Quantitative and Qualitative Analysis of Sewage Sludge Application to Soil Degraded by Livestock

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Abstract: ***Sludge presents a high organic matter content (OM) and, therefore, can play an essential role in soil conditioning. Thus, the present study's objective was to analyze, quantitatively, and qualitatively, the physical and chemical changes caused by the application of sewage sludge to soil degraded by livestock. The experimental area is located in the city of Paragominas, PA, and it is 36 m^2. Regarding the sludge applied, it was generated at the Wastewater Treatment Plant (WWTP) of the condominium "Morada do Sol," within the city's urban area. We applied the deductive method, with a quantitative and qualitative approach, associated with research in a time frame between 2011 and 2020 to collect documentary data. The data analysis allowed to infer that: 1) the sludge presented high nutritional content, which can be indicated by the level of OM ($\bar{x}$ = 86.5%); 2) in control (untreated) soil, we verified critical data on soil density ($\bar{x}$ = 1.2 g/cm³) and nutritional deficiency of both P, with a "shallow" content ($\bar{x} \cong$ 2.6 mg/kg), and K, with "low" content ($\bar{x} \cong$ 38.7 mg/kg); 3) in the soil, 60 days after the application of 3.0 kg/m^2 of sludge, occurred a decrease of 8.3% in soil density and increases in the concentrations of P (392.3%) and K (70.5%), which now are in "good" and "average" levels, respectively, and 4) the data variation was considered not significant for physical attributes and significant for the chemical ones. Therefore, the sewage sludge proved to be viable for the recovery of degraded pastures.***

Keywords: Degraded pastures, organic matter, soil conditioning

1. Introduction

In the WWTP, the Wastewater Treatment Plant, part of the effluent (1.0 to 2.0%) is absorbed, converted, and becomes part of the microbial biomass named as "sewage sludge," a solid byproduct from wastewater processing, composed mainly of biological solids [1].The sludge generated in a WWTP contains nutritional elements: organic matter (OM); macronutrients such as carbon (C), phosphorus (P), nitrogen (N), potassium (K); micronutrients such as copper (Cu), manganese (Mn), and zinc (Zn). Besides the aluminum (Al), cadmium (Cd), iron (Fe), and mercury (Hg) in the sludge, there are also fecal coliforms, protozoan cysts in varying proportions, helminth eggs, and Salmonella [2] - [3].

Due to the enormous volume of sewage continually produced in Brazil (1,5×10^5 to 2,2×10^5 ton/year), its final disposal became a complex issue. It is discussed in Chapter 21 of Agenda 21, which emphasizes solid waste environmentally-safe management and states the need for developing plans to encourage recycling and make it viable [4] - [5]. Regarding the final sludge disposal, the mainstream alternatives are sludge destination to landfills, its use as a substrate component for the production of forest species seedlings, oceanic deposition, incineration, and degraded recovery areas, reforesting, and its use in agriculture [6] - [7].

The recovery of degraded areas is a process with many ecological goals, such as restoring the fertility and biodiversity of an area altered beyond its natural recovery limits. The restoration aims to turn the area into a stage as similar as possible to the initial one. However, it is often highly tricky or, sometimes, impossible to do so, considering the intensity of soil degradation [8].Concerning the areas degraded by livestock, the pastures lose their naturally regenerating capacity, productivity, and vigor. It occurs **due to** the intensive land use associated with the deployment of improper management practices, which lead to changes in physical, chemical, and biological soil properties [9] - [10].

Thereby, such arguments justify this research, which is relevant because it generates data regarding the need for setting up proper disposal of sewage sludge. Moreover, it will make possible to analyze, quantitatively and qualitatively, the physical and chemical alteration led by the sewage sludge application to soil degraded by livestock, besides determining, utilizing statistical tests of hypotheses, the significance of data variation from physical and chemical soil attributes, before and after the application of this organic waste.

2. Literature Review

2.1 Final disposal of WWTP sludge – main problems

Within Brazilian territory, there is an estimative of 1120 WWTPs, which dispose of the sludge in different ways (Table 1).

Table 1: Final disposal of sludge by WWTPs in Brazil [5]

Number of WWTP	Final Disposal
452	Landfills.
164	Environmental was Lotic watercourses (e.g., rivers and seas).
19	Incineration.
169	Reuse.
316	Other processes.

The operational expenses of a WWTP may be reduced up to 50.0% when the organic waste is disposed of in landfills, but placing the sludge in such areas may lead to landfill slope fragility resulting from a significant concentration of fluids in the input (the sludge). When the liquid and gas pressure in porous elements' interior equals the usual tension, the material (slope) shear strength gets compromised [11].

Moreover, the incineration results are the pollutant gas release, such as carbon dioxide (CO_2) and sulfur dioxide (SO_2). The process also produces ashes, in which the potentially toxic elements from sludge (e.g., Cd and Al) get even more concentrated [12] - [13].

Likewise, the deposition in lotic watercourses may further a phenomenon is known as eutrophication. It causes a decrease in light penetration into the system due to the excessive increase in phytoplankton biomass. This scenario reduces dissolved oxygen (DO) concentration and, hence, aerobic aquatic species' death, like fishes [14].

2.2 Livestock and soil degradation

Livestock is one of the most problematic ways to degrade the soil since, in Brazilian lands, 1.75×10^8 ha are pastures. An estimative of more than 0.1×10^9 ha is in different degrees of degradation between Central Brazil and the Brazilian Amazon. In the North of the country, approximately 60.0% of cultivated pastures might be degraded or in the process of degradation [15].

This scenario is a result, primarily, of wildfires in pastures, which take place at the end of the warm season or the beginning of the rainy one, to control weed growth, as Blue Dawn Flower (*Ipomoea acuminata* (Vahl) Roem. & Schult.). On the other hand, it is a process that can raise soilsusceptibility to erosion; it decreases macro porosity, the water infiltration rate, OM amount, and the population of microorganisms in the soil and favors nutrients leaching and percolation [16].

Furthermore, excessive stocking rates on pastures, which may arise from the tremendous pressure (up to 400kPa) caused by cattle trampling in a small contact area and by the frequency of grazing, is another cause of soil degradation in these areas, for it is a factor that leads to the soil compaction [17].

Among the effects of soil compaction, we may mention root growth inhibition (due to the increase of the resistance to horizontal and vertical expansion) and the reduction of macro porosity, which impacts the soil resilience negatively because of hydraulic conductivity decrease, gas transportation, and nutrients cycling by soil microbiota [18].

2.3 WWTPssludge use for recovering soils degraded by livestock

When the WWTP sludge's application dosage is not controlled, it causes a significant problem since the N balance is not considered. It is a problem because the OM from the sludge applied to the land is mineralized and releases N in ammoniacal and nitric forms, which are not added to the ones present in the soil since before the application [1] - [19].

For this reason, sludge dosage must have a quantity of nitrate (NO_3) or ammonium (NH_{4+}) that do not surpasses the one the plant is capable of absorbing because, otherwise, the residual fraction could be easily leachable, what could lead to underground watercourses contamination [10].

Likewise, the increase in P's content by successive and continuous sewage sludge applications might cause the accumulation of this soil element. This accumulation arises from the input of OM from the organic waste, which induces the reduction of P adsorption due to humic and fulvic acids, and other composts present in it, for they show anionic character and stick to P adsorption sites what increase this nutrient availability in the soil [20].

3. Material and Methods

3.1 City physiography

The research was carried out in Paragominas, located in the southeastern mesoregion of Para state. The city territory is 19342.565 km²; its estimated population is 114503 inhabitants; the local climate is classified as tropical rainy with a well delimitated warm season (Aw), and the soil is, predominantly (95.0%), the yellow oxisol with clayey texture [21] - [22].

3.2 Studied area

The studied area is located in *Vitória* Farm, by PA-125 Highway, Km 9, countryside of Paragominas, PA, and it is placed under the coordinates 2°59’58.37” S and 47°21’21.29” W (Figure 1). It is a portion of surface land, with an extension of 36 m², used for pasture cultivation.

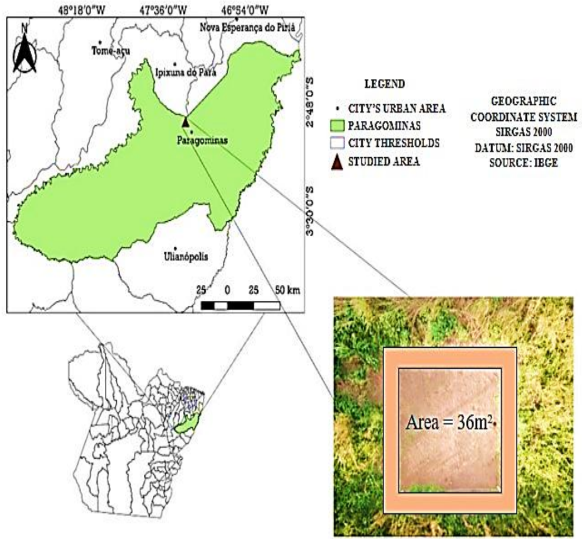


Figure 1: Localization map of the studied area within the city of Paragominas, PA

In the experiment area, we observed a weed infestation, like Giant Sensitive Plant (*Mimosa invisa* Mart. ex Colla) and Blue Dawn Flower (*Ipomoea acuminata* (Vahl) Roem. & Schult.); a low ratio of forages and spots of bare soil (Figure 2).

