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Physical soil properties after seven years of composted tannery-sludge application

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ABSTRACT. This study was performed to investigate the effects of composted tannery sludge (CTS) on the physical properties of tropical sandy soil after seven years of CTS application. CTS was applied to a Fluvisol at five rates (0.0, 2.5, 5.0, 10.0, and 20.0 Mg ha^{-1}) in experimental plots (sized 20 m^2) with four replications. Water infiltration into the soil was determined in the field with the concentric-ring infiltrometer method. Bulk density, total porosity, macroporosity, and microporosity were determined in the soil samples. The permanent CTS application altered the physical properties of the soil and led to a decrease in bulk density. The total porosity, microporosity and macroporosity values in the CTS-applied soil ranged from 44.1–51.7, 34.6–39.4, and 9.1–12.8%, respectively. Water-infiltration rates were significantly influenced by CTS. The cumulative infiltrated water in the soil varied from 21.3–34.7 cm. The basic infiltration rate was lower in the unamended soil and increased with an increase in the rate of CTS application. This study confirmed that the physical soil parameters improved after the permanent CTS application. Therefore, this application may be a suitable strategy for improving physical soil properties over time.

Keywords: soil properties; industrial effluent; composting; waste management.

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Introduction

Increased use of natural resources to satisfy the demand of the world population has increased the generation of industrial solid wastes such as tannery sludge (TS) (Miranda et al., 2018), which is a particular type of solid waste generated during the tanning process that promotes environmental pollution in case of disposal in the environment (Vergara & Tchobanoglous, 2012). Some studies have proposed alternative uses for TS such as soil conditioning (Alvarez-Bernal et al., 2006; Teixeira, Gonçalves, Filho, Carvalho, Araújo, & Santos, 2006); however, there are limitations involved in the direct use of TS in soil mainly due to its high Cr concentrations and alkalinity (Nur-E-Alam, Mia, Ahmad, & Rahman, 2020).

Since the direct use of TS in soil could lead to environmental issues, recycling alternatives of TS before its use in soil - such as composting - have been proposed (Silva et al., 2011; Singh et al., 2015). As a biological process, composting can decrease toxicity (de Moraes Cunha Gonçalves et al., 2020) and improve the quality of TS mainly in terms of chemical and biological properties (Araujo, Silva, Leite, Araujo, & Dias, 2013). Thus, composted tannery sludge (CTS) application in soil can improve soil fertility, organic matter content, and microbial biomass. Earlier studies reported improved soil properties and crop yield after permanent CTS application in soils (Araújo, De Melo, Araujo, & Van Den Brink, 2020; Miranda, Nunes, Oliveira, Melo, & Araujo, 2014). Araujo et al. (2020) reported higher organic matter content and nutrients, such as N, P, and K, while Araujo, Lima, Melo, Santos, and Araujo (2016) reported higher cowpea and maize yield after six years of CTS application. However, although the permanent CTS application changed the chemical and biological soil properties - i.e., soil organic matter content, nutrients, and microbial biomass - over the course of a few years, the effect of CTS on physical soil properties remained unclear.

Physical soil properties are essential for agriculture because they influence water availability, root growth, and absorption of nutrients (Almendro-Candel, Lucas, Navarro-Pedreño, & Zorpas, 2018). Increased organic matter content by permanent application of organic amendments improves physical soil properties, such as soil density, water-infiltration rates, hydraulic conductivity, aggregate stability, and soil porosity (Abdelrhman et al., 2021; Edeh, Mašek, & Buss, 2020; Ozores-Hampton, Stansly, & Salame, 2011). For instance, Maria, Chiba, Costa, and Berton (2010) assessed the effect of permanent sewage-sludge application on physical soil properties and reported a decrease in bulk density and microporosity, while microporosity increased after three years of sewage-sludge application.

Although the effect of organic amendments on physical soil properties is known, there is no information about the effect of permanent CTS application in sandy soil for several years. In this study, we hypothesize that the permanent CTS application in soil and the subsequent increase in soil organic matter content (Araujo et al., 2020) can improve the physical soil properties over time; hence, we evaluate the changes of the physical properties of tropical sandy soil after seven years of CTS application.

Material and methods

Study area

The experimental field was located at the Federal University of Piauí State, Brazil (05°05′ S, 42°48′ W; 75 m above sea level), which had undergone seven years of CTS application. The regional climate is *dry tropical*, As type according to the Köppen classification, characterized by two distinct seasons (wet and dry) and 30°C annual average air temperature. The soil is classified as fluvisol (Baxter, 2007). CTS was produced by mixing the tannery sludge with sugarcane bagasse and bovine manure (ratio 1:3:1; v:v:v) using aerated static pile composting for 90 days. The soil and CTS were analyzed according to Empresa Brasileira de Pesquisa Agropecuária [Embrapa] (1997) and United States Environmental Protection Agency [USEPA] (1996), respectively; their chemical characteristics are presented in Table 1.

