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Research Article

Biomass and Yield of Peanut Grown on Tropical Soil Amended with Sewage Sludge Contaminated with Lead

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Application of sewage sludge with high lead (Pb) contents may pollute soils and contaminate crops. The objective of this work was to evaluate peanut responses to application of sewage sludge with varying Pb contents in order to supply phosphorus (P) to the plant. A greenhouse experiment was carried out with peanut grown on soil sample from a medium-textured Haplustox. Treatments were arranged in $3 \times 2 + 2$ factorial scheme, replicated three times, distributed in randomized block design, and consisted of: three Pb rates applied to soil with sewage sludge (3, 21, and 42 mg kg^{-1}) $\times$ two times of sewage sludge application (30 days before peanut sowing and at the day of the sowing) + mineral fertilization + control (without sewage sludge and mineral fertilization). Sewage sludge was efficient to supply P to peanut. Sewage sludge containing high rates of Pb, when applied, did not harm biomass and yield of the plant, but increased HCl-extractable Pb in soil and Pb content in shoot, roots, and pod husks. Increase of Pb content in pod husks may represent contamination risk of kernels and their products with fragments from husks detached during manipulation or industrial processing of peanuts.

1. Introduction

Lead in a naturally occurring trace element in soils with variable total concentrations depending on the parent material and prevalent pedogenetic processes [1], whereas its total content is far higher than the background concentrations in contaminated soils. Elevated Pb concentrations in soil may impact plants and soil microorganisms and cause serious effects in humans such as neurological problems and damages to the central nervous system [2].

Sewage sludge contains Pb and other heavy metals and its application on agricultural soils has been a way sought for disposal of high amounts produced of this waste particularly in large urban areas [3, 4]. While solving the problem of disposal repeated applications of sludge may increase Pb content in soils. Crops grown on these soils can uptake large Pb amounts and transfer it to edible parts [5]. Intake of these parts increases risks to human health.

Sewage sludge has been used in agriculture with the purpose of improving soil properties and to supply nutrients to crops [6]. In São Paulo state, Brazil, research results show the possibility of using the sludge to supply nutrients to sugarcane without impairing yield and quality of stalks [7] and with low potential for contamination of soil-plant system by heavy metals, including Pb [8]. However, it is essential to know the responses of other crops which might eventually be planted in areas of sugarcane grown on soils amended with sewage sludge. Peanut crop has been the preferred crop to grow in many traditional areas of sugarcane production in São Paulo state. In these areas, it is planted during reform of sugarcane plantation in order to establish a crop rotation. Responses of peanut to sewage sludge application are not known in Brazil.

Sewage sludge can increase peanut yield since it is applied in high rates because its content of macronutrients is relatively low [9]. As a phosphorus (P) source to the crop,

Table 1: Selected chemical characteristics of soil samples used in this study and interpretation of values†.

$pHCaCl_2$	OM	Resin P	K	Ca	Mg	SB‡	H+Al	CEC§	BS¶
	$g\ dm^{-3}$	$mg\ dm^{-3}$			$mmol_c\ dm^{-3}$				%
5.6	17.8	1.0	5.2	18.2	4.7	28.1	11.0	39.1	71.9
Low acidity	—	Very low	High	High	Low	—	—	—	High

† According to Raij et. al. [10].
‡ Sum of bases (K + Ca + Mg).
§ Cation exchange capacity (SB + H+Al).
¶ Base saturation ((SB/CEC) × 100).

Table 2: Contents of nutrients and Pb in original sewage sludge used in this study.

C	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Mo	Zn	Pb
		$g\ kg^{-1}$							$mg\ kg^{-1}$			
390.0	79.1	10.6	0.63	22.1	2.1	118.0	98.0	42224.0	242.0	9.8	1868.0	127.0

Table 3: Nutrients applied with sewage sludge and mineral fertilization to soil samples before peanut sowing.