Figure 2: Condition of pasture degradation of the area under study. Paragominas, PA

We highlight that, after the present research, the surface where the WWTP sludge was applied is not going to be used for pasture cultivation, as established in Section IV, Art. 12 of Resolution No. 375/2006 of the National Council for the Environment (CONAMA) [23]. Regarding the future use, the farm owner intends to use it for *Paricá* (*Schizolobium parahyba* var. *amazonicum* Huber ex. Ducke) cultivation.

3.3 Sludge used for application – generation and treatment

The sludge applied was produced in the WWTP of the condominium *Morada do Sol*, located in the urban zone of Paragominas. The unit receives a sanitary effluent contribution of 1.501 L/capita/day. It can meet the demand of 5000 people and admits a flow rate of 445.44 m³/day [24]. Concerning the sludge treatment process, it had two steps (Figure 3).

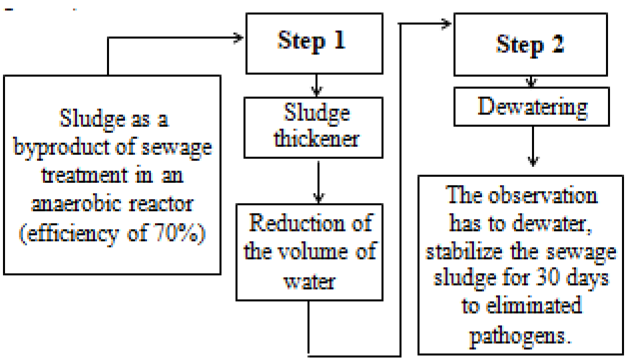


Figure 3: Treatment process of the sludge used for application [25]. Paragominas, PA.

During the sludge rest for dewatering (Figure 4a), we observed the formation of cracks and grooves in the WWTP sludge (Figure 4b), which shows the dewatering process efficiency.

Figure 4: a) Sludge placed for dewatering; b) groove formation in the sludge after 30 days in dewatering. Paragominas, PA.

3.4 Method

The method consists of four summaries composed by other researchers regarding research methods (Table 2).

Table 2: Research methods applied

Methods	Summaries
Deductive	Employing it, we can draw undeniable conclusions from two truthful premises [25].
A quantitative and qualitative approach	We use quantitative and qualitative research to collect more information than we could by using one of them alone because it widens the data collection and perceives the practical problems [26].
Applied research	New knowledge is created from the practical application since involving local truths and interests lead to solving specific problems [27].
Experimental procedure	We define the objective of the study. Then, we establish variables capable of influencing it and the control lines, and we observe the results the variable generates on the object [28].

The data survey was carried out in both national and international journals (Table 3).

Table 3: Basis for scientific literature survey

Free access *links*	Acronym
Higher Education Personnel Improvement Coordination.	CAPES (in Portuguese)
Google Scholar.	---
Science Electronic Library Online.	SicELO
SciVerse Scopus.	---
WebScience.	---

We considered the time frame from the last 10 years (2011-2020) to index and search the documental data, with 30.0% from 2011-2014 and 70.0% from 2015-2020, intending to select more recent literature, except for seven pioneer bibliographic references or normative and legislative ones, published before the time frame set: [29], [30], [31], [32], [23], [33], and [34]. To support the research on the data basis, avoid the repetition of publications, and explore literature that could contribute to the research background, we considered four descriptors and three requirements (Table 4).

Table 4: Descriptors and requirements considered

Descriptors	**Characteristics**
1	Sewage sludge.
2	Livestock.
3	Recovery of degraded areas.
4	Degraded soils.
Requirements	**Characteristics**
1	least publishing year (studies published within the time frame set).
2	A specific has information about the author (s).
3	Academic registered: (1) *Digital Object Identifier* (DOI), (2) *International Standard Book Number* (ISBN), or (3) *International Standard Serial Number* (ISSN).

3.5 Sampling plan – steps

The sludge sampling was carried out in three steps, and the soil sampling in four steps (Table 5).

Table 5: Steps of sludge and soil sampling plans

Steps	Sludge [31]
1	Division of dewatering area surface into four plots (A, B, C, and D).
2	The collection has three samples representing each plot.
3	We are packaging the 12 samples in sterilized glass containers (volume of 250 mL).
Steps	Soil [35]
1	Division of the area into four regular plots of 3 m × 3 m (A, B, C, and D); within them, we opened three small trenches of 50 cm × 50 cm, designed in zigzag (Figure 5).
2	Samplings in 3 depths (0-10 cm; 10-20 cm; 20-40 cm).
3	Storage of the samples from the 12 small trenches in a plastic bucket of 2 kg according to their depth and, then, turning them into composite pieces.
4	Transfer the samples into plastic bags of 500g.

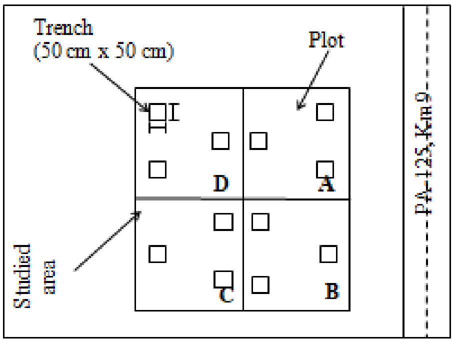


Figure 5: Sketch of the soil sampling plan, with the plots determined anticlockwise. Paragominas, PA.

The sludge and soil samples were immediately identified with tags (Figure 6a) and stored in Styrofoam boxes of 100 L (Figure 6b) to be analyzed in a specialized laboratory. Thus, the organic waste was headed to the Brazilian Institute of Analysis (IBRA) and the soil to the Laboratory of Soil Analysis, from the Coordination of Earth Science and Ecology (CCTE), in the Research *Campus* of Para Museum Emílio Goeldi (MPEG).

State University of Para
Natural Science and Technology
Laboratory of Environmental Quality –
Campus VI, Paragominas, Para

Project

Plot: ( ) A ( ) B ( ) C ( ) D
Coordinates:
Type of sampling: ( ) Sludge ( ) Soil
Depth (cm): ( ) 0-10 ( ) 10-20 ( ) 20-40
Sample number:
MOREIRA, S. F.; SANTOS, S. D. O. (2019)

Figure 6: a) Tag for identifying sludge and soil samples; b) soil samples adequately identified and stored in a Styrofoam box. Paragominas, PA.

3.6 Method steps

The method applied in this study was divided into six steps (Figure 7).

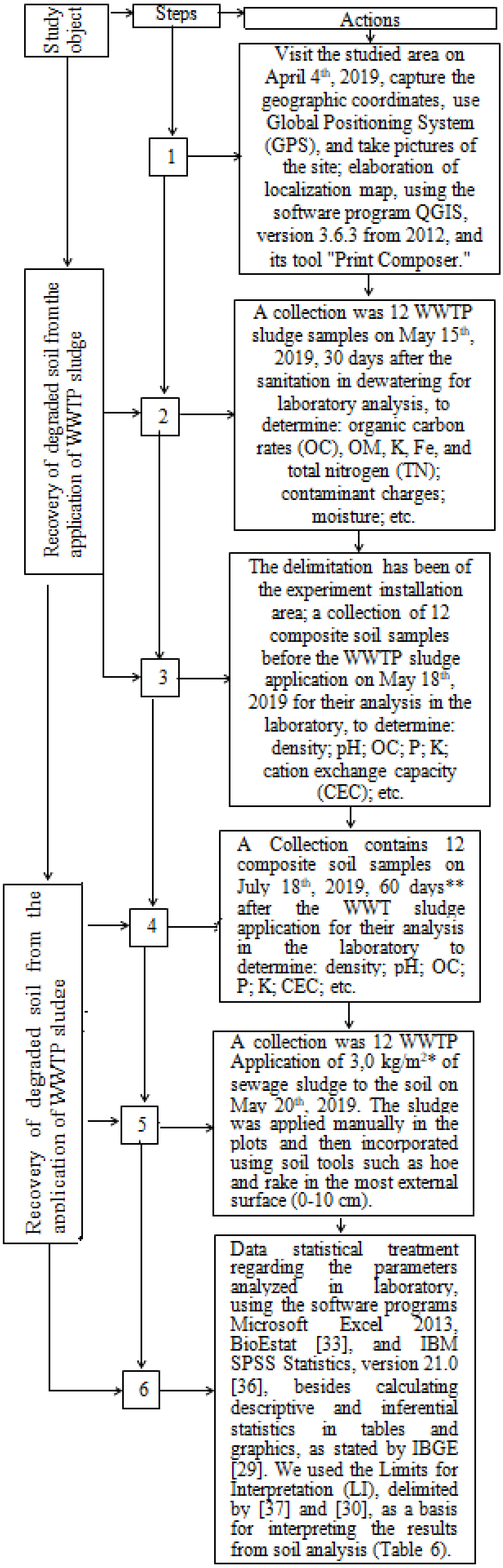


Figure 7: Flowchart of the method steps.

