 80 cm from the region of Maringá (Paraná, Brazil). Typical chemical and physical properties of the Red Nitosol are shown on Table 1.

Biosolid (sewage sludge)

Sewage sludge was collected at SANEPAR (Companhia Paranaense de Saneamento - Paraná Company of Sanitation) Sewage Treatment Plant, Maringá (PR). After homogenized and dried, three portions were taken, digested in a nitric perchloric solution; K, Ca, Mg, S, Cu, Zn, Fe, Mn, Pb and Cd concentrations were determined by atomic absorption spectrometry (flame mode). Concentrations of N, P and C were determined according to methodology describe by Embrapa (1999) and Pavan *et al.* (1992). Table 2 shows results of the sludge analysis.

Table 1. Chemical and physical characteristics of soil (Red Nitosol) at 0 - 20 cm depth level used in the experiment

Soil	pH (H_2O)	Al^{3+}	$H^+ + Al^{3+}$	Ca^{2+}	Mg^{2+}	K^+	Fe	Cu	Mn	clay	silt	sand
		←— $cmol_c\ dm^{-3}$ —→					← $mg\ dm^{-3}$ →			←— % —→		
RN	5.80	0.00	0.72	3.74	1.32	0.190	119	25.9	448	52.0	27.0	21.0

RN -Red Nitosol

Table 2. Chemical characteristics of original sewage sludge (biosolid) used in the experiment

Material	N	P	K	Ca	Mg	S	C	Cu	Zn	Fe	Mn	Pb	Cd
	←— % —→							←— $\mu g\ g^{-1}$ —→					
Sludge*	2.92	0.82	0.18	3.08	1.02	0.32	24.3	146	1327	6128	262	122	3.50

* Sewage sludge

Soil and Plant Sampling

An experiment in PVC (polyvinylchloride) pots (θ = 10 cm and height = 80 cm) was carried out in a green house. Along the vase, beginning from 20 cm in depth, gauge tubes containing the same soil of the vase were placed vertically at 10 cm intervals up to 60 cm (Figure 1 - Part A). The internal part of the gauge tubes containing samples for analysis was perforated to allow water (soil solution), together with the contaminator, to flow throughout the soil in gauge. Concentration, percolation, and possible diffusion could be determined (Figure 1 - Part B).

The first layer of each vase (0-20 cm) was manured with a 6 $t.ha^{-1}$ dose of sewage sludge with five treatments related to the lead contaminator. Treatments consisted of sewage sludge without Pb^{2+}, control test, two with sewage contaminated by Pb^{2+} 2,500 and 5,000 $\mu g.g^{-1}$. And finally, two treatments with a mixture of lead (Pb^{2+}) plus cadmium (Cd^{2+}), as a possible interferer to lead behavior, in concentrations of 2,500 and 5,000 $\mu g.g^{-1}$, respectively. This experiment was implanted 18 months after the first treatment had been developed under the same conditions. All treatments were carried out in three replicates.

The pH values were determined by glass electrode potentiometer (soil:water ratio at 1:2.5). Liming need was determined by SMP method. Calcium carbonate and magnesium carbonate was used for liming at a ratio of 3:1. The soil was incubated for 15 days to achieve pH value 6.5.

After the incubation period, five maize seeds were sown in each pot. Seven days after germination, plants were selected and three plants per pot were left. The shoots were tended daily. Random shiftings were made in the pot position. In order to allow the percolation of contaminants, plants were watered every seven days with twice as much water as that generated by the highest rainfall season in Maringá (PR) area during the last 21 years (151.5 mm) (Ministério da Agricultura, 1977). Percolated water was collected and Pb content analyzed by atomic absorption spectrometry, air/acetylene flame mode, after samples acidification (HNO_3) and pre-concentration with reducing volume.

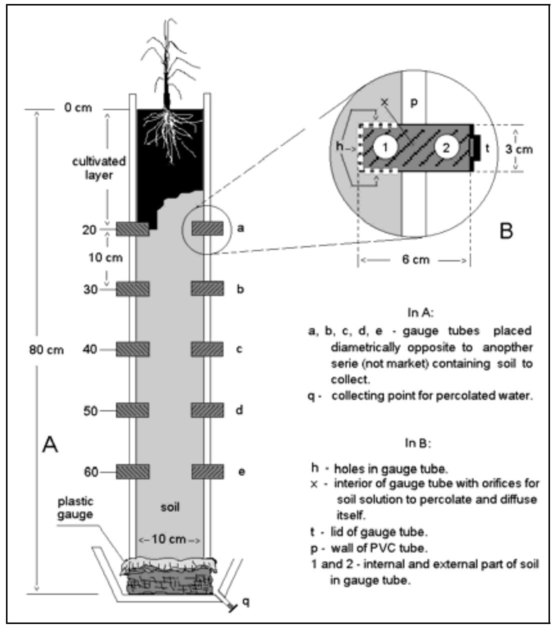

Figure 1. A - Vertical cross-section representation of front PVC tube (ϕ = 10 cm; height = 80 cm) with soil and gauge tubes. B - Amplification of cross-section of gauge tube

Plant and soil analysis

Seventy-five days after the emergence of the maize plants, the shoot part of maize plants was cut close to the ground. It was then placed in a stove at 80°C for 48 hours (Scott *et al.*, 1971), weighted, ground and digested with a mixture of nitric and perchloric acid (Malavolta, 1997). Pb concentration was determined by atomic absorption spectrometer, air/acetylene flame mode (Welz and Sperling, 1999; Analytical Methods Committee, 1987).