Nutrient	Sewage sludge	Mineral fertilizer
	$mg\ kg^{-1}$	
N	1990.0	100.0
P	267.0	200.0
K	16.0	150.0
Ca	556.0	
Mg	53.0	
S		
B	3.0	5.0
Cu	2.5	15.5
Fe	1062.3	
Mn	6.1	22.2
Mo	0.2	3.1
Zn	47.0	50.0

it has been more efficient than other sources such as vermicompost, farmyard manure, poultry manure, and single superphosphate [11]. Furthermore, King and Hajjar [12] have found that sewage sludge applications to previous crops did not significantly increase Pb content in peanut plant. However, since sludge has a very varied composition in Brazil [13], it can contain high Pb contents and its agricultural use can contaminate soil and harm the peanut crop.

The objective of this work was to evaluate peanut responses to application of sewage sludge with varying Pb contents in order to supply P to the plant.

2. Material and Methods

A greenhouse experiment was carried out from November 2000 to March 2001 in Jaboticabal, São Paulo state, Brazil. Soil samples from 0–20 cm layer of a medium-textured Haplustox were used in this study. The samples were air-dried, sieved, homogenized, prepared, and chemically analyzed. Selected chemical characteristics of these samples are given in Table 1. Soil pH was measured in 0.01 M $CaCl_2$ (1 : 2.5 soil : solution ratio). Organic matter was obtained by Walkley-Black method [14]. Phosphorus, K, Ca, and Mg were extracted by an ion-exchange resin procedure [15]. Potential acidity (H+Al) was estimated by SMP-buffer alternative method [16].

Sewage sludge used in this research was obtained from a sewage treatment plant in Franca, São Paulo state, Brazil. Sludge air-dried revealed the composition shown in Table 2. The Pb content was below from maximum limit allowed in São Paulo state (840 $mg\ kg^{-1}$) [17]. To increase it, $PbCl_2$ was added and well-mixed to the sludge, and the mixture was incubated for 30 d. The reagent was applied to raise the Pb content to 840 and 1680 $mg\ kg^{-1}$, that is, 1 × and 2 × the maximum allowed, respectively. Thus, sewage sludges used in this work had three Pb contents: 127 (original content; see Table 2), 840, and 1680 $mg\ kg^{-1}$.

Soil samples were placed in plastic pots with capacity to 8 L. Each pot was filled with 8 kg of soil sample. In part of the pots, sewage sludges with varying Pb contents were applied and well-mixed to the soil 30 d before peanut sowing or at the day of the sowing. The rate of sludge was fixed and defined in order to supply the peanut P requirement, since soil had low availability of P (Table 1). It was applied equivalent to 25.2 $g\ kg^{-1}$ of sewage sludge. In this application, the following Pb rates were added to soil by sludge: 3, 21, and 42 $mg\ kg^{-1}$. In another part of the pots, mineral fertilizers were applied and well-mixed to soil at the day of the sowing. Fertilizers were the following reagents: $CO(NH_2)_2$, $Ca(H_2PO_4)_2$, KCl, H_3BO_3, $CuSO_4 \cdot 5H_2O$, $MnSO_4 \cdot 4H_2O$, $NaMoO_4 \cdot 2H_2O$, and $ZnSO_4 \cdot 7H_2O$. The rates of nutrients applied with sewage sludge and mineral fertilizers are presented in Table 3. Finally, some pots did not receive both products. These treatments were arranged in 3 × 2 + 2 factorial scheme [three Pb rates applied with sewage sludge (3, 21, and 42 $mg\ kg^{-1}$) × two times of sewage sludge application (30 d before peanut sowing and at the day of the sowing) + mineral fertilization (reagents) + control (without sewage sludge and mineral fertilization)] and replicated three times.

The pots were placed in a greenhouse and were organized in a randomized complete block design. In each pot, 9 seeds of peanut (*Arachis hypogaea* L. cv. Tatu) were sown, and 20 d after sowing, plants were thinned out, leaving 2 plants per

Table 4: Dry matter of peanut as a function of Pb rates applied to soil with sewage sludge, time of sewage sludge application, mineral fertilization, and control.