Legend: (*) volume established after obtaining an average quantity used by other ten studies about this issue, and (**) period for incubation proposed to achieve higher adsorption of OM by the soil determined after the analysis of studies cited in this research.

Table 6: Limits for Interpretation (LI) of soil analysis results

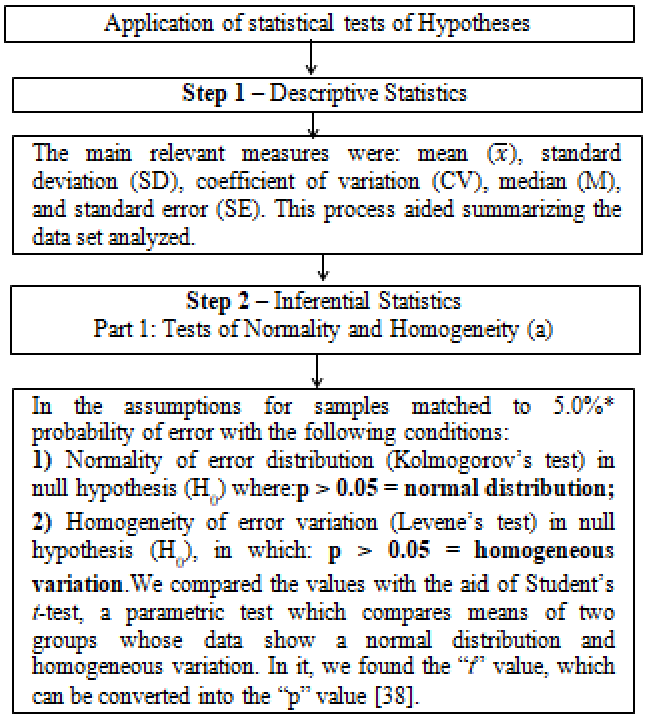
[37]	
Attributes	LI
Granulometry %	< 15.0% clay = "sandy texture". 15.0% a 35.0% clay = "medium-textured". 35.0% a 60.0% clay = "clayey texture". > 60.0% clay = "heavy clayey texture".
Hydrogen Potential (pH) Dimensionless	> 7.8 = "high alkalinity". 7.1 – 7.8 = "low alkalinity". 7.0 = "neutral". 6.1 – 6.9 = "low acidity". 5.1 – 6.0 = "medium acidity". 4.5 – 5.0 = "high acidity". < 4.5 = "very high acidity".
Potassium (K) mg/kg	> 120.0 = "very good". 71.0 – 120.0 = "good". 41.0 – 70.0 = "medium". 16.0 – 40.0 = "low". ≤ 15.0 = "very low".
Magnesium (Mg) $cmol_c$/kg	> 2.0 = "very good". 1.01 – 2.0 = "good". 0.51 – 1.0 = "medium". 0.21 – 0.5 = "low". ≤ 0.2 = "very low".
Organic Matter (OM) g/kg	> 70.0 = "very good" 40.1 – 70.0 = "good". 20.1 – 40.0 = "medium". 7.1 – 20.0 = "low". ≤ 7.0 = "very low".
Sum of Bases (SB) $cmol_c$/kg	> 6.0 = "very good". 3.61 – 6.0 = "good". 1.81 – 3.6 = "medium". 0.61 – 1.8 = "low". ≤ 0.6 = "very low".
[30]	
ATTRIBUTES	LI
Soil Density g/cm^3	0.2 – 0.49 = "variation in peat soils". 0.5 – 0.9 = "variation in humic soils". 0.91 – 1.24 = "variation in clayey soils". 1.25 – 1.6 = "variation in sandy soils".
Phosphorus (P) (mg/kg)	**< 15.0% clay:** > 45.0 = "very good". 30.1 – 45.0 = "good". 20.1 – 30.0 = "medium". 10.1 – 20.0 = "low". ≤ 10.0 = "very low". **15.0% to 35.0% clay:** > 30.0 = "very good". 20.1 – 30.0 = "good". 12.1 – 20.0 = "medium". 6.7 – 12.0 = "low". ≤ 6.6 = "very low". **35.0% to 60.0% clay:** > 18.0 = "very good". 12.1 – 18.0 = "good". 8.1 – 12.0 = "medium". 4.1 – 8.0 = "low". ≤ 4.0 = "very low". **> 60.0% clay:** > 12.0 = "very good". 8.1 – 12.0 = "good". 5.5 – 8.0 = "medium". 2.8 – 5.4 = "low". ≤ 2.7 = "very low".
Calcium (Ca) $cmol_c$/kg	> 4.0 = "very good". 2.41 – 4.0 = "good". 1.21 – 2.4 = "medium". 0.41 – 1.2 = "low". ≤ 0.4 = "very low".
Organic Carbon (OC) (g/kg)	> 40.6 = "very good". 23.3 – 40.6 = "good". 11.7 – 23.2 = "medium". 4.1 – 11.6 = "low". ≤ 4.0 = "very low".
Cation Exchange Capacity (CEC) $cmol_c$/kg	> 15.0 = "very good". 8.61 – 15.0 = "good". 4.31 – 8.6 = "medium". 1.61 – 4.3 = "low". ≤ 1.6 = "very low".

Table 6: Limits for Interpretation (LI) of soil analysis results.

Final	
Bases Saturation (V) %	> 80.0 = "very good". 60.1 – 80.0 = "good". 40.1 – 60.0 = "medium". 20.01 – 40.0 = "low". ≤ 20.0 = "very low".

3.7 Statistical tests of hypotheses

The statistical tests of hypotheses were carried out in three steps (Figure 8), with the aid of the software program IBM SPSS Statistics, version 21.0 [36]. It enabled determining whether the variation of data regarding the analyzed physical and chemical attributes was significant or not before and after WWTP injection sludge into the soil.



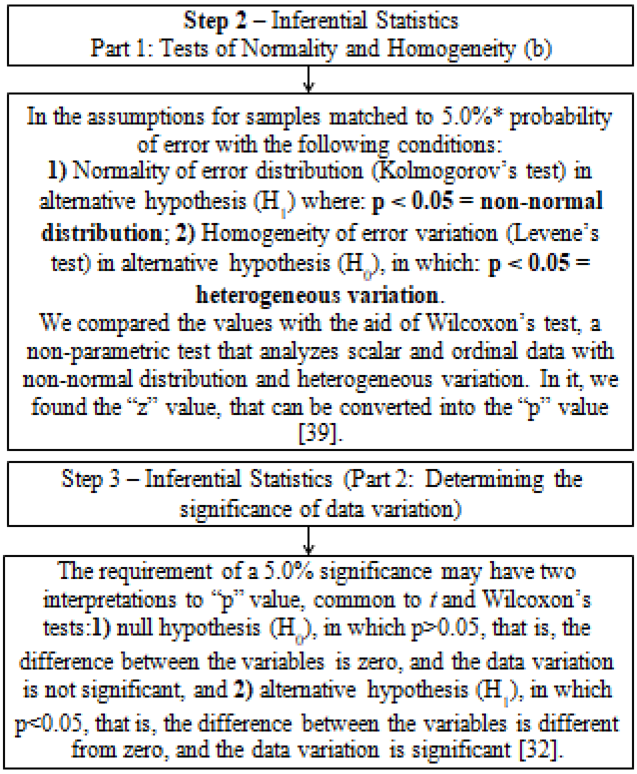


Figure 8: Steps for the application of statistical tests of hypotheses

Legend: (*) probability of the error occurs when considering a 95.0% confidence, deemed as an acceptable level of significance and mostly used in scientific research; (p) probability of the event occurrence; ("t") result of Student's *t*-test, and ("z") result of Wilcoxon's test.

4. Results and Discussion

4.1 Sludge characteristics

The sludge characteristics produced in the WWTP of the condominium *Morada do Sol*, in Paragominas, PA, presented quite different physical, chemical, and biological aspects (Table 7).

Table 7: Physical, chemical, and microbial analyses of the WWTP sludge. Paragominas, PA

Physical, Chemical, And Microbial Properties of WWTP Sludge				
ATR	Mean concentrations ($\bar{x}$)			
	PHY	CHC	MICB	UNIT
Soil moisture (65°C)	34.5	--	--	%
pH-$CaCl_2$	--	6.8	--	DN
Ashes	--	37.4	--	%
TN	--	2.0	--	%
P	--	5.7	--	%
K	--	1.5	--	%
Fe	--	1.4	--	%
Ca	--	9.2	--	%
Mg	--	5.5	--	%
OM	--	86.5	--	%
OC	--	24.3	--	%
C: N ratio	--	12.0	--	DN
Salmonella sp.	--	--	Absence	DN
Viable Helminth Eggs	--	--	Absence	ova/g TS
Thermotolerant coliforms	--	--	16.4	MPN/g TS

Legend: (DN) dimensionless number; (TS) total solids, and (MPN) most probable number. ATR – Attributes; Physical; CHC – Chemical; MCB – MicCroBial.

