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Effect of applying compost from gelatin industry residues on sweet potato yield and soil properties

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Abstract

Sweet potato crops produce a high quantity of tuberous roots within a short period. Thus, a proper soil fertility is essential for reaching the crop production potential. The objective of this study was to assess the effect of applying different rates of a compost produced from gelatin industry residues on the total and commercial yields of sweet potato crops, tuberous root shape, and soil physical and chemical properties. The treatments consisted of five compost rates (0, 6, 12, 18, and 24 Mg ha^{-1}) arranged in a randomized block design with five replications. The compost application did not affect total and commercial yields (48.37 and 41.53 Mg ha^{-1}, respectively) but changed the shape of sweet potato tuberous roots. The compost application did not change soil physical properties but increased the pH, Ca, P, sum of bases, cation exchange capacity, and base saturation. The findings indicated that the application of compost from gelatin industry residues improves the fertility of low-fertility sandy soils.

Keywords: composting; *Ipomoea batatas*; soil fertility; soil physics; root shape.
Abbreviations: Al_aluminum; B_boron; C_carbon; °C_degree Celsius; Ca_calcium; Cu_copper; Fe_iron; K_potassium; Mg_ magnesium; Mn_manganese; N_nitrogen; Na_sodium; P_phosphorus; pH_hydrogen potential; S_sulfur; Zn – zinc.

Introduction

Sweet potato is among the most important foods in the world, as it is source of calories, proteins, vitamins, and minerals (Yang et al., 2017). Sweet potato plants produce a substantial amount of food per unit area and time (Rós et al., 2012; Rós, 2017; Rós et al., 2023). Sweet potato crops are primarily grown for human consumption, but also for animal feed (Gakige et al., 2020; Mibach et al., 2021) and ethanol production (Weber et al, 2020; Rizzolo et al., 2021).
Considering their high yields, sweet potato crops extract a large amount of nutrients from the soil, especially nitrogen, potassium, and calcium (Echer et al., 2009; Fernandes et al., 2020). Thus, these crops are highly affected by nutritional deficiency, which results in delayed plant development and lower yield and quality of tuberous roots (Paulo, 2013).
Research findings have indicated that sweet potato plants respond well to soil fertilizer applications (Floyd et al., 1998; Rós et al., 2014; Mukhongo et al., 2017). The required nutrients for this crop can be provided by the existing nutrients in the soil or through application of organic or mineral fertilizers (Rós et al., 2014; Oliveira et al., 2017).
The application of organic fertilizers can provide greater benefits to the soil chemical and physical properties compared to the application of chemical fertilizers (Salomão et al., 2020), resulting in higher crop yields. Studies have shown improvements in sweet potato crop yield when applying chicken manure (Rós et al., 2014; Désiré et al., 2017) or organic composts (Aguirre et al., 2020) compared to the application of chemical fertilizers.
Organic fertilizers can decrease density and increase total porosity of soils (Xin et al., 2016), promoting the growth and development of the root system of sweet potato plants. Rós (2017) found higher production of tuberous roots with increased dry matter content in areas with lower soil density and higher total porosity. Improvements in these soil properties also reduce the production of crooked tuberous roots, which have lower commercial value (Paulo, 2013).
These fertilizers are also important for maintaining soil fertility and crop yield in systems where the same crop is grown sequentially in the same area (Conz 2021), as they provide a slower and more gradual release of chemical elements compared to mineral fertilizers (Sediyama et al., 2009), thus reducing losses through leaching (Rós et al., 2014).
Besides animal manure, organic residues from industrial processes can be used as fertilizers, which, in general, increase soil organic matter and pH (Guimarães et al., 2012). Studies have shown that the use of residues from slaughterhouses (Souza et al., 2012) and industries such as cellulose and paper, beer (Maeda et al., 2006), gelatin (Guimarães et al., 2012; Araújo, 2016), sugar, and alcohol (Menezes et al., 2021) has resulted in benefits for both soils and crops. These residues can be processed through composting, transforming them into stable and sanitized products rich in humic compounds without posing risks to the environment (Valente et al., 2009).
Changes in soil fertility depend on the soil physical and chemical properties, as well as the type and amount of organic compost applied (Carmo et al 2016). The benefits of applying organic compost to soil properties and crop yield are greater when using higher amounts and frequencies of application (Diacono and Montemurro, 2011; Salis et al., 2024). Besides improving soil properties, the use of compost

contributes to reductions in the volume of industrial residues and the presence of potentially harmful organisms in these residues (Pergola et al., 2017).
Thus, the objective of this study was to assess the effect of applying different rates of a compost produced from gelatin industry residues on the total and commercial yields of sweet potato crops, tuberous root shape, and physical and chemical properties of a sandy soil.