At the same time, soil samples from the 0-20 cm level and from the gauge tube were taken. Samples from each gauge tube were divided into internal (**i**) and external (**e**) samples. They were ground in a porcelain mortar and sieved. Soil samples were digested with a mixture of nitric and perchloric acid (Horwitz, 1980). Pb concentration was obtained by atomic absorption spectrometry, air/acetylene flame mode.

Treatments were evaluated by variance analysis and Tukey's test at 5% level by SANEST software.

Results and discussion

Total metal within the profile of amended soil

Sewage sludge may be an important source of heavy metals in agricultural soils (Hooda and Alloway, 1994). Experiment showed that, in the second application of Pb contaminated sewage sludge, after 18 months interval from first application, an accumulation of Pb was observed in the Red Nitosol (Table 3 and Figure 2).

According to the results of Pb concentration in the soil (Table 3), after two applications, a higher concentration of this metal was detected in the 0 - 20 cm layer. In 20-60 cm layer, the concentration of Pb remained stable and there was no significant difference between Pb concentrations in the internal and external sections of the gauge tube. On the other hand, Pb was not detected in the collected percolation water in the simulation of the highest rainfall season of Maringá region. It may be supposed that there was no percolation and that diffusion process of this heavy metal throughout the soil column was probably minimum or it was not detected in this experimental condition. These results agree with those obtained by other researchers (Silva, 1997; Chang *et al*., 1984).

Table 3. Pb concentrations, $\mu g\ g^{-1}$, in Red Nitosol

Depth		Treatments				
		Control	Pb (2,500)	Pb (5.000)	Pb (2,500) + Cd (2,500)	Pb (5,000) + Cd (5,000)
Surface		87.72 a	119.50 a	176.25 a	124.55 a	157.92 a
20	**i**	65.90 b	61.28 b	69.69 b	75.52 b	80.37 b
	e	68.83 b	61.39 b	69.44 b	77.56 b	78.74 b
30	**i**	70.55 b	62.02 b	69.22 b	74.69 b	72.10 b
	e	72.44 b	62.80 b	68.58 b	71.63 b	71.42 b
40	**i**	72.97 b	63.44 b	68.64 b	73.41 b	72.28 b
	e	73.88 b	62.44 b	67.41 b	75.30 b	72.28 b
50	**i**	74.78 b	61.33 b	67.82 b	77.69 b	71.22 b
	e	72.08 b	59.72 b	67.05 b	73.19 b	72.86 b
60	**i**	65.64 b	60.75 b	67.42 b	72.16 b	74.38 b
	e	64.78 b	59.83 b	69.02 b	69.47 b	73.50 b

i - internal part of the gauge tube; e - external part of the gauge tube; (a, b, …) -Values followed by the same letter are not significantly different at 5% level for each depth

Many researches showed that distribution of metals concerning depth in the profiles of sludged soils presented little downward movement (Alloway and Jackson, 1991). Nyamangara and Mzezewa (1997) in their sewage sludge treatment research reported significant EDTA-extractable metal accumulation in the topsoil (Pb: 0-15 cm) with no evidence of further movement. Increases in metal concentrations below the depth of 30 cm, however, did not appear to be significant when compared to background values. This suggests that the movement of metals downward in the soil profile was minimal (Zhang *et al.*, 1997; Sterckeman *et al.*, 2000). However, other authors have reported a more pronounced movement of metals within the profiles of amended soils (Baveye *et al.*, 1999; Planquart *et al.*, 1999). Among the metals in this investigation, Pb is often mentioned as the less mobile (Sheppard and Thibault, 1992; Matos *et al.*, 1996).