According to the sludge analysis, the moisture content was $\bar{x}$= 34.5%. Such a value is related to the solarization process. The prolonged exposure to the sun in dewatering (30 days) makes it possible to decrease the percentage of water in the organic compost significantly. About that, a study carried out in Rio de Janeiro, RJ [40], verified that the moisture of the sludge used in their experiment had a content of 20.0% after passing through the same process for 75 days. Thus, besides the region, climate, and insolation index, the divergence between the moisture levels is directly related to the exposure time since, in Paragominas, this period was 30 days long.

The chemical diagnosis of sewage sludge indicated that the mean **pH** is $\bar{x}$= 6.8 and, for this reason, it is deemed acid, although closer to the neutrality (7.0). Since this attribute expresses the stage of OM decomposition, the higher its value, the greater the benefits to microbial activity and nutrient mineralization. The analyzed sludge will also influence the bases saturation level, as the anions are easily exchangeable in this pH range.In research performed in the city of Feira de Santana, BA [41], the data showed a pH variation in the sludge, following the exposure time during the solarization process. For a stabilized sludge after 30 days of dewatering, the pH values varied between 6.7 and 7.4. Therefore, the sewage sludge pH from the WWTP of Paragominas is similar to the one found in Feira de Santana (± 6.8). This fact can be attributed to the sludge stabilization process's efficiency, which is a common factor in both studies.

Concerning the sludge ashes, the value found ($\bar{x}$= 37.4%) represents the percentage of fixed solids related to the sludge stabilization process conditions. In this case, if there are contaminants or disease vectors in the application and storage sites, the selected solids, assessed with the aid of ashes concentration, indicate the nonconforming state of the sludge.

Regarding this attribute, a study carried out in Selvíria, MS [42], reported a concentration of fixed solids of 47.8%. The sewage sludge with less than 30.0% content is selected as the minimum threshold for agricultural use. It allows us to infer that Paragominas WWTP sludge shows satisfactory stabilization standards and is less likely to attract disease vectors to the spot in which it is placed.The data obtained in this research for the average concentrations of the parameters which have agronomic value, with emphasis on the nutritional components of the WWTP sludge (TN, P, K, Fe, Ca, Mg, OM, and OC), do not have a minimum or maximum concentration pre-established by the Resolution No. 375/2006, of CONAMA.

In the presence of chemical elements in the sewage sludge, the TN ($\bar{x}$= 2.0%) is found in its organic form, and its availability depends on the mineralization rate. It varies according to the microbial activity of the medium in which the sludge will be incorporated, the moisture, and climatic factors. Studies performed in the cities of Campinas and

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Jaguariúna, both in São Paulo state [43], concluded that the addition of sewage sludge into the soil increased TN's availability medium, which it was disposed of. Furthermore, the researchers observed that the higher the nutrient availability, the higher its consumption by the corn plants (*Zea mays* L.) in the experimental area, the ones used to measure the soil's nitrogen consumption and accumulation after continuous applications of WWTP sludge.

In this regard, the Paragominas WWTP sludge can be deemed as a potential source of TN to the soil. Nevertheless, it is essential to avoid the application of excessive dosage. It can further the N loss by leaching and compromise this nutrient mineralization in future applications of the organic compost into the soil, besides causing high-rate nitrification.
As an elementary part of the sludge, the **P** ($\bar{x}$ = 5.7%) usually comes from the characteristics of the sewage treated in the treatment plant, which may contain soap, detergents, and synthetics concentrations, besides organic waste under decomposition. Concerning P levels, it was obtained values of 2.5% in the sewage from the WWTP of Jundiai, SP [20]. The authors also described that sewage use increased P, OM, and CEC in the soil. In Paragominas, the sewage generated in the WWTP of condominium *Morada do Sol* showed a higher P than Jundiai.

The contents of **K** ($\bar{x}$= 1,5%), **Fe** ($\bar{x}$= 1,4%), **Ca** ($\bar{x}$= 9,2%), and **Mg** ($\bar{x}$= 5,5%) also expressed the nutritional capacity of the WWTP sludge. The availability of these nutrients in the sludge, associated with OM's high concentration, turns it into compost capable of enhancing the soil's physical, chemical, and microbial properties. Research carried out in the city of Selvíria, MS [44], noticed that, from the constituents verified in the sewage sludge, the ones which revealed higher rates were: K (1.3%), Fe (1.2%), Ca (13.4%), and Mg (5.2%). Considering these aspects, the sludge's nutritional quality from the Paragominas WWTP is similar to the Selvíria one.

Another data from the chemical analysis was the **OM** content. It is a substance paramount for verifying the WWTP sludge potential as compost for soil fertilization. When applied to the soil, the OM is adsorbed, and microbial activation occurs, leading to an increase of OC content in the medium. The relation between OM and OC is confirmed by the study in Rio de Janeiro, RJ [45], in which the high concentration of the first one (88.7%) influenced, directly, the content of the second one (28.7%). Moreover, the study notices their high concentrations further the solubilization of soil nutrients, increases the CEC, and supports a slow release of water and essential nutrients (e.g., N, P, and K) into the soil. In Paragominas, it was also found high levels of OM ($\bar{x}$= 86.5%) and OC ($\bar{x}$= 24.3%).

As an index which enables us to assess the OM mineralization rate in the soil and also the solid waste and composts present, the **C: N ratio** verified in the WWTP sludge ($\bar{x}$ = 12.0) is within the allowable limits so that the mineralization can occur easier and liberate N. It can be said because the C: N ratio over 12.0 indicates the decomposition is slow, with high energy release (due to the higher concentration of C) and N immobilization by microorganisms, according to the Normative Instruction No. 25/2009, of the Brazilian Ministry of Agriculture, Livestock and Food Supply [34].

In research performed in Santa Maria, RS [46], the C: N ratio in the sewage sludge was 10.0. Should the Paragominas WWTP sludge be applied into the soil, it tends, just as the one studied in Santa Maria, to accelerate the OM decomposition and consume less N to achieve the C: N ratio stability in the medium. Concerning the microbial attributes, the data obtained and assessed did not reveal the presence of ***Salmonellasp.*** nor **Viable Helminth Eggs**. Regarding the **Thermotolerant Coliforms** ($\bar{x}$= 16.4 MPN/g TS), the content found was acceptable, since in its Section III, Art. 11, the Resolution No. 375/2003, of CONAMA, states that this pathogen's concentration must be < 10^3 MPN/g TS. It might be attributed to the sludge stabilization process's efficiency, which aims to reduce such pathogens. About this type of analysis, a pioneer study carried out in the city Paragominas, PA [47], reported the absence of ***Salmonellasp.*** and **Viable Helminth Eggs** in all ten analyzed samples, as well as a medium value of 9.0 MPN/g TS of **Thermotolerant Coliforms**. All these characteristics considered; the researchers classified the sludge as "Class A."

When we interpret the present research data considering such classification, we can claim that, concerning the microbial sludge analysis, the designation "Class A" also applies to the WWTP Paragominas sludge. Once part of this category, it is possible to admit that it does not represent sanitation or environmental risks to its forest or agriculture reuse, as stated by its reuse principles. The main sludge characteristics, which are necessary to the sludge recovery, were verified with the aid of laboratory analyses, except for the inorganic substances present in the sludge (heavy metals). We highlight that, due to this research performance's costs, we sought to prioritize the analysis of attributes that may reveal the sludge efficiency for recovering the soil fertility.

4.2 Characterization of soilcontrol samples

4.2.1 Physical Attributes

The data obtained about the control soil's physical properties made it possible to verify its granulometry and density (Table 8).

Table 8: Analysis of the physical attributes of the control soil. Paragominas, PA.

Soil physical properties control sample						
ATR	U	DEPTHS (cm)			$\bar{x}$	LI
		0-10	10-20	20-40		
Sand	%	16.0	22.0	31.0	23	C.T
Clay		60.0	60.0	47.0	56	
Silt		24.0	19.0	21.0	21	
Soil density	g/cm³	1.1	1.2	1.3	1	V. C. S

Legends: ATR – Attributes; U – unit; ($\bar{x}$) mean and (LI) limits for interpretation; C. T. – Clayey Texture.; V. C. S – Variations Clayey Soils

Regarding the **granulometry**, the soil showed the right amount of clay ($\bar{x}\cong$ 55.7%) and, because of that, it is classified as "clayey texture." In that case, it is possible to infer that, lithologically, it refers to an ancient soil, since along its formation time, the primary minerals, derived from the rock and that are part of both sand and silt, transformed themselves into clay by weathering processes (e.g., climatic changes, rainfall, and winds).