Results and Discussion

Yield characteristics of sweet potatoes

The applied organic compost rates had no significant effect on total yield (48.37 Mg ha^{-1}), commercial yield (41.53 Mg ha^{-1}), commercial tuber length (19.13 cm), commercial tuber fresh weight (276.25 g), and commercial tuber dry weight (24.80%) of the evaluated sweet potato plants.
Sweet potato crop responses to soil fertilizer application depend on the initial soil fertility conditions. Sweet potato plants grown in moderately to highly fertile soils show little or no response to soil fertilizer applications; however, the crop yield increases in response to fertilizer application to low-fertility soils (Silva et al., 2002). Darko et al. (2020) found no significant effects of applying inorganic fertilizers on the growth and yield of different sweet potato varieties. According to Peressin et al. (2022), fertilizer application is not necessary for highly fertile soils when sweet potato plants are grown in rotation systems after other crops grown under fertilizer applications. Prabowo et al (2020) found that the application of a compost from mushroom residues up to the rate of 30 Mg ha^{-1} did not increase the sweet potato crop yield.
Fatokun et al. (2022) assessed the effects of applying a compost from macadamia husks on sweet potato crops and reported that yield increases may not occur in the first but in the second crop cycle.
The results denoted that the soil had adequate nutrient availability for achieving high crop yields after applying limestone, without compost application. The total and commercial yields obtained were higher than the mean in the studied region, which was 25.6 Mg ha^{-1} in 2022 (IEA, 2023). Studies on the same cultivar have shown high yields, reaching total and commercial yields of 44.9 Mg ha^{-1} and 40.7 Mg ha^{-1} (Rós et al., 2012), 52.7 and 47.9 Mg ha^{-1} (Rós et al., 2023), and 52.30 Mg ha^{-1} and 20.31 Mg ha^{-1} (Nasser et al., 2020), respectively. Darko et al. (2020) found that different agroecological environments have different effects on sweet potato crop performance, with an interaction between sweet potato variety and environment for most growth parameters, depending on the sweet potato variety used.
Several factors contribute to proper crop development. Peressin et al. (2022) emphasized that achieving high yields depend on soil fertility and other factors such as irrigation, health of the propagation material, and cultural practices. Floyd et al. (1988) found that sweet potato yield varies depending on the soil type, and the crop presented significant responses to all evaluated soil fertilizers (organic and mineral); however, the crop response to organic compost was lower when applied to high-fertility soils.
The results obtained in the present study are consistent with those reported by Gonçalves et al. (2018), who found no increases in crop yield when applying compost to the soil, although they recommended this practice for maintaining soil fertility. Moreover, compost application to soils can result in gains in yield and quality of tuberous roots, as reported by Novianantya et al. (2017), who used a compost from ground fish bones and plant residues. Thus, different composts, production environments, and plant species and varieties can affect the results.

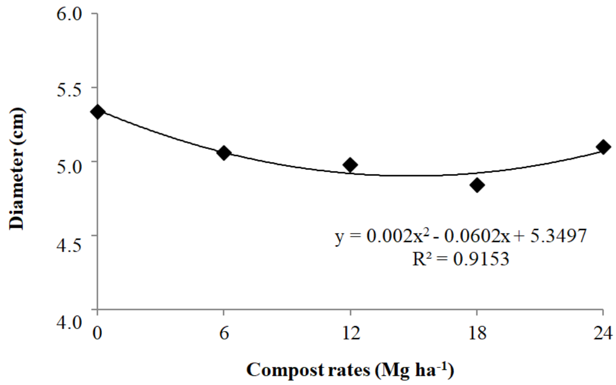

Figure 1. Diameter of sweet potato tubers as a function of compost rates.