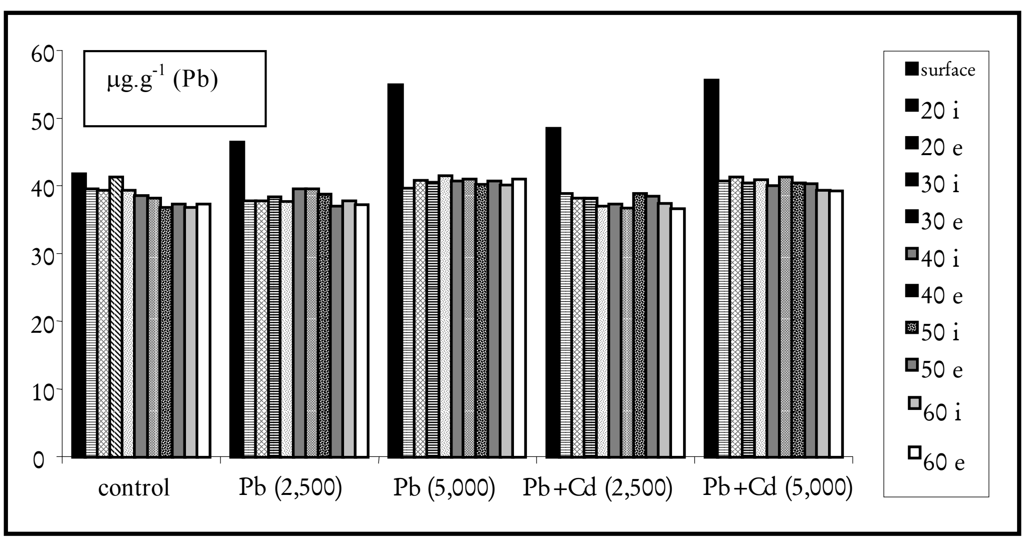

Figure 2. Concentration of Pb in soils treated with sewage sludge contaminated - first application (Silva, 1997)

The accumulation of Pb to the surface soil depth may be attributed to the high affinity of metals to organic matter (McGrath and Lane, 1989). In this study, the process may have also been facilitated by pH values in the surface soil of the sludge treatment. Organic matter and pH are the most important factors that control the availability of heavy metals in the soil (Ge *et al.*, 2000; Illera *et al.*, 2000).

In such an experimental condition the interactions or interferences of Cd on Pb behavior in the treated soils were not significant.

The typical behavior of Pb in contaminated soils includes high retention (Amaral Sobrinho *et al*., 1997), low mobility (Matos *et al*., 1996; Sheppard and Thibault, 1992; Chang *et al*., 1984) and low bioavailability (Kádár, 1994; Alloway, 1990). This behavior is associated with its high affinity to the fractions: Fe-oxide, Mn-oxide and residual. (Amaral Sobrinho *et al*., 1997; Gomes *et al*., 1997; Zufiaurre *et al*., 1998). According to Adriano (1986), available forms of Pb, soluble + exchangeable, resulting from sewage sludge application correspond to 1.6% - 8.0 % of total accumulation.

Concentrations of trace metal in plant tissues

Table 4 shows the results of Pb concentrations in the shoot of maize plants. Little absorption of metal by the maize plants was detected. Pb concentrations in plant samples (dry weight of plant tissue) may be classified according to levels of metal toxicity in plant species tabulated by Kabata-Pendias and Pendias (1992): a) normal concentration, 5-10 $\mu g\ g^{-1}$; b) excessive or toxic concentration, 30-300 $\mu g\ g^{-1}$; c); tolerance in agronomic crops, 10 $\mu g\ g^{-1}$. Table 4 shows normal levels of Pb concentration for all treatments. Concerning the production of dry matter, there was no significant difference between all treatments and control.

Table 4. Pb concentration and dry matter production of shoot maize plants

Treatment	Pb ($\mu g\ g^{-1}$) (*)	g/vase (*)
Control	2.40	32.41
Pb (2,500)	3.14	28.67
Pb (5,000)	4.89	27.98
Pb (2,500) + Cd (2,500)	2.44	27.46
Pb (5,000) + Cd (5,000)	4.71	29.14

(*) Results are means of three replicates

Absorption and translocation of metals in plants occur differently for each metal and culture (Wallace and Romney, *apud* Adriano 1986): a) B, Mn, Ni and Zn in plants are usually distributed more or less uniformly between roots and shoots; b) Co, Cu, Mo and Cd generally have higher rates in roots and are moderate to great quantities in shoots; c) Cr, Pb, As, Sn, Ti and V concentrate themselves mainly in roots and slightly in shoots. However, distribution standards may be modified according to species and to the concentration of the element in the layer.

Silva (1995) reported no effect in metal concentration in the tissue and in the export of Cd, Cr, N, Pb and Se in the sugar cane stalk + leaves with the addition of sewage sludge. Berti and Jacobs (1996) stated that Pb was not detected in the plant in all crops evaluated.

The little absorption of Pb by maize plants may be attributed to its probable retention in the roots (Malavolta, 1994) and to its high retention in the soil complex system (Hooda and Alloway, 1994; McBride, 1995; Berti and Jacobs, 1996; Sloan *et al.*, 1997; Zufiaurre *et al*., 1998).

The Pb concentration, detected in maize plants cultivated in soil treated with sewage sludge, is considered normal and lies below the phytotoxic interval reported in the literature.

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