After the investigation of a soil under pasture by a study carried out in the city of Ulianópolis, PA [22], it was verified a "clayey texture" ($\bar{x}$ = 55.6% clay). The soils included in this texture classification have higher CEC when compared to the sandy ones and, for they are a source of H^+ (hydrogen) and Al^{3+} (aluminum), they also have higher buffer capacity at pH variation; besides, the increase in CEC causes more excellent fixation of P. The micro porosity and the total porosity are also higher in clayey soils. Therefore, we can infer that the soil now studied tends to be more resistant to the pH alterations and demands a higher dosage of phosphate fertilizers. Moreover, the retention and storage of water tend to be higher since, in the micropores, such processes are ordinary.

Regarding the **soil density**, it is amid the variation stated for clayey-textured soils ($\bar{x}$ = 1.2 g/cm³). However, research performed in the city of Lages, SC [48], about the linkage between density and soil compaction concluded that it is more likely to be risky to root growth when the density is around 1.18 g/cm³ in clayey soils. Thus, the value observed in Paragominas is considered critical and might be related to the elevated pressure ($\bar{x}$ =400 kPa) caused by cattle trampling in the intensive pasture management area. Study carried out in Uberaba, MG [49], found similar data ($\bar{x}$ = 1.2 g/cm³). We highlight that the density is one of the most affected by the type of pasture management.

In Paragominas, the high density indicated a tendency to compaction, which furthers the development of soil degraded structure since it causes an increase of mechanical resistance to the horizontal and vertical root expansion, as well as the reduction of aeration, the alteration of water flow, and heat, and the removal of water and nutrient availability.

4.3Chemical Attributes

The data analyzed the chemical characterization of the control soil state the fertility conditions (Table 9).

Table 9: Analysis of the control of soil chemical attributes. Paragominas, PA

Soil chemical properties control sample						
ATR	U	DEPTHS (cm)				
		0-10	10-20	20-40	$\bar{x}$	LI
pH	DN	4.4	4.4	4.5	≅4.4	VHA
P	--mg/kg--	2.9	3.0	2.0	≅2.6	V. L.
K		62.0	35.2	18.8	≅38.7	L
Ca	$cmol_c$/kg	1.8	0.9	0.6	= 1.1	L
Mg		0.7	0.5	0.2	≅0.5	L
OC	--g/kg--	22.2	19.2	18.0	= 19.8	M
OM		48.1	38.3	31.0	≅39.1	M
CEC	-$cmol_c$/kg-	8.9	5.4	4.0	= 6.1	M
SB		2.1	1.8	1.5	= 1.8	L
V	%	35.6	27.8	38.1	≅33.8	L

Legend: ATR – Attributes; (DN) dimensionless number; ($\bar{x}$) means, and (LI) limits for interpretation; V. L. A – Very High Acidity; V. L – Very Low; L – Low; M – Medium.

For **pH**, the "very high acidity" ($\bar{x}$≅ 4.4) class might be directly linked to the Amazonian soil's natural characteristics since 78% of the region's soils are acids, with a range varying between 3.5 and 4.5.

In Humaitá, AM [50], researchers observed a pH value in a planted pasture area that qualifies it as "very high acidity" ($\bar{x}$ = 4.3). This way, the leaching of the bases (as a result of the high temperature ($\bar{x}$ = 25ºC), increased rainfall rate ($\bar{x}$ = 2.450 mm/year), and changes in the source material) make the Amazon soils acid and, consequently, poorly fertile. As a fertility indicator, the high acidity pH in Paragominas contributes to the experimental area being chemically deficient

.

The "shallow" content of **P** ($\bar{x}$≅ 2.6 mg/kg) as well as the "low" contents of **K** ($\bar{x}$≅ 38.7 mg/kg), **Ca** ($\bar{x}$ = 1.1 $cmol_c$/kg), and **Mg** ($\bar{x}$≅ 0.5 $cmol_c$/kg) may be linked to the pH ($\bar{x}$≅ 4.4), which is an attribute that directly manages the chemical reactions in the soil and, because of that, low fertility is a natural occurrence in low pH states.

In a study carried out in the city of Selvíria, MS [51], the authors found that "low" contents of P ($\bar{x}$ = 4.3 mg/kg), K ($\bar{x}$ = 31,6 mg/kg), Ca ($\bar{x}$ = 1.2 $cmol_c$/kg), and Mg ($\bar{x}$ = 0.4 $cmol_c$/kg) in a soil degraded by livestock is an outcome of low pH (± 4.5), for it is a factor which reduces and interferes into the supply of soil nutrients. In Paragominas, the critical levels of P and K (primary macronutrients) and Ca and Mg (secondary macronutrients) tend to delay plants' longitudinal development. Furthermore, the medium levels of plant metabolites and the potential of the medium for the addition of wastes, animals, and microorganisms may be related to the medium content of **OC** ($\bar{x}$ = 19.8 g/kg) since they are about 98.0% (the majority) of this variable in the soil.

In research performed in Selvíria, MS [42], the concentration of **OC** was "medium" ($\bar{x}$ = 20.1 g/kg). It is the most abundant constituent of OM, equivalent to 50.0%, and hence the attribute most vulnerable to the transformations in the organic molecules. Thus, the soil analyzed in Paragominas should be supplied with OM to increase OC uptake and storage rates.

The **OM** ($\bar{x}$≅ 39.1 g/kg) "medium" content can be linked to the climatic conditions of Paragominas, with expressive temperature ($\bar{x}$ = 26.6°C) and rainfall ($\bar{x}$ = 1.805 mm/year). In such a scenario, OM degradation and nutrient availability in the medium occurs at a more accelerated rate since the moisture and the heat guarantee a conducive environment for the proliferation of fungi and bacteria and the reproduction of microorganisms responsible for the decomposition process.

In Rio Verde, GO [17], from a clayey soil analysis in three depths compatible to the ones used in the present study (0-10 cm; 10-20 cm; 20-40 cm), researches verified that besides the climatic influence, the "medium" level found of OM ($\bar{x}$ = 33.7 g/kg) also arises from the improper pasture management. The wildfires are a limiting factor of this variable level in Paragominas because they are an alternative technique for pasture cleaning that results in the elimination of vegetation residues, which are part of the soil's OM formation.

Regarding the CEC ($\bar{x}$ = 6.1 $cmol_c$/kg), the “medium” level could be justified by the “medium” content of OM in the soil ($\bar{x}$≅ 39.1 g/kg) since it is a potential source of nutrients and also have negative charges in its surface which contributes to CEC elevation, i.e., it strengthens the number of negative charges in the soil capacity to retain cations (e.g., Ca^{2+} and Mg^{2+}) which become accessible to the plants.

From a clayey soil analysis under pasture in Selvíria, MS [4], researchers identified a “medium” level of CEC ($\bar{x}$ = 5.7 cmolc/kg). They underlined that the clay fraction, for it has negative charges, also influences this attribute. But these charges come from unsatisfied or partially satisfied chemical bonds, that even when in high quantities, the soil shows low or medium CEC, just like in tropical regions. Hence, in the analyzed ground from Paragominas, the increase in CEC is strongly dependent on OM.

The “low” levels of SB ($\bar{x}$ = 1.8 cmolc/kg) and V ($\bar{x}$≅33.8%) suggest that the negative charges of soil colloids tend to adsorb more H^+ and Al^{3+}, and lower quantities of exchangeable cations, also defined as essential nutrients (e.g., K^+, Ca^{2+}, and Mg^{2+}). Such characteristics are the ones from acid soils.

Concerning that, another study in Selvíria, MS [44], found “medium” contents of SB ($\bar{x}$ = 2.2 cmolc/kg) and V ($\bar{x}$ = 48.5%). Along with CEC, such attributes are excellent indicators of soil fertility, for they are related to the essential nutrients release. We can, then, conclude that the soil analyzed in Paragominas is dystrophic, i.e., shows low fertility.

4.4Soil characterization 60 days after the application of WWTP sludge

4.4.1 Physical Attributes

We verified the soil textural class and density after the WWTP sludge application (Table 10).

Table 10: Analysis of soil physical attributes after WWTP sludge application. Paragominas, PA.

Soil physical properties After WWTN sludge application						
ATR	U	---DEPTH (cm)---			$\bar{x}$	LI
		0-10	10-20	20-40		
Sand	%	15.0	21.0	30.0	22.0	----C.T---
Clay		64.0	61.0	49.0	58.0	
Silt		22.0	17.0	20.0	19.7	
Soil density	g/cm³	1.0	1.1	1.2	1.1	V.C.S

Legend: ATR – Attributes; U – Units; ($\bar{x}$) mean and (LI); C. T. – Clayey Texture; C. C. S. – Variations on Clayey Solis; LI - Limits for Interpretation.

The **granulometry** of the soil was not expressively altered, only a small increase of 4.1% (Figure 9), remaining in the “clayey texture” class ($\bar{x}$ = 58.0% clay). Although it was a small increase, it could be an outcome of the OM added by the sludge ($\bar{x}$ = 86.5%), considering its implications over the soil’s physical behavior, associated with the lithological characteristics.

