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Soil Microbial Biomass After Three-Year Consecutive Composted Tannery Sludge Amendment*1

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ABSTRACT

Brazilian industry produces huge amounts of tannery sludge as residues, which is often disposed by landfilling or land application. However, consecutive amendment of such composted industrial wastes may cause shifts in soil microbial biomass (SMB) and enzyme activity. This study aimed to evaluate SMB and enzyme activity after 3-year consecutive composted tannery sludge (CTS) amendment in tropical sandy soils. Different amounts of CTS (0.0, 2.5, 5.0, 10.0, and 20.0 t ha^{-1}) were applied to a sandy soil. The C and N contents of SMB, basal and substrate-induced respiration, respiratory quotient (qCO_2), and enzyme activities were determined in the soil samples collected after CTS amendment for 60 d at the third year. After 3 years, significant changes were found in soil microbial properties in response to different CTS amounts applied. The organic matter and Cr contents significantly increased with increasing CTS amounts. SMB and soil respiration peaked following amendment with 10.0 and 20.0 t ha^{-1} of CTS, respectively, while qCO_2 was not significantly affected by CTS amendment. However, soil enzyme activity decreased significantly with increasing CTS amounts. Consecutive CTS amendment for 3 years showed inconsistent and contrasting effects on SMB and enzyme activities. The decrease in soil enzyme activities was proportional to a substantial increase in soil Cr concentration, with the latter exceeding the permitted concentrations by more than twofold. Thus, our results suggest that a maximum CTS quantity of 5.0 t ha^{-1} can be applied annually to tropical sandy soil, without causing potential risks to SMB and enzyme activity.

Key Words: Cr concentration, enzyme activity, industrial wastes, soil microbial properties, tropical soil

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INTRODUCTION

The tannery industry occupies an important place in the Brazilian economy with assets of 21 billion dollars per year (Silva *et al.*, 2010). However, this industry releases 1 million tons of tannery sludge annually, of which 3% is solid waste (Santos *et al.*, 2011), and this waste presents chemical elements produced after the tanning process. Landfilling is the main disposal method for tannery sludge in Brazil. Alternatively, application to soil has been suggested as a suitable method (Singh and Agrawal, 2008). As tannery sludge contains trace elements, mainly Cr, its direct application to soil may cause environmental contamination (Singh and Agrawal, 2008; Silva *et al.*, 2010) and may change the functioning of soil. Recently, alternative methods for tannery sludge recycling have been evaluated, such as composting process (Rihani *et al.*, 2010; Santos *et al.*, 2011; Gonçalves *et al.*, 2014).

Composting has long been recognized as one of the most cost-effective and environmental-friendly alternatives for organic waste recycling (Santos *et al.*, 2011), and has been used to process sludge from different origins, such as sewage, tannery, and textile sludge (Bernal *et al.*, 1998; Araújo *et al.*, 2007; Gonçalves *et al.*, 2014). During composting, plant nutrients present in the wastes are converted by microbial action into soluble forms that are available to plants (Ndegwa and Thompson, 2001). In addition, as reported by Araújo *et al.* (2009) for textile sludge, composting can also decrease or eliminate the toxicity of tannery sludge.

The knowledge of the effects of composted tannery sludge (CTS) on soil microbial properties, such as microbial biomass and enzyme activities, is important to

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understand the consequences of CTS amendment on soil quality and health. Soil microbial biomass (SMB), the living component of soil organic matter (SOM) (Jenkinson and Ladd, 1981), is considered as an early and sensitive indicator of soil stress caused by wastes (Araújo and Monteiro, 2006). Moreover, enzyme activities can provide an indication of quantitative changes in SOM as well as in soil microbial community composition and activity. Previous studies have been conducted on the effects of composted wastes, such as textile (Araújo and Monteiro, 2006; Araújo *et al.*, 2007) and tannery sludge (Santos *et al.*, 2011), on soil microbial properties under controlled laboratory conditions. Santos *et al.* (2011) evaluated the effects of CTS on SMB in a short-term study using a pot experiment with soil, and reported no significant effects on the SMB. On the other hand, the same study showed a decrease in dehydrogenase activity (DHA) and fluorescein diacetate (FDA) hydrolysis following CTS treatment. Furthermore, Giacometti *et al.* (2012) estimated, in short term, the effect of tannery waste on soil biochemical parameters, and found positive effects on SMB and activity, suggesting no toxic or detrimental effect of the waste on soil. However, the effect of repeated applications of tannery wastes should be tested in order to evaluate the possibility of medium- or long-term accumulation of Cr in soil as well as its effects on biochemical parameters (Giacometti *et al.*, 2012).