	Dry matter (g per pot)				
Treatment	Shoot	Roots	Pods	Pod husks	Kernels
Additional treatments					
Control	54.76a[†]	3.59a	32.61a	13.91a	18.10a
Mineral fertilization	46.31a	3.06a	41.22a	15.73a	25.49a
Sewage sludge					
Pb rate (mg kg^{-1})					
3	67.99a	5.28a	44.23a	17.02a	27.39a
21	66.81a	4.90a	47.50a	18.11a	29.44a
42	74.65a	5.42a	42.04a	16.98a	25.03a
Time of application					
30 d before sowing	77.14a	5.66a	41.18a	16.87a	24.40b
At the day of sowing	62.49a	4.73a	48.00a	17.87a	30.16a
Analysis of variance					
Source of variation	*F* test[‡]				
Additional treatments	NS	NS	NS	NS	NS
Pb rate	NS	NS	NS	NS	NS
Time of application	NS	NS	NS	NS	*
Pb rate × time of application	NS	NS	NS	NS	NS
Sewage sludge × additional treatments	*	**	*	*	NS
CV (%)	29.46	23.67	17.66	12.16	22.45

[†] Means followed by same letter in column within additional treatments and each factor of factorial do not differ significantly by Tukey test at $P < 0.05$.
[‡] NS: not significant. *, ** significant at $P < 0.05$ and $P < 0.01$, respectively.

pot. In all pots, except those which did not receive sewage sludge and mineral fertilizers, potassium was applied as KCl at the sowing and at 30 and 60 d after sowing. At each application, 50 mg kg^{-1} of K were added.

At 110 d after sowing, the plants were harvested, and a soil sample was collected from each pot. The plants were separated into shoot, root, pod, pod husk, and kernel, washed with distilled water, and dried in a forced-air oven at 65°C. After drying, all plant parts were weighed for determining dry matter. Plant material was digested in an acid mixture ($HNO_3 + HClO_4$) [18], and Pb was determined in extracts by atomic absorption spectrophotometry (AAS). Soil samples were air-dried, passed through 2 mm sieve, and Pb was extracted with 0.1 M HCl [19]. Lead concentration in soil extracts was determined by AAS.

Results were submitted to analysis of variance. When there was significance, means were compared by Tukey test at $P < 0.05$. Linear regression was adjusted to data of Pb rates and HCl-extractable Pb contents.

3. Results and Discussion

No significant differences in dry matter of shoot, roots, pods, pod husks, and kernels of the peanut between control and mineral fertilization were observed (Table 4). Phosphorus fertilization did not increase the plant dry matter but only increased the P content in the shoot (Table 5), probably due to the low P requirement of the peanut [20], confirmed by field studies [21, 22]. Another explanation for this lack of response to P fertilization is a possible Mg deficiency in the peanut (Table 5), which may have been induced by K application. Interactions between Mg and K have been previously reported [23]. In this case, as the soil used had high K content and low Mg content (Table 1), the applied K may have rapidly saturated the rhizosphere and restricted the Mg uptake, causing reduction in the Mg content in the shoot (Table 5). This probable deficiency induced by K application may therefore have limited the crop response to P fertilization.

When sewage sludge with increased Pb rate was added to soil, it did not significantly affect the dry matter of shoot, roots, pods, pod husks, and kernels of the peanut (Table 4). Time of Pb application also did not affect the dry matters of these plant parts, except for kernels, which were minor in Pb application 30 d before planting than at the day of planting (Table 4). This reduction was probably not directly related to Pb, because there was no rate effect of this heavy metal in kernel dry matter. Additional treatments significantly differed from Pb treatments in dry matter of shoot, roots, pods, and pod husks (Table 4). On average, dry matters of these parts were higher in Pb treatments than mineral fertilization and control together (in g per pot, 69.8 × 50.5 for shoot, 5.2 × 3.3 for roots, 44.6 × 36.9 for pods, and 17.4 × 14.8 for pod husks). Since Pb was added to soil with sewage sludge and Pb is not a nutrient, this positive effect of Pb treatments is due to the sludge and not to Pb. Although sewage sludge increased dry matter of non-kernel parts, there was no significant difference in kernel

Table 5: Phosphorus and Mg contents in peanut shoot as a function of Pb rates applied to soil with sewage sludge, time of sewage sludge application, mineral fertilization, and control.