Table 1. Soil properties and the composted tannery sludge used in the experiment.

Parameters	Soil	Tannery sludge
pH (1:2.5)	6.6 ± 0.6	7.5 ± 0.3
P (mg kg^{-1})	8.0 ± 0.4	4,900.0 ± 26.5
K^+ (mg kg^{-1})	23.5 ± 3.9	2,900.0 ± 55.7
Ca^{2+} (mg kg^{-1})	352.7 ± 8.1	121,000.0 ± 1,816.7
Mg^{2+} (mg kg^{-1})	44.9 ± 2.3	7,200.0 ± 165.2
Na^+ (mg kg^{-1})	3.6 ± 0.3	49,100.0 ± 327.9
OM (g kg^{-1})	12.2 ± 2.0	345.7 ± 5.0
Ni (mg kg^{-1})	---	23.0 ± 3.1
Cd (mg kg^{-1})	---	1.9 ± 0.2
Cr (mg kg^{-1})	---	1,943.0 ± 63.9
Pb (mg kg^{-1})	---	40.0 ± 2.6

Mean ± standard error (n = 3); OM – organic matter.

Since 2010, CTS has been applied to the soil at five rates (i.e., 0.0, 2.5, 5.0, 10.0, and 20.0 Mg ha^{-1}) in experimental plots (i.e., 20 m^2) with four replications. The annual CTS application was conducted by incorporation into the soil at 20 cm depth. Detailed information on this experiment can be found in Sousa et al. (2018).

Infiltration measurement

The concentric-ring infiltrometer method was used to assess water infiltration into the soil. The infiltrometer consists of a large (i.e., 50 cm in diameter and 30 cm in height) and a small metallic ring (i.e., 25 cm in diameter and 30 cm in height) according to Bernardo, Soares, and Mantovani (2006). The rings were installed in the soil at 15 cm depth, with the small ring inserted inside the large ring; subsequently, water was added simultaneously to both rings. Water infiltration was measured at 1, 2, 3, 4, 5, 10, 15, 20, 25, 33, 41, 49, 59, 69, and 79 min. after installation; the values obtained during this test were used to estimate the cumulative infiltrated water in the soil (CIW) as a function of time (T), while the parameters (i.e., k and n) proposed by Kostiakov (1932) were obtained by regression (i.e., $CIW = k \cdot T^n$). Water-infiltration rate was obtained by deriving the accumulated infiltration equation as a function of time (i.e., IR = dCIW/dt, or $IR = k \cdot n \cdot T^{n-1}$). As the water-infiltration rate generally stabilized between 59 and 79 min., 79 min. were considered as the upper limit for each infiltration measurement in this study. The average infiltration rate of the final 20 min. (i.e., 59-79 min.) was taken as the basic infiltration rate (BIR).

Soil sampling and analysis

After measuring the water-infiltration rates, soil samples were collected at 0–20 cm depth in each experimental plot for physical analysis. Undisturbed soil samples were collected using a ring (5 cm diameter and 5 cm height). Total porosity (TP) was estimated using gravimetric method from saturation volumetric humidity (θS); pore size distribution was determined by the tension table method for drainage, at a matric potential of - 6 kPa; macroporosity (MAC) is the volume of pores drained at - 6 kPa; and microporosity (MIC) are waterfilled pores at - 6 kPa water potential. The bulk density (BD) was calculated as the ratio between dry soil mass and the soil volume sample (Teixeira, Donagemma, Fontana, & Teixeira, 2017).

Chemical soil parameters were also assessed in air-dried and sieved (i.e., 2 mm) samples; soil pH, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and P were estimated according to Teixeira et al. (2017), while soil organic matter (SOM) was estimated through the wet oxidation method according to Embrapa (1997).

Data analysis

One-way analysis of variance (ANOVA) was employed to test whether the effects of the experimental treatments on the physical soil properties and water infiltration in the soil were significant. When effects were significant at the 0.05 probability level, the means of the factors were separated using Tukey's test. All analyses were performed using the R software with ExpDes.pt. Linear regression analysis was performed to explore the relationships between BD, SOM, and CTS rates. The correlations between accumulated water infiltration, BIR, and soil properties were assessed using Pearson's linear coefficients; a heat map was also applied to the correlation-matrix analysis. Redundancy analysis (RDA) with Monte Carlo permutation test (i.e., 999 permutations) was performed to examine which soil properties could contribute significantly to variations in cumulative infiltration and BIR; RDA was conducted using the vegan package. All analyses were implemented in R v 3.6.1 (R Core Team, 2019).