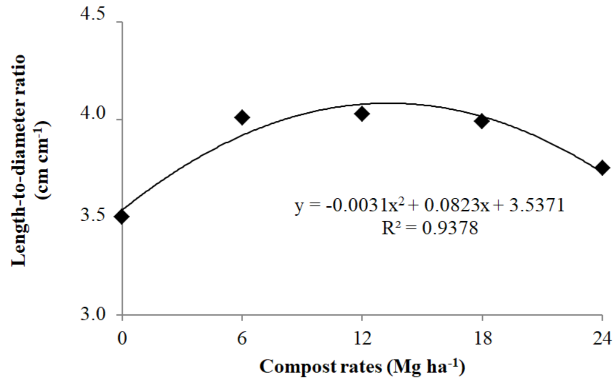

Figure 2. Length-to-diameter ratio of sweet potato tubers as a function of compost rates.

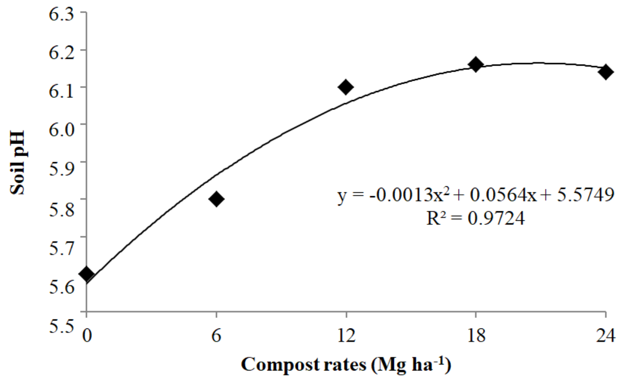

Figure 3. Soil pH as a function of compost rates.

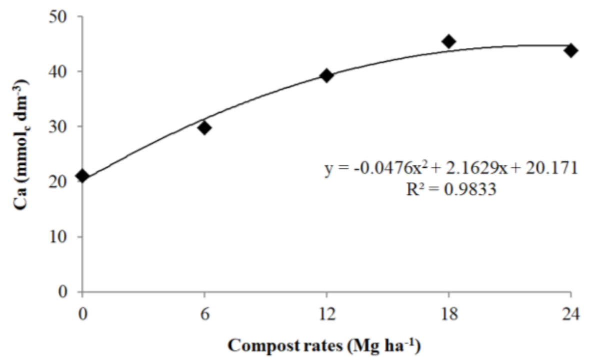

Figure 4. Calcium contents in the soil as a function of compost rates.

Shape of sweet potato tuberous roots

Regarding the shape of sweet potato tuberous roots, the compost application did not affect tuber length (19.13 cm) but affected the diameter and length-to-diameter ratio of commercial tubers. The diameters decreased up to the compost rate of 15 Mg ha^{-1} and increased when applying higher rates (Figure 1). The diameter was 5.3 cm at the compost rate 0, decreasing to 4.9 cm at the rate of 15 Mg ha^{-1} and reaching 5.1 cm at the compost rate of 24 Mg ha^{-1}. According to Gregory and Wojciechowski (2020), the greatest lengths coincide with the beginning of rapid growth of tuberous roots. Different growth patterns can result in differences in water and nutrient availability in the soil, which may explain the varying effects of the applied compost rates. Rahmawati and Basqoro (2022) evaluated three sweet potato cultivars, and two of them presented higher root length when a compost from rice husks was applied to the soil, while one cultivar was not affected regarding this characteristic.

The length-to-diameter ratio of tubers responded to compost application with changes in tuber diameter (Figure 2). This ratio was 3.5 cm at rate 0, increasing to 4.1 cm at the compost rate of 13.7 Mg ha^{-1}, with a subsequent decrease. However, these changes did not result in gains or losses in commercial tuber characteristics.

Soil physical properties

The tested treatments had no significant effects on soil physical properties, which presented means of soil density and total porosity of 1.29 kg dm^{-3} and 0.51 cm^3 cm^{-3}, respectively. Gomes et al. (2005) also found no changes in soil physical properties after applying a compost rate of 10 m^3 ha^{-1}, attributing this result to the lack of increases in soil organic matter content. Contrastingly, Adekiya et al. (2019) and Agbede and Oyewumi (2022) found that biochar and chicken manure reduced soil density and increased soil porosity and moisture content compared to the control. Rós et al. (2013) pointed out that responses in soil density and porosity-related attributes differ depending on the soil type, land use, and cultivation history.