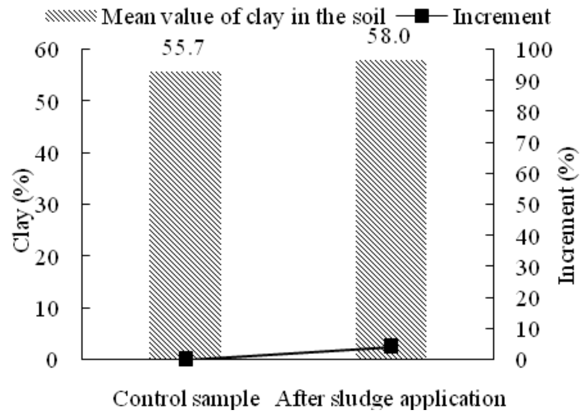

Figure 9: Evolution of the clay percentage in soil granulometry. Paragominas, PA.

In a study performed in an area degraded by the loss of the superficial soil layer and by the high compaction level, in the region of Itatinga, SP [52], the authors observed an increase of 14.5% in the clay content in a clay-textured soil, which went from 51.0% clay in the first sampling to 58.4% in the second one (after the sludge dosage). The Paragominas earth analyzed presented approximately a medium value ($\bar{x}$) of 55.7% clay regarding the first sampling.

The results were favorable to the **soil density** since it remained within the range for clay-textured soils ($\bar{x}$ = 1.1 g/cm³). However, it no longer is under the critical condition verified in the first sampling ($\bar{x}$=1.2 g/cm³), concerning the risk of compaction in clayey soil with a density of around 1.18 g/cm³.

The decrease of 8.3% (Figure 10) might be an effect of the OM found in the sewage sludge ($\bar{x}$ = 86.5%), for the OM density is lower than the mineral density. Such reduction represents a soil trend for good aeration, enabling roots to develop more efficiently and make more comfortable water and oxygen uptake.

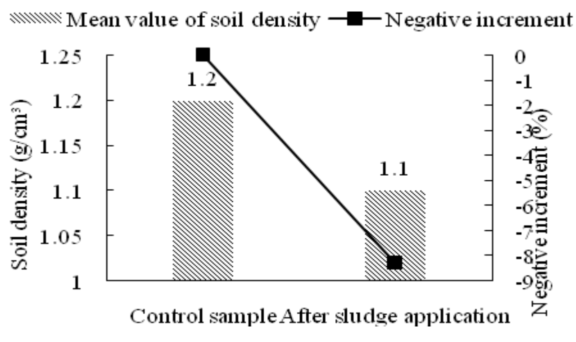

Figure 10: Decrease in soil density. Paragominas, PA

Researchers reported the alteration in the density of a sludge-applied soil 60 days after the sludge application in an area with a pasture of Marandu palisade grass (*Brachiaria brizantha* cv Marandu) in the experimental farm of Federal University of Tocantins, in Gurupi, TO [53].The authors observed a density of 0.9 g/cm³ at the depth 0-10 cm, to a sludge dosage of 2.0 km/m², which was significantly different from the control soil (1.2 g/cm³) same depth. In the experiment in Paragominas, to a sludge dosage of 3.0 kg/m², the earth presented a density of 1.0 g/cm³ at a depth of 0-10 cm, whereas in the control sample, it was 1.1 g/cm³.

4.4.2 Chemical Attributes

The data analyzed regarding soil fertility status after WWTP sludge application (Table 11).

Table 11: Analysis of soil chemical attributes after WWTP sludge application. Paragominas, PA.

Soil chemical properties After WWTP sludge application						
ATR	U	DEPTH (cm) 0-10	10-20	20-40	$\bar{x}$	LI
pH	DN	5.8	5.5	5.2	= 5.5	MA
P	mg/kg	18.9	11.7	7.8	= 12.8	G
K		123.0	38.0	37.0	= 66.0	M
Ca	cmolc/kg	2.7	2.3	1.6	= 2.2	M
Mg		1.7	1.1	1.1	= 1.3	G
OC	g/kg	32.6	25.9	18.4	≅ 25.6	
OM		58.9	47.3	32.1	= 46.1	
CEC	cmolc/kg	13.0	9.7	7.2	≅ 10.0	
SB		4.0	4.0	4.0	= 4.0	
V	%	65.4	57.3	62.0	≅ 61.6	

Legends: (DN) dimensionless number, ($\bar{x}$) mean, and (LI) limits for interpretation.

Concerning the **pH**, the sludge application significantly reduced potential soil acidity, and it turned into "medium acidity" ($\bar{x}$ = 5.5), different from the former status (control sample), characterized as "very high acidity" ($\bar{x}$ ≅ 4.4).

Such an increase might result from ammonium formation due to TN's oxidation, which is present in large quantities in the sewage sludge used ($\bar{x}$ = 2.0%). Besides, the increase in soil pH at all depths can be related to the leaching, along with the rainwater, of several alkalizing substances present in the applied organic waste, such as Ca ($\bar{x}$ = 9.2%).

In Selvíria, MS [44], a degraded soil initially with "high acidity" ($\bar{x}$ = 4.6) became, after the treatment with WWTP sludge, one with "medium acidity," revealing an increase of 17.4%. About that, pH evolution in the experimental area in Paragominas was 25.0% (Figure 11).

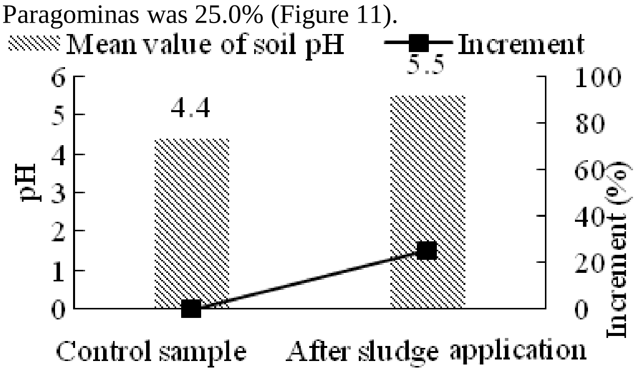

Figure 11: Evolution of soil pH evolution. Paragominas, PA.

The **P** was deemed to be "very low" ($\bar{x}$≅ 2.6 mg/kg) in the first sampling and, then, became "good" ($\bar{x}$= 12.8 mg/kg), with an increase of 392.3% (Figure 12a) after the organic compost dosage. Regarding **K** concentration, we observed an increase of 70.5% (Figure 12b) and it went from "low" ($\bar{x}$≅ 38.7 mg/kg) to "medium" ($\bar{x}$ = 66.0 mg/kg) content.

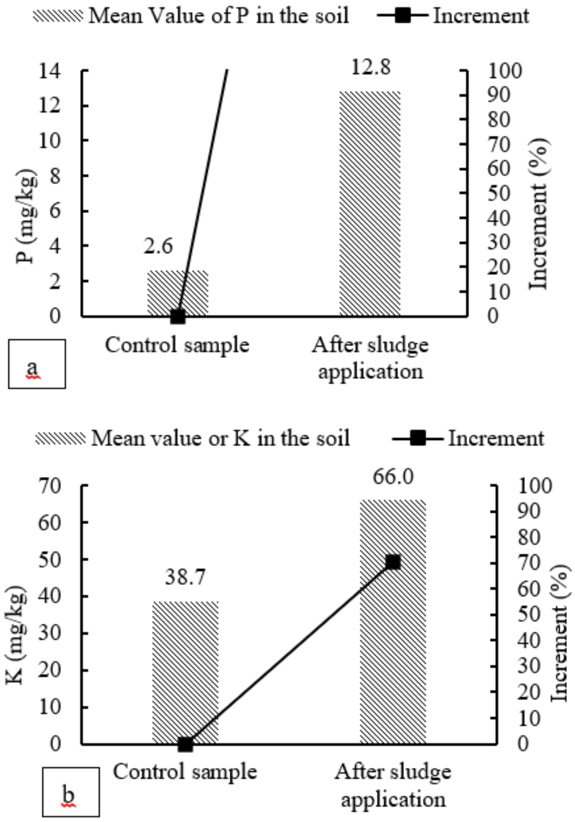

Figure 12: a) Evolution of P content in soil solution; b) evolution of K content in soil solution. Paragominas, PA.

The statistical analysis of the data was entirely complimentary for the primary macronutrients, what might be a result of a "medium acidity" pH ($\bar{x}$ = 5.5) 60 days after the WWTP sludge application, and tend to favor higher accumulations of P and K, as well as other nutrients, in soil solution. Furthermore, we can relate the most satisfactory results of P to its higher concentration in the sludge ($\bar{x}$ = 5.7%) when compared to K concentration ($\bar{x}$ = 1.5%).