Results and discussion

The permanent CTS application changed the physical soil properties ($p < 0.001$; Table 2). BD decreased while SOM increased after CTS application (Figure 1), suggesting a positive effect of increased SOM on lower bulk density. Earlier studies have also reported increased SOM after permanent application of organic wastes (Arthur, Cornelis, & Razzaghi, 2012; Oldfield, Wood, & Bradford, 2017), which contributes to a decrease in soil density because organic matter naturally presents a lower density (Larney & Angers, 2012). In particular, Araujo et al. (2020) reported a significant SOM increase after the permanent CTS application.

Table 2. Descriptive statistics of soil properties after seven years of CTS amendment.

Treatment		Soil properties*						
		MIC*	TP	MAC	BD	SOM	CIW	BIR
		----------%----------			g cm^{-3}	g kg^{-1}	cm	cm h^{-1}
Control	Mean	35.9	45.2	9.3	1.58	8.49	21.3	13.4
	SD[a]	± 0.78	± 0.78	± 0.28	± 0.01	± 0.67	± 0.84	± 1.14
2.5	Mean	35.1	46.8	11.7	1.51	11.75	26.2	17.3
	SD	± 0.53	± 0.29	± 0.55	± 0.01	± 0.62	± 0.53	± 0.57
5	Mean	38.0	49.4	12.4	1.52	12.33	27.4	18.4
	SD	± 0.54	± 0.97	± 0.64	± 0.02	± 1.49	± 0.50	± 0.49
10	Mean	37.1	49.2	12.1	1.50	13.37	27.4	18.3
	SD	± 1.21	± 0.90	± 0.42	± 0.02	± 1.33	± 0.25	± 0.39
20	Mean	38.4	50.3	11.9	1.49	14.98	34.7	22.2
	SD	± 0.80	± 0.88	± 0.41	± 0.01	± 0.56	± 0.79	± 0.85
p - value		0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a]SD: standard deviation; *MIC: Microporosity; TP: Total soil porosity; MAC: Macroporosity; BD: Soil bulk density; SOM: Soil organic matter; CIW: Cumulative infiltrated water; BIR: Basic infiltration rate. Note: p – value was obtained in the analysis of variance.

CTS promoted significant shifts in soil porosity (Figure 2). TP ranged between 44.1 and 51.7%, while MIC and MAC ranged between 34.6 and 39.4%, and 9.1 and 12.8%, respectively. Water-infiltration rates were significantly influenced by CTS (i.e., $p < 0.001$; Table 2). CIW varied from 21.30 to 34.68 cm, where the highest CTS rate contributed to higher infiltration rate (Figure 3). In particular, the basic infiltration rates in each treatment were lower in unamended soil and increased with increasing CTS rates.

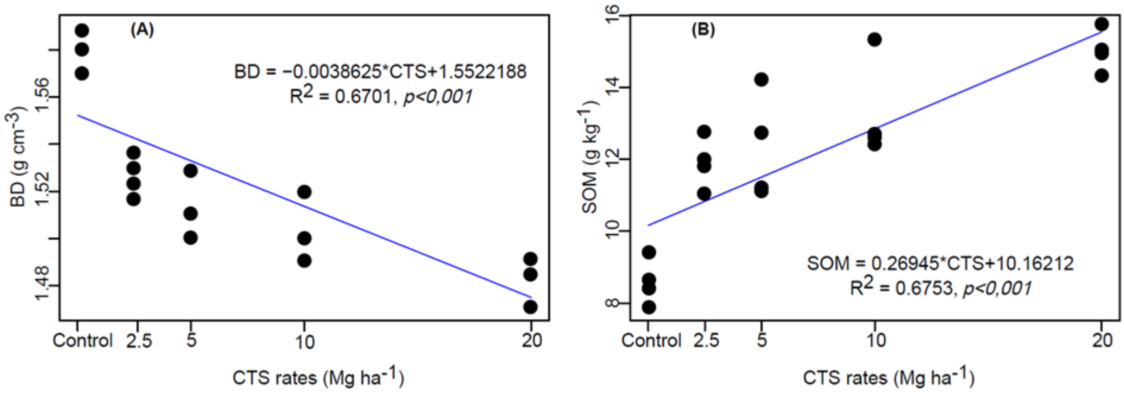

Figure 1. Scatter plot of BD: soil bulk density (A) and SOM: soil organic matter (B) versus CTS rates.