Treatment	Nutrient content (g kg^{-1}) P	Mg
Additional treatments		
Control	0.8a[†]	4.1a
Mineral fertilization	1.7a	2.3b
Sewage sludge		
Pb rate (mg kg^{-1})		
3	1.8a	3.1a
21	1.9a	3.1a
42	1.8a	3.0a
Time of application		
30 d before sowing	1.9a	2.8a
At the day of sowing	1.8a	3.3a
Analysis of variance		
Source of variation	F test[‡]	
Additional treatments	**	**
Pb rate	NS	NS
Time of application	NS	NS
Pb rate × time of application	NS	NS
Sewage sludge × additional treatments	**	*
CV (%)	11.97	16.16

[†] Means followed by same letter in column within additional treatments and each factor of factorial do not differ significantly by Tukey test at $P < 0.05$.
[‡] NS: not significant. *, ** significant at $P < 0.05$ and $P < 0.01$, respectively.

production among sewage sludge treatments and mineral fertilization and control together (Table 4).

Sewage sludge treatment increased the P content in the shoot at the same level as mineral fertilization (Table 5), thus confirming its potential as fertilizer. Mohanty et al. [11] reported that sewage sludge was more efficient than single superphosphate to supply P to the peanut using a ^{32}P probing technique. Sewage sludge also increased the Mg content in the shoot as compared to mineral fertilization (Table 5), probably due to the Mg release from the sludge (Table 2), suggesting that the sludge minimized possible Mg deficiency induced by K application.

Lead content in the shoot was influenced by Pb rates applied with sewage sludge (Table 6). The highest Pb concentration in the shoot was 20.0 mg kg^{-1}, which is below the hypothetical reported toxicity threshold of 35 mg kg^{-1} in plant tissues [24], although the Pb concentrations in plants may vary in the range from 30 to 300 mg kg^{-1} [25]. The highest Pb content in the peanut shoot was not associated to reduction of the plant dry matter (Tables 5 and 6), and therefore 20 mg kg^{-1} in this case could be considered as nontoxic.

In the sludge treatments, the Pb contents in shoot, roots, and pod husks (Table 6) increased by 33%, 118%, and 130%, respectively. The pronounced increase in the roots as compared to the shoot suggests a limited translocation of Pb from root to shoot. Wierzbicka [26] and Verma and Dubey [27] have shown data that confirm this tendency for several other plant species. Studies have indicated that the roots act as a barrier for the Pb transport to shoot. In these studies, it was found that the Pb entries the roots and accumulates in the cell wall of endodermis cells, possibly due to the Pb movement restriction by Casparian strips [28–30]. Jarvis and Leung [31] have suggested that the Pb accumulation in the root is based on (i) binding of Pb^{2+} to ion exchangeable sites on the cell wall and (ii) extracellular precipitation, mainly in the form of Pb-carbonates deposited on the cell wall. The Pb retention in the root endodermis limits the Pb transport to the central vascular tissue, restricting the Pb translocation to shoot [32]. Thus, plants tend to prevent excessive accumulation of Pb in the shoot, and subsequent Pb redistribution to grains. King and Hajjar [12] reported no detection of Pb in peanut kernels grown on soil after repeated applications of metal-contaminated sewage sludge, including Pb. In the present work, kernels were not analyzed for Pb, and although it was observed limited Pb translocation, further studies are needed to assess whether kernels are not directly contaminated with Pb.