The compost application did not change the soil organic matter content (13.9 g dm^{-3}), as also found by Gomes et al. (2005) and Giácomo et al. (2019) when using organic composts from plant residues and manure, and pulp industry residues, respectively. However, some studies have reported increases in organic matter content due to the application of composts from urban waste (Pedra et al., 2007), animal and plant residues (Silva et al., 2013), and poultry litter and soybean bran (Cardoso et al., 2011), although in the latter, higher rates were applied (up to 120 Mg ha^{-1}) compared to those tested in the present study.

The soil pH was affected by the applied compost rates, presenting a quadratic response, according to estimates of the model (Figure 3). The soil pH ranged from 5.57 (rate 0) to 6.34 (rate of 24 Mg ha^{-1}), which is considered ideal for sweet potato crops (Peressin and Feltran, 2014; Peressin et al., 2022). Sweet potato crops are affected by soil pH, but cultivars differ regarding tolerance to low pH (Ila'ava et al., 2000). Increases in soil pH due to increases in compost rate may be connected to the high pH of the compost compared to the soil, as well as to soluble organic anions in the compost. According to Mantovani et al. (2005), when these soluble organic anions are released, they adsorb H^+ from the soil solution through exchange reactions, increasing soil pH. Guimarães et al. (2012) found increased pH in the studied

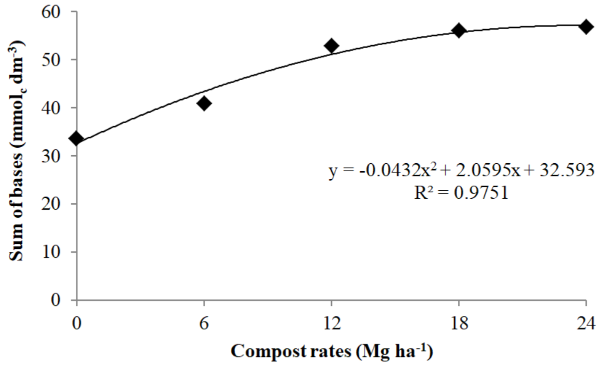

Figure 5. Sum of bases as a function of compost rates.

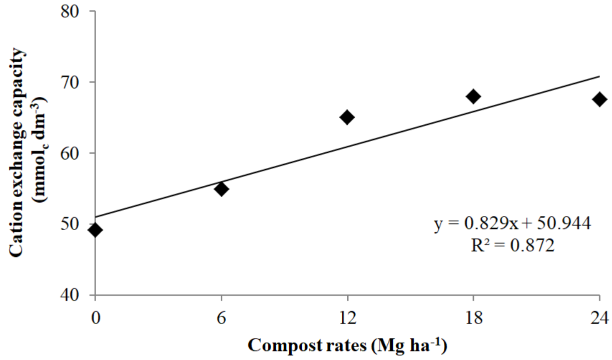

Figure 6. Cation exchange capacity of the soil as a function of compost rates.

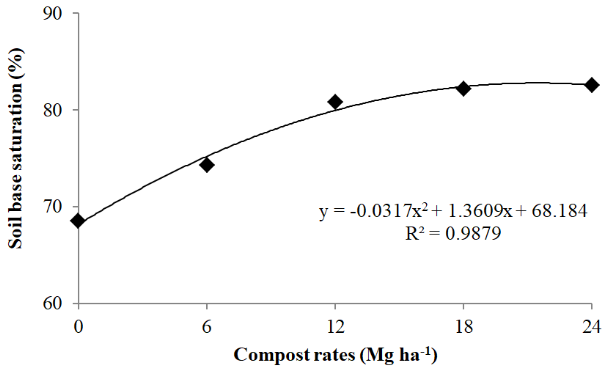

Figure 7. Percentage of soil base saturation as a function of compost rates.

soils due to application of gelatin industry sludge, especially in the soil with a higher sand content.

Regarding the soil chemical properties, the applied compost rates resulted in significant differences in calcium content, sum of bases, cation exchange capacity, base saturation, and phosphorus content. However, the treatments had no significant effect on magnesium (10.60 mmol$_c$ dm^{-3}), potassium (1.33 mmol$_c$ dm^{-3}), and sulfur (4.92 mg dm^{-3}) contents.