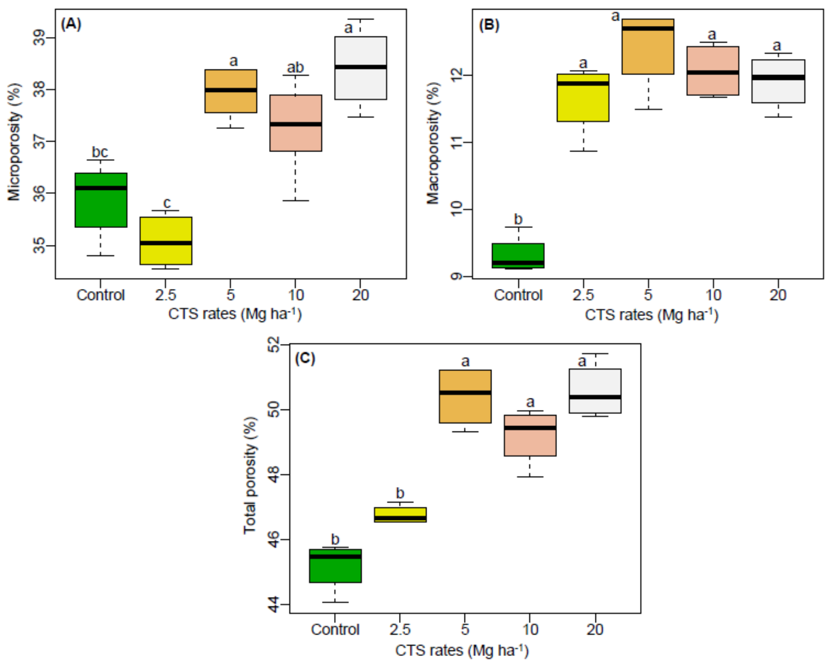

Figure 2. Box plot analysis of Microporosity (A), Macroporosity (B), and Total soil porosity (C) in a Fluvisol after seven years of CTS amendment (N = 20). Horizontal bars within boxes represent median. The tops and bottoms of boxes represent 75th and 25th quartiles, respectively. Boxes with different lowercase letters indicate statistically significant differences, based on Tukey's test (p < 0.01).

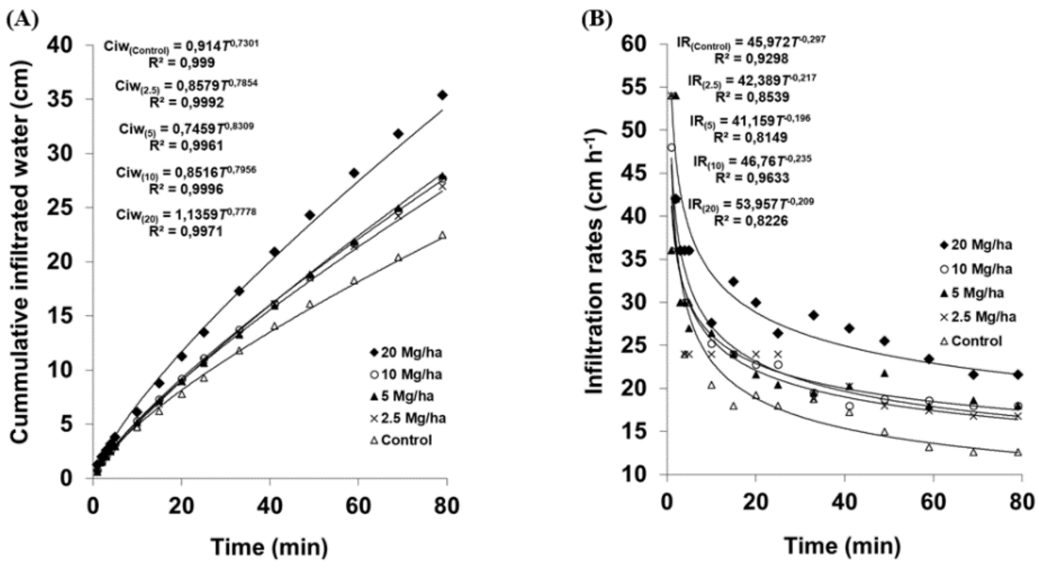

Figure 3. Cumulative infiltrated water (A) and Infiltration rates (B) in a Fluvisol after seven years of the CTS amendment (N = 20). Means for cumulative infiltrated water and infiltration rates were statistically significant at p ≤ 0.01.