In fact, studies with repeated applications of CTS under field conditions, mainly in tropical soils, are scarce, and the limited information from earlier studies does not provide a clear picture. Therefore, a long-term study of CTS application was conducted in tropical sandy soil to evaluate the effect of consecutive CTS amendment on SMB and enzyme activities. We hypothesized that SMB and activity may shift in response to consecutive and cumulative addition of CTS and consequently Cr concentration may increase. Furthermore, as related by Araújo *et al.* (2013), we considered that soil alkalinity and salinity may increase after CTS application and affect SMB.

MATERIALS AND METHODS

The tannery sludge was collected from the wastewater treatment plant of a tannery industry located at Teresina City, Piauí State, Brazil. The compost was produced with tannery sludge and structuring materials (sugarcane straw and cattle manure) mixed at a ratio 1:1:3 (tannery sludge:sugarcane straw:cattle manure, v/v/v). The composting process was carried out using the aerated-pile method for 85 d. The size of the pile was 2 m × 1 m × 1.5 m. The pile was turned twice a week during the first 30 d and twice a month during the remainder of the composting process. The temperature of compost was approximately 70 °C during the first month, and decreased and remained at approximately 30 °C until the end of the process (USDA, 1980). At the end of the composting process each year, three samples were randomly collected from the CTS to evaluate its chemical properties. The water content was determined after oven drying the samples at 105 °C for 24 h, the pH and electrical conductivity (EC) were read directly, and the total solids were measured by drying the samples at 65 °C (APHA, 2005). The total organic C content was analyzed by oxidation of the samples with dichromate under external heating (Nelson and Sommers, 1996). The total N content was determined by the Kjeldahl method after sulfuric digestion of the samples (Bremner, 1996). The total Ca, Mg, K, P, S, Na, Zn, Cu, Cd, Pb, Ni, and Cr concentrations were determined using atomic absorption spectrophotometry after nitric digestion of the samples in a microwave oven (USEPA, 1986) and the results are shown in Table I.

TABLE I

Chemical properties of composted tannery sludge at the end of composting process in each year (2009–2011)

Chemical property	2009	2010	2011	Permitted limit[a)]
Water content (g kg^{-1})	651	704	680	-
pH	7.8	7.2	7.5	-
Electrical conductivity (dS m^{-1})	22.7	21.0	19.2	-
Organic C (g kg^{-1})	187.5	195.3	201.2	-
Total N (g kg^{-1})	12.8	13.9	15.1	-
C/N ratio	18.6	14.0	13.3	-
Total P (g kg^{-1})	4.02	3.83	4.91	-
Total K (g kg^{-1})	3.25	3.51	2.90	-
Total Ca (g kg^{-1})	95.33	84.28	121.18	-
Total Mg (g kg^{-1})	6.80	5.71	7.21	-
Total S (g kg^{-1})	9.39	8.43	10.20	-
Total Cu (mg kg^{-1})	17.80	19.51	16.38	1 500
Total Zn (mg kg^{-1})	141.67	128.31	127.81	2 800
Total Ni (mg kg^{-1})	21.92	28.61	23.26	420
Total Cd (mg kg^{-1})	2.87	3.93	1.93	39
Total Cr (mg kg^{-1})	2 255	2 581	1 943	1 000
Total Pb (mg kg^{-1})	42.67	38.54	40.31	300

[a)]Cited from CONAMA (2006).

The experiment was conducted under field conditions at the Long-Term Experimental Field of the Agricultural Science Center, Teresina City (05°05′ S; 42°48′ W, 75 m above sea level). The regional climate is dry tropical (Köppen), and is characterized by two distinct seasons, a rainy summer and a dry winter, with an annual average temperature of 30 °C and a rainfall level of 1 200 mm. The rainy season extends from January to April, during which 90% of the total annual rainfall oc-