Calcium contents in the soil presented a quadratic response (Figure 4). Calcium contents increased up to the compost rate of 23 Mg ha^{-1}, ranging from 20.17 (rate 0) to 45.03 mmol$_c$ dm^{-3} (rate of 23 Mg ha^{-1}), representing an increase of 123%. This increase may be attributed to the amount of calcium applied to the soil through the compost (359 g of Ca per kg). Echer et al. (2009) and Fernandes et al. (2020) reported that calcium is the third most extracted nutrient by sweet potato plants; however, the calcium provided through limestone application probably met the needs of the sweet potato plants evaluated in the present study. Increases in calcium contents were found in studies using gelatin industry sludge (Guimarães et al. 2012) and composts from maize crop residues and cattle manure (Gomes et al., 2005), sawdust and cattle manure (Damatto Junior et al., 2006), goat and sheep slaughterhouse wastewaters (Souza et al., 2012), and animal manure and plant residues (Cardoso et al., 2019).

Magnesium, potassium, and sulfur contents in the soil were not affected by the application of compost rates, as the contents of these nutrients in the compost were not high. Damatto Junior et al. (2006) reported that magnesium can be displaced from the exchange complex by calcium, and even by potassium, favoring its leaching. Nevertheless, magnesium contents in the soil were adequate for the crop (Peressin and Feltran, 2014).

The potassium content in the soil at the end of the experiment (1.33 $mmol_c$ dm^{-3}) was lower than that found in the initial soil analysis (1.9 $mmol_c$ dm^{-3}). The sweet potato yield was high and, consequently, the potassium extraction by plants was high. According to Echer et al. (2009), potassium is the second most demanded nutrient by crops, after nitrogen, and the period of higher potassium demand by tuberous roots is between 115 and 130 days after transplanting, which explains the decrease in soil potassium contents at the end of the crop cycle, when the soil sampling was carried out.

The increase in soil calcium content resulted in an increase in sum of bases, cation exchange capacity, and base saturation, as expected when the calcium, magnesium, or potassium content in the soil increases. Santos et al. (2004) and Cardoso et al. (2019) applied composts from poultry litter and manure and plant residues, respectively, and found improvements in these soil chemical properties.

The sum of bases showed a quadratic response, with the highest value found for the compost rate of 23.94 Mg ha^{-1}. It ranged from 32.59 (rate 0) to 57.24 $mmol_c$ dm^{-3} (rate 23.94), representing an increase of 75.6% (Figure 5).

According to model estimates, cation exchange capacity showed a linear response to increases in the compost rate, ranging from 50.94 (rate 0) to 70.84 $mmol_c$ dm^{-3} (rate of 24 Mg ha^{-1}), representing an increase of 39% (Figure 6).

The base saturation in the initial soil analysis was 22%, whereas it was 68.18% at harvest in the area with no compost application (rate 0) due to the application of limestone in the entire area, reaching the highest value (82.10%) for the compost rate of 21.94 Mg ha^{-1}. Therefore, base saturation presented a quadratic response (Figure 7). The application of the compost also increased base saturation due to the higher calcium content in the soil.

The phosphorus content in the soil showed a linear response to the increase in the compost rate (Figure 8). Agbede and Oyewumi (2022) found increases in phosphorus contents when applying organic fertilizers to the soil. In the present study, phosphorus contents ranged from 12.08 (rate 0) to 35.67 mg dm^{-3} (rate of 24 Mg ha^{-1}), representing an increase of 195.3%. According to Mantovani and Yagi (2010), applications of byproducts and composts can increase soil phosphorus contents, depending on the presence of the nutrient in the material.

Some micronutrients in the soil presented significant differences, according to the compost rates applied. Boron, iron, and zinc contents presented no response to the application of compost, with means of 0.18, 10.4, and 1.44 mg dm^{-3}, respectively. Considering the increase in soil pH, an increase in boron content and a decrease in iron and zinc contents were expected, but it did not occur. Abreu et al. (2007) emphasized that some soils subjected to limestone

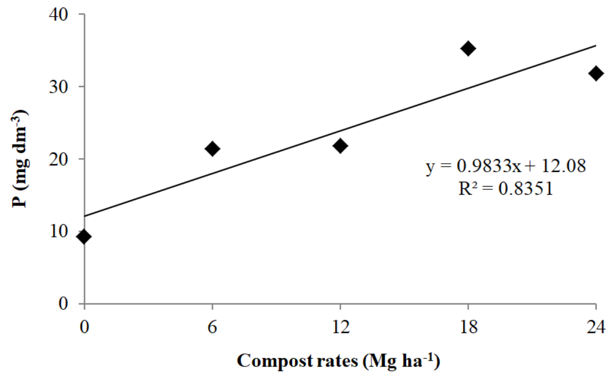

Figure 8. Phosphorus contents in the soil as a function of compost rates.