Soil type is the main driver explaining variations in water-infiltration rates (Ma, Zhang, Zhen, & Zhang, 2015); however, as this study assessed one soil type, this variation in water-infiltration rates after CTS application could be attributed to the increased amendment of organic matter into the soil (Martens & Frankenberger, 1992; McGrath & Henry, 2016). Thus, the permanent CTS application contributed to consistently increasing CIW and BIR, which positively influenced the availability of water to plants (Desrochers, Brye, Gbur, & Mason, 2019). Similarly, Ozores-Hampton et al. (2011) assessed the effect of long-term application of composted and non-composted amendments (i.e., municipal solid waste, yard trimmings, and biosolids) on soil properties and observed lower soil density and higher water-infiltration rates.

Pearson's correlation analysis revealed the relationship between soil properties and water infiltration (CIW and BIR): significant correlations were found between CIW and BIR and all assessed soil properties (Figure 1). In addition, the RDA results explained 88.58% of the total variation and showed that the main soil properties drive the water-infiltration rates (Figure 4). BD (i.e., F = 15.95, p = 0.005), MAC (i.e., F = 7.88, p = 0.010), TP (i.e., F = 5.46, p = 0.025), and SOM (i.e., F = 4.93, p = 0.020) were the significant parameters influencing the water-infiltration rates in this study; however, some parameters, such as MAC, TP, and SOM, were positively correlated with water-infiltration rates, while bulk density was negatively correlated.

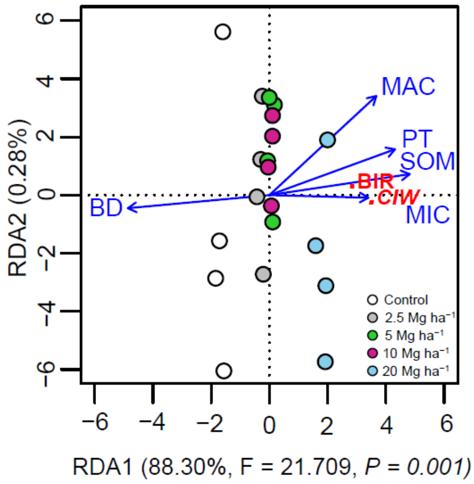

Figure 4. Redundancy analysis (RDA) between soil properties after seven years of CTS amendment in a Fluvisol (n = 20). BD: Soil bulk density; TP: Total soil porosity; MAC: Macroporosity; SOM: Soil organic matter; CIW: Cumulative infiltrated water; BIR: Basic infiltration rate. Arrows represent the soil physical properties.

These results show that the physical soil properties that positively drive the water-infiltration rates in a CTS-treated soil may be associated with higher SOM content promoted by CTS application because SOM also influences the majority of soil properties (McGrath & Henry, 2016; Mendonça et al., 2009; Tejada, Gonzalez, García-Martínez, & Parrado, 2008; Tejada, García-Martínez, & Parrado, 2009). This explanation can be supported by the relationship between CTS rates and SOM content, as well as the relationship between SOM and soil properties. The positive effects of SOM on water-infiltration rates can be explained by i) the improved soil structure, and the increased water maintenance and MIC (Gregorich, Carter, Angers, Monreal, & Ellert, 1994; Horn & Peth, 2009), and ii) the decreased soil density (Johnston, Poulton, & Coleman, 2009; Santos et al., 2018).

Trannin, Siqueira, and Moreira (2008) evaluated the use of different doses of industrial biosolids in a distrophic Inceptisol under *Brachiaria* sp. and found that the addition of this type of waste resulted in increased TP and MIC, and reduced BD; however, Xin, Zhang, Zhu, and Zhang (2016) reported that the application of organic compost in Fluvisols Calcaric for 23 consecutive years decreased BD and increased the porosity, but did not significantly alter MAC.

Earlier studies have also reported that SOM improves physical soil properties and increases water-infiltration rates (McGrath & Henry, 2016; Mendonça et al., 2009; Tejada et al., 2008; 2009). The observed MIC and MAC increases indicate that there was an increase in inter-aggregate spaces, which are responsible for the aeration, infiltration, and drainage of water in the soil, as well as in the internal and intra-aggregate spaces, which are responsible for water retention (Schjønning & Lamandé, 2010). Our findings are important because increased soil porosity results in increased air and water movement, thus improving the soil environment for plants (Abraha, Tesfamariam, & Truter, 2019; Oladele, 2019).

Conclusion

Permanent composted tannery-sludge application results in a significant increase in soil organic matter, thereby improving the chemical and physical soil properties over time. This study confirmed that the physical soil parameters improved after the permanent composted tannery-sludge application; therefore, this application can be a suitable strategy for improving physical soil properties over time.

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