Contamination can also occur indirectly. In fact, it has been reported that the peanut husk has an ability to adsorb heavy metals in solution including Pb [33–35]. Based on this ability, it is hypothesized that Pb released from the sewage sludge passed to soil solution and a considerable part of it was adsorbed on the pod husk. This would explain the large increase of Pb content in the pod husk with increasing Pb rate. High Pb contents in the pod husk may contaminate the final products with fragments detached of the husk during manipulation or industrial processing. Therefore, the risk of Pb contamination of products derived from pods harvested from peanut crops grown on soil receiving elevated rates of sewage sludge with high Pb contents cannot be excluded by the presented data.

The HCl-extractable Pb significantly increased ($P < 0.01$) in soils amended with increasing Pb rates, with mean concentrations ranging from 0.94 to 6.89 mg kg^{-1} at Pb rates of 3 and 42 mg kg^{-1}, respectively (Figure 1). Borges and Coutinho [36] reported lower range (0.37 to 1.27 mg kg^{-1}) for Brazilian soils amended with no metal spiked sludge. The observed increase of Pb content in soil (Figure 1) was consistent with the increase of Pb in the plant (Table 6). Lead in soil was higher ($P < 0.05$) with Pb applied 30 d before sowing than in Pb applied in the day of sowing, probably due to longer time taken by Pb to be released from the sludge.

4. Conclusion

Sewage sludge with twice the maximum allowed content of Pb applied to soil to supply P to peanut did not harm biomass and yield of the plant. However, pod husks had their Pb contents increased, what may represent contamination risk of kernels and their products with fragments from husks detached during manipulation or industrial processing of peanuts.

Table 6: Lead content in peanut as a function of Pb rates applied to soil with sewage sludge, time of sewage sludge application, mineral fertilization, and control.

Treatment	Pb content (mg kg^{-1}) Shoot	Roots	Pod husks
Additional treatments			
Control	15.66a†	13.99a	10.66a
Mineral fertilization	15.32a	12.65a	9.66a
Sewage sludge			
Pb rate (mg kg^{-1})			
3	14.99b	15.99b	12.16b
21	18.99ab	24.49ab	16.50b
42	19.99a	34.85a	28.00a
Time of application			
30 d before sowing	17.88a	25.11a	17.44a
At the day of sowing	18.10a	23.10a	20.33a
Analysis of variance			
Source of variation		*F* test‡	
Additional treatments	NS	NS	NS
Pb rate	*	*	**
Time of application	NS	NS	NS
Pb rate × time of application	NS	NS	NS
Sewage sludge × additional treatments	NS	**	*
CV (%)	16.26	31.40	24.10

† Means followed by same letter in column within additional treatments and each factor of factorial do not differ significantly by Tukey test at $P < 0.05$.
‡NS: not significant. *, **significant at $P < 0.05$ and $P < 0.01$, respectively.

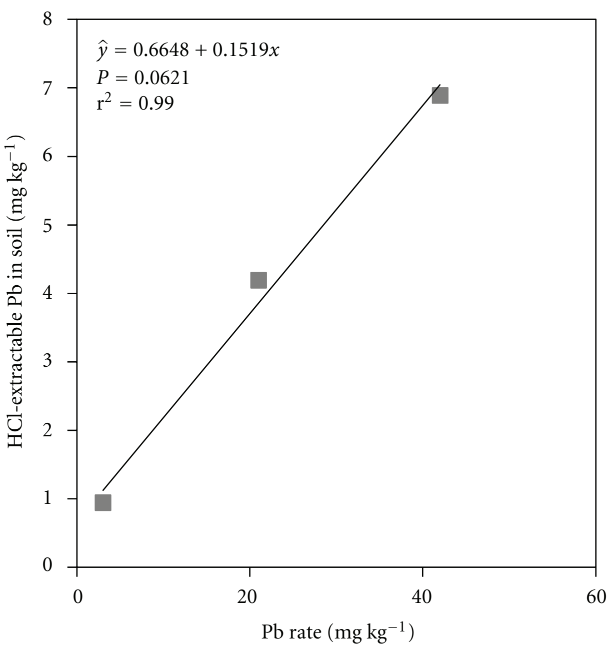

Figure 1: HCl-extractable Pb in soil as a function of Pb rates applied with sewage sludge varying content Pb.

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