In the study performed in Jaboticabal, SP [54], the authors concluded that the fertilization by using sewage sludge enabled a more significant rise of P (76.0%) and K (69.0%) contents at 0-10 cm depth. Likewise, in Paragominas, the increase at the most superficial center outdid the ones at other depths, with a 551.7% increase of P and 98.4% of K. It indicates that these elements were little leachate within the soil profile.

About the secondary macronutrients, after the experiment, we observed an increase of 100.0% (Figure 13a) and 160.0% (Figure 13b) in the levels of **Ca** and **Mg**, respectively. Along with other reasons, the sharp increases might be related to the presence of Ca ($\bar{x}$ = 9.2%) and Mg ($\bar{x}$ = 5.5%) in the WWTP sludge which, added to the former content already in the soil, caused significant modifications in the concentrations of such cations.

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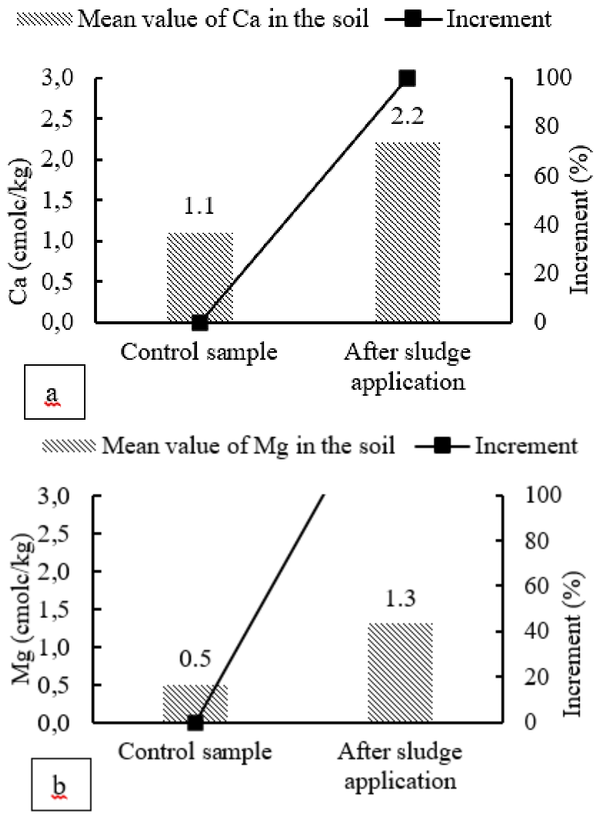


Figure 13: a) Evolution of Ca content in soil solution; b) Evolution of Mg content in soil solution.Paragominas, PA.

Research performed in the city of Sabará, MG [55], verified "medium" content of Ca ($\bar{x}$ = 1.6 $cmol_c$/kg) and Mg ($\bar{x}$ = 0.7 $cmol_c$/kg) before the fertilization by applying the sludge, and "good" content of Ca ($\bar{x}$ = 2.5 $cmol_c$/kg) and Mg ($\bar{x}$ = 1.4 $cmol_c$/kg) after this process. In Paragominas, however, the control soil showed "low" content of Ca ($\bar{x}$ = 1.1 $cmol_c$/kg) and Mg ($\bar{x}\cong$ 0.5 $cmol_c$/kg), whereas the conditions after the treatment with sewage sludge were "medium" for Ca ($\bar{x}$ = 2.2 $cmol_c$/kg) and "good" for Mg ($\bar{x}$ = 1.3 $cmol_c$/kg).

In the soil, the insertion of the organic compost allowed the content of **OC** to change from "medium" ($\bar{x}$ = 19.8 g/kg) to "good" ($\bar{x}\cong$ 25.6 g/kg), what, among other possible factors, could be a result of the high percentual of OC in the sludge used ($\bar{x}$ = 24.3%).

A study carried out in Goiânia, GO [56] reported an increase of 26.0% in OC concentration after 30 days of sludge application to land. In the plots in Paragominas, the sludge incubation time was 60 days, and we observed an increase of 29.3% (Figure 14).

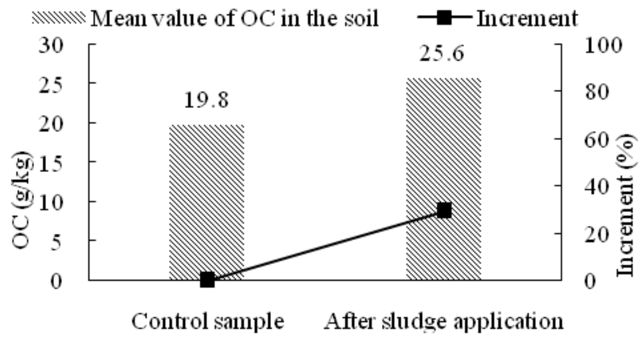


Figure 14: Evolution of OC content in the soil. Paragominas, PA.

Regarding **OM** content, the data indicated an increase of 17.9% (Figure 15) from the sludge dosage incorporated into the soil and, thus, went from "medium" ($\bar{x}\cong$ 39.1 g/kg) to "good" ($\bar{x}$ = 46.1 g/kg), what we can attribute to the high concentration of OM in the organic compost used to treatment ($\bar{x}$ = 86.5%), which is the primary nutritional component of the sludge.

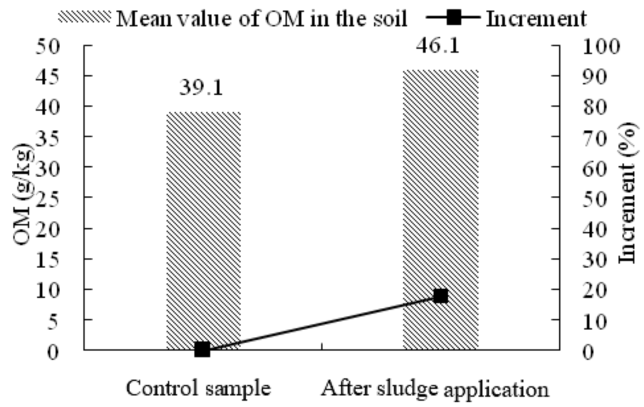


Figure 15: Evolution of OM content in the soil. Paragominas, PA.

A study performed in Seropédica, RJ [1], verified the OM concentration in the soil was initially $\bar{x}$ = 36.9 g/kg and rose to $\bar{x}$ = 48.0 g/kg, after the application of the organic compost, i.e., an increment of 30.1%, and also that the increase of organic molecules contained in the clayey soil analyzed occurred, especially, at 0-10 cm depth, with about 26.0%.

In Paragominas, the increase at the most superficial layer of the soil was 22.4%. Such increase in the concentration of OM acts positively in the process of recovery of degraded areas, especially in tropical grounds, due to the importance of this attribute for the maintenance of the physical properties (e.g., density and aggregation) adequate to the soil and for the reduction of macronutrients (e.g., P and K) using the mineralization.

After the addition of the organic waste, we observed an increase of 63.9% in **CEC** (Figure 16), what changed it from "medium" ($\bar{x}$ = 6.1 $cmol_c$/kg) in the first soil analysis to "good" ($\bar{x}\cong$ 10.0 $cmol_c$/kg) in the second one. A factor that could have possibly contributed to this scenario is the increase in the OM fraction in the sludge-applied soil since, in it; there are superficial charges that support CEC increase.

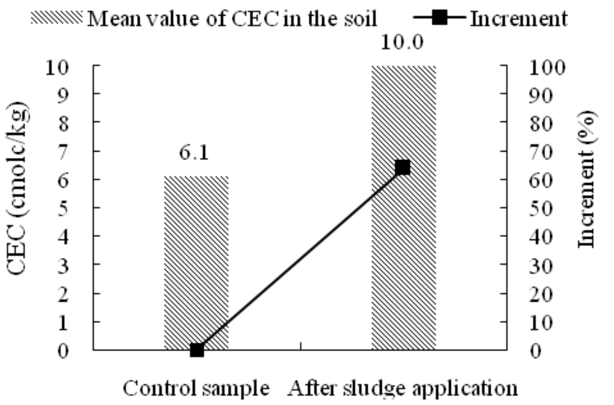
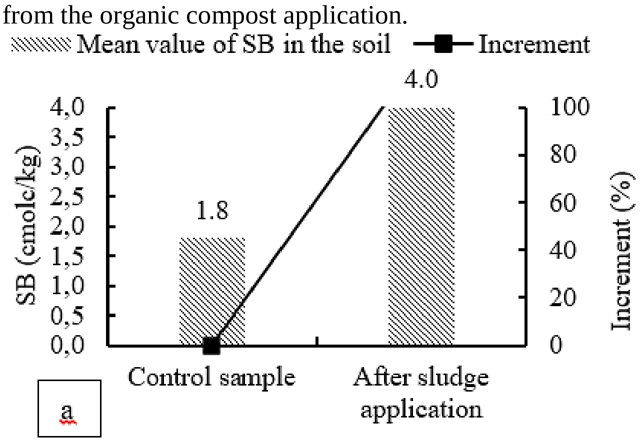


Figure 17: Evolution of CEC in the soil. Paragominas, PA.