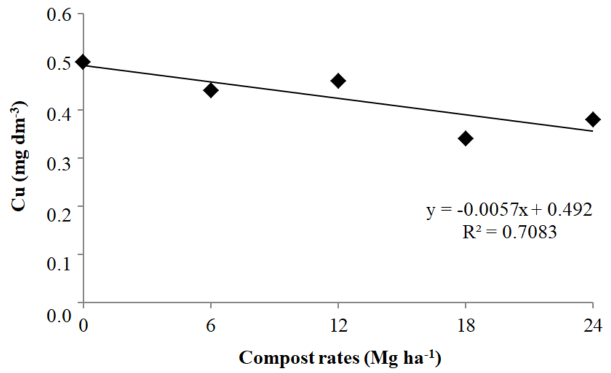

Figure 9. Copper contents in the soil as a function of compost rates.

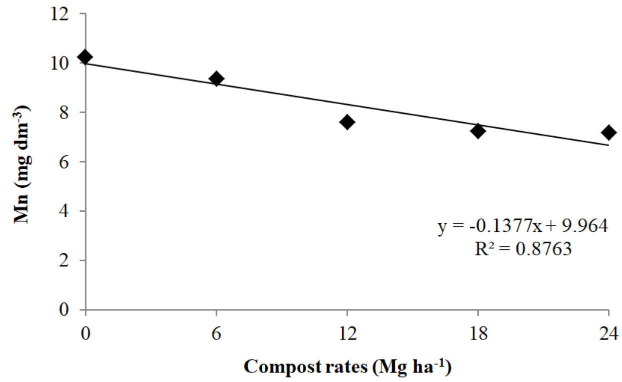

Figure 10. Manganese contents in the soil as a function of compost rates.

application to raise the pH above 6.0 may present Zn deficiency, mainly sandy soils. Carmo et al. (2016) found that applications of organic compounds decreased the soil pH and increased Zn contents but did not affect B contents.

Copper and manganese contents in the soil were affected, presenting decreases as the compost rate was increased (Figures 9 and 10). Decreases in Cu and Mn contents in the soil are associated with increases in pH, which reduces the mobilization of Cu (Strobel et al., 2005), favors oxidation, and decreases Mn^{2+} concentration in the soil solution (Souza et al., 2010). According to Abreu et al. (2007), Cu is the micronutrient that most interacts with organic compounds in the soil, forming stable complexes; thus, most Cu deficiencies have been associated with organic soils.

Materials and Methods

Experimental site

The experiment was conducted at the experimental farm of

Table 1. Physical and chemical characteristics of the soil and the organic compost used.

Soil physical and chemical properties	Compost physical and chemical properties
pH ($CaCl_2$) = 4.4	pH (in water 1:10) = 9.1
P = 3.0 mg dm^{-3}	P = 0.44 g kg^{-1}
S = 3.0 mg dm^{-3}	S = 0.73 g kg^{-1}
K = 1.9 $mmol_c$ dm^{-3}	K = 344 mg kg^{-1}
Al = 28.0 $mmol_c$ dm^{-3}	Al = 52.107 mg kg^{-1}
Ca = 4.0 $mmol_c$ dm^{-3}	Ca = 359 g kg^{-1}
Mg = 3.0 $mmol_c$ dm^{-3}	Mg = 0.98 g kg^{-1}
B = 0.11 mg dm^{-3}	B = <16.7 mg kg^{-1}
Cu = 0.6 mg dm^{-3}	Cu = <12 mg kg^{-1}
Fe = 21.0 mg dm^{-3}	Fe = 264 mg kg^{-1}
Mn = 20.9 mg dm^{-3}	Mn = 15.3 mg kg^{-1}
Zn = 1.0 mg dm^{-3}	Zn = 9.5 mg kg^{-1}
Organic matter = 13.0 g dm^{-3}	Organic C = 219 g kg^{-1}
Sum of bases = 8.0 $mmol_c$ dm^{-3}	Na = 23.112 mg kg^{-1}
Cation exchange capacity = 36.0 $mmol_c$ dm^{-3}	Cation exchange capacity = 300 $mmol_c$ kg^{-1}
Base saturation = 22%	Ammonium N = 835 mg kg^{-1}
854 g kg^{-1} of sand	Kjeldahl N = 4.6 g kg^{-1}
65 g kg^{-1} of silt	Nitrate-nitrite N = 40.0 mg kg^{-1}
81 g kg^{-1} of clay	Total solids = 92.4% m m^{-1}
-	Volatile solids = 34.3% m m^{-1}
-	Moisture at 60% to 65% = 7.8% m m^{-1}

the Agribusiness Technology Agency of the State of São Paulo, in Presidente Prudente, SP, Brazil, from October 2020 to May 2021, in a Typic Hapludult (Argissolo Vermelho-Amarelo tipico; Santos et al., 2018) of sandy texture. The region's climate was classified as Aw, rainy tropical climate with dry winters, according to the Köppen classification (CEPAGRI, 2015).

Physical and chemical description of the soil and the compost produced from gelatin industry residues

Information about physical and chemical characteristic of the 0-0.2 m soil layer and the compost are shown in Table 1.

The organic compost consisted of sludge resulting resulting from industrial processes used for gelatin production, leaves and branches of trees, sawdust, diatomaceous earth, and wood ashes. The industrial sludge was acquired from two tanks: primary sludge sedimentation and secondary sludge sedimentation (residue from the sludge used in the biodigester). The sludge from both tanks was mixed, centrifuged, and used for composting.

Experimental design and cultivation

The experiment was conducted in a randomized block design, with five replications. The treatments consisted of five rates (0, 6, 12, 18, and 24 Mg ha^{-1}) the compost based on gelatin industry residues, whose raw material is bovine skin.

The soil of the experimental area was prepared through plowing. Dolomitic limestone (with a total neutralizing power of 93%) was applied and incorporated to a depth of 0.35 m on November 06, 2020, to raise the base saturation to 65%. The compost was broadcasted on November 30, 2020 and incorporated into the soil using a leveling disc harrow. Ridges of 0.35 m in height were made using a furrower.

The sweet potato planting was conducted on December 10, 2020. The experimental unit consisted of three 8-meter rows spaced 0.9 m apart, each containing 20 plants spaced 0.4 m apart. The plant density was 27,777 plants ha^{-1}. The evaluation area consisted of the 18 central plants in the central ridge. The propagation material used consisted of 0.4 m long vines from sweet potato plants of the variety Londrina, also known as Canadense.

Yield characteristics

Total and commercial yields were assessed at 150 days after planting. Total yield consisted of all tuberous roots with weights equal to or higher than 0.1 kg. Commercial yield consisted of tuberous roots weighting between 0.1 and 1 kg, with a length-to-diameter ratio between 1.75 and 8.0 and a good aspect (uniform and smooth shape). Individual commercial tubers were weighed, and the mean fresh weight of tubers was calculated. The shape of the tuberous roots was determined by the length-to-diameter ratio calculated for each tuber. The mean dry weight of the tubers was evaluated in cubes cut from the middle part of the tubers, which were homogenized to form a 1.0 kg sample for each plot. The material was taken to a forced air circulation oven at 60 °C until a constant weight.

Soil physical and chemical properties

The following soil physical and chemical properties were evaluated: soil density and total porosity, active acidity (pH), organic matter, phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, manganese, zinc, sum of bases, cation exchange capacity, and base saturation. Soil samples were collected at 140 days after planting.

Soil density and total porosity were determined in undisturbed soil samples collected from the central part of the ridges. Soil density was determined using the volumetric ring method, in which the weight of a soil sample dried at 105 °C is correlated with the sum of the volumes occupied by particles and pores. Total porosity was assessed through the ratio between soil density and particle density; particle density was calculated using the volumetric flask method. The soil physical attributes were determined according to Claessen (1997).

Composite soil samples were collected from the 0-0.2 m layer to evaluated soil fertility. Chemical analyses were conducted following the methodology proposed by Raij et al. (2001).

Statistical analysis
The data were subjected to analysis of variance, and when differences were significant, the means were adjusted using polynomial regression equations. Maximum points were determined by derivatives of the regression equations. A 5% error probability was applied.

Conclusions

The application of a compost from gelatin industry residues to soils with adequate fertility conditions for growing sweet potato crops does not change total and commercial yields but affects the tuberous root shape. Applying compost rates up to 24 Mg ha^{-1} does not affect the physical properties of the soil. The compost application improves the fertility of sandy soils by increasing pH, calcium and phosphorus contents, sum of bases, cation exchange capacity, and base saturation.

Acknowledgments

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