In research carried out in Brasília, DF [57], the CEC content rose 340.0% (from $\bar{x}$ = 1.5 $cmol_c$/kg to $\bar{x}$ = 6.6 $cmol_c$/kg) after the treatment with WWTP sludge in an area degraded by the exploration of lateritic gravel. When the authors compared the CEC at three soil layers (0-10 cm, 10-20 cm, and 20-40 cm), they observed that the sludge application's result was higher at 10-20 cm depth, an increase of 67.0%. In Paragominas, the higher increment was at 20-40 cm, with 80.0%.

The **SB** and **V** in the sludge-applied plots increased, respectively, in 122.2% (Figure 17a) and 82.2% (Figure 17b), when compared to the control sample. Such increments might be connected to the increase in the contents of exchangeable cations (e.g., K^+, Ca^{2+}, and Mg^{2+}) from the organic compost application.



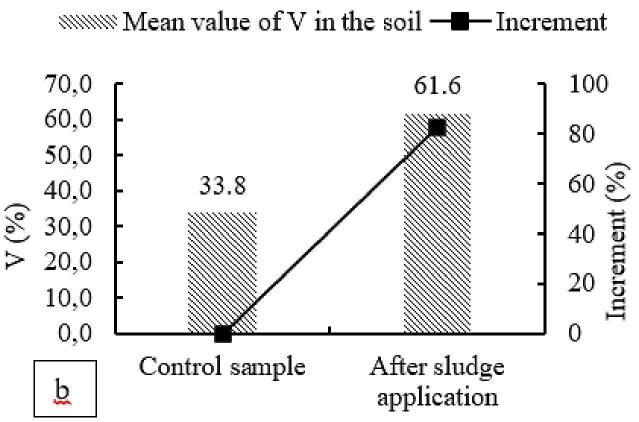


Figure 17: a) Evolution of SB in the soil; b**)** evolution of V in the earth. Paragominas, PA

In a study performed in Jaboticabal, SP [53], the authors concluded that as a result of the WWTP sludge application, the "medium" contents of SB ($\bar{x}$ = 3.4 $cmol_c$/kg) and V ($\bar{x}$ = 59.3%) in the soil rose to "good" contents ($\bar{x}$ = 5.0 $cmol_c$/kg and $\bar{x}$ = 67.4%, respectively).In the city of Paragominas, however, the values of SB ($\bar{x}$ = 1.8 $cmol_c$/kg) and V ($\bar{x}$≅33.8%) in the control soil was deemed to be "low." After the sludge dosage, the SB ($\bar{x}$ = 4.0 $cmol_c$/kg) and V ($\bar{x}$≅ 61.6%) levels in the experimental area were qualified as "good," which could imply the soil became eutrophic, i.e., its fertility has increased.

4.5 Significance analysis of the soil data variation – statistical tests of hypotheses

4.5.1 Physical Attributes

Regarding the physical attributes data, the normal distribution (p = 0.8 → p > 0.05) and the homogeneous variation (p = 0.9 → p > 0.05) determined, respectively, by the normality and homogeneity tests allowed the application of Student's *t*-test (Table 12).

Table 12: Student'*st*-test applied to the physical attributes data.

Student's *T*-Test Applied to The Physical Attributes Data	
Soil data	Data pairs from Analysis 1 (Control sample) and Analysis 2 (60 days after WWTP sludge application
N	12.0
$\neq\bar{x}$	0.7
SD	1.7
SE	0.5
V min	-1.0
V max	1.2
t	0.2
DF	11.0
P	0.8

Legend: (N) number of analyzed elements; ($\neq\bar{x}$) difference between the means of Analysis 1 and Analysis 2; (SD) standard deviation; (SE) standard error; (V min) minimum value in a 95% confidence interval; (V max) maximum value in a 95% confidence interval; (t) result of Student's *t*-test; (DF) degree of freedom; and (p)probability of the event occurrence.

The value of p = 0.8 indicates a non-significant variation between the data (p > 0.05). It suggests that the data distribution in both analyses 1 and 2 occurred as described by the null hypothesis (H_0), i.e., the difference between the means analyzed is not significant. Such a situation can be related to the experimental research period since the alteration of soil physical attributes is remarkable after long experimental periods and rising sludge dosages, especially at the shallowest depths (0-10 cm).

Furthermore, the attributes selected for the analyses might also be related to the lower data variability, for the nutrients provided by the sludge may positively influence the soil granulometry and density and other indicators of soil physical quality. About that, research carried out in Selvíria, MS [4], concluded that 60 days after the application of 1.5 kg/cm² of sludge to the soil, alterations more significant in physical attributes took places, such as the hydraulic conductivity, aggregate stability, macro porosity, and total porosity, and, less significantly, soil granulometry and density. In Paragominas, the variability analysis of physical parameters was limited to the two last ones.

4.5.2 Chemical Attributes

The application of normality and homogeneity tests to the chemical attributes data showed, in the following order, a non-normal distribution ($p = 0.001 \rightarrow p < 0.05$) and a heterogeneous variation ($p = 0.002 \rightarrow p < 0.05$), what allowed us to apply Wilcoxon's test (Table 13).

Table 13: Wilcoxon's test to the chemical attributes data

Wilcoxon's test to the chemical attributes		
Soil data	Analysis 1 (Control sample)	Analysis 2 (60 days after WWTP sludge application)
N	30,0	30,0
$\bar{x}$	14,8	23,5

Wilcoxon's test to the chemical attributes Conclusion		
Soil data	Analysis 1 (Control sample)	Analysis 2 (60 days after WWTP sludge application)
SD	17,1	27,9
CV (%)	115,7	118,8
$\bar{x}$	4,5	10,7
Final Values for Wilcoxon Analysis		
NR	0,0	
PR	30,0	
E	0,0	
z	-4,8	
P	0,0	

Legends: (N) number of analyzed elements; ($\bar{x}$) mean; (SD) standard deviation; (CV) coefficient of variation; (M) median; (NR) negative rank = analysis 2 < analysis 1; (PR) positive rank= analysis 2 > analysis 1; (E) equivalence = analysis 2 = analysis 1; (z) Wilcoxon's teste result; and (p) probability of the event occurrence.

From the test analysis, we obtained a value of $p = 0$. Therefore, we can claim that the variation in data from study 1 compared to the data from 2 is significant ($p < 0.05$) because it reflects the alternative hypothesis (H_1), which states there is a substantial difference between the analyzed means. Furthermore, we observed that this study's chemical attributes presented higher contents in analysis two than comment 1. Thus, they are deemed to be part of the positive rank (PR = 30.0).

The significant variation between analyses 1 and 2 for chemical attributes might be linked to the positive influence of the treatment with WWTP sludge on interpreting the fertility elements. This one is more related to the soil chemical properties, such as the acidity decrease, the increase in nutrients availability (e.g., Ca, K, Mg, and P), the increase in OM provision, and the increment in CEC content.

Regarding the sharp alterations in the soil chemical parameters, in research performed in Selvíria, MS [58], the sludge application led to significant increases, especially in the chemical elements as a result of this analysis (Ca, Cu, Fe, Mg, Mn, P, and Zn).

However, the authors identified results as non-satisfactory for CEC and SB since these attributes' levels decreased during the experimental period. Yet, in Paragominas, it was verified quite prominent to CEC (63.9%) and SB (122.2%).

5. Conclusion

The sewage sludge revealed itself as viable to the recovery of soils degraded by pasture. However, the microorganisms present in it might accumulate in the ground, which certifies the need to monitor and analyze the sludge-applied areas each semester.

After the sewage sludge application, the soil had a "shallow" content of P ($\bar{x} \cong 2.6$ mg/kg) and a "low" range of K ($\bar{x} \cong 38.7$ mg/kg). Such primary macronutrients are essential to soil solution, and the lack of just one of them might weaken forest cultivations development and production.

With the application of the organic waste, we noticed that the dosage used (3.0 kg/m²) influenced the analyzed physical (soil granulometry and density) positively and chemical (pH, P, K, Ca, Mg, OC, OM, CEC, SB, and V) attributes, what provided an improvement in the soil fertility in the sludge-applied plots when compared the control soil. It was indicated primarily by the increment of P (392.3%), K (70.5%), and OM (17.9%) contents, which turned into "good," "medium," and "good" levels, respectively.

Regarding the application of statistical tests of hypotheses (Student's *t*-test and Wilcoxon's test), the significant variation in the chemical attributes data shows that the application of sludge in the mid- or long term to degraded areas tends to balance the contents of chemical elements in the soil. It happened differently from physical attributes; whose data variation was not significant. The expressive alteration of such details requires a more extensive experimental period, and it is necessary to make adjustments in the sewage sludge dosage.

Therefore, the data generated in this research are real and will further other studies onwards that approach the viability of sewage sludge utilization as a conditioning treatment of degraded soils. We recommend performing more complex analyses of the organic waste, primarily inorganic substances and the potentially toxic ones (heavy metals).

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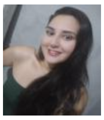

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