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REGULAR ARTICLE

Use of biosolids from a wastewater treatment plant for sunflower cultivation

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Abstract

The increase in solid waste and effluent generation due to urban and industrial activities represents a global challenge, especially in the management of sludge from wastewater treatment plants (WWTPs). Biosolids, a byproduct of this process, have high potential as a fertilizer, promoting nutrient recycling and improving the physicochemical properties of the soil. This study evaluated the use of different proportions of WWTP biosolids on the germination and growth of sunflowers (*Helianthus annuus*). The experiment was conducted under field conditions in the state of Rio de Janeiro. Five treatments were established in experimental design. After scarifying the experimental area, different volume ratios of biosolids and soil were applied to each treatment to a depth of 30 cm: 0:1 (soil only, control); 1:1; 2:1; 3:1; 1:0 (biosolids only). A total of 1,260 kg of biosolids was used. Germination and growth parameters were monitored weekly. The growth data obtained were subjected to statistical analysis using the Kruskal-Wallis and Dunn tests. The results showed that biosolid application accelerated seed germination and promoted greater plant growth. In the 1:0 treatment, the maximum germination rate was 77%, whereas in the pure soil, only 40% of the seeds germinated. Analysis of the growth parameters revealed that treatments with a higher proportion of biosolids (1:0 and 3:1) had significantly higher means, highlighting the positive impact of the nutrients present in the biosolids.

Keywords

Composting; Sludge; Waste; Sustainability

1. Introduction

Global population growth and rapid industrial development have driven sewage sludge production to critical levels, reaching approximately 45 million metric tons of dry matter annually worldwide (Giwa et al., 2023). The management of this waste poses a complex environmental challenge, as improper disposal can cause secondary pollution of soils and water bodies due to heavy metals, pathogenic microorganisms, and emerging contaminants (Zhang et al., 2020). Similarly, transporting raw sludge to landfills is financially burdensome due to the material's high volume and moisture content, and this practice is increasingly restricted by legislation aimed at reducing greenhouse gas emissions and groundwater contamination from leachate (Manea & Bumbac, 2024).

In this context, the transformation of sludge into biosolids has emerged as a key strategy within the circular economy, enabling the efficient recycling of nutrients and reducing dependence on energy-intensive synthetic mineral fertilizers (Araújo et al., 2022). Among treatment methods, composting stands out as a sustainable and effective technique for stabilizing organic matter and eliminating pathogenic microorganisms through strict temperature control during thermophilic phases (Manea & Bumbac, 2024). This process reduces the bioavailability of heavy metals and produces a stable end product with high agronomic value that is safe for application to soil (Yamashita et al., 2024).

The application of biosolids significantly improves the physicochemical properties of the soil (Zhao et al., 2025). The addition of organic matter reduces bulk density and increases porosity, which optimizes the substrate's water-holding capacity and aeration (Lins & Lima, 2022). Chemically, biosolids are a rich source of essential macronutrients, such as nitrogen (N), phosphorus (P), and potassium (K), which are fundamental to plant metabolism (Alauddin, Rahman & Ali, 2023). Studies indicate that the use of sludge-based fertilizers can dramatically increase the productivity of industrial crops: Kominko, Gorazda & Wzorek (2022) observed increases in fresh biomass of up to 138% in canola and corn, while Cristina et al. (2020) reported an increase of up to 37.5 times in the biomass of tomato plants grown in poor soils with the use of sewage digestate.

Sunflower (*Helianthus annuus*) is among the most promising crops for agricultural biosolid application, due to its high nutritional requirements and physiological resilience to abiotic stresses, such as salinity and drought (Pereira et al., 2023; Ribeiro et al., 2024). Grown primarily for the production of edible oils and biofuels, the crop has a deep root system capable of exploring large volumes of soil, which facilitates the uptake of slow-release nutrients present in organic waste (Yazdanbakhsh et al., 2020). In addition, sunflowers have been successfully used in soil phytoremediation, demonstrating the ability to accumulate heavy metals in their vegetative tissues without compromising

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the commercial quality of the oil produced (Alauddin, Rahman & Ali, 2023; Pande et al., 2022; Zhang et al., 2025).

Despite the fertilizing potential of biosolids, recent literature points to a significant geographical gap, with a lack of data on the use of these wastes in South America (Hoang et al., 2026; Kumar et al., 2023). Furthermore, authors emphasize the need for field studies that consider the interaction between agronomic application rates and local soil and climate conditions, since nutrient dynamics and crop response vary depending on soil type and management practices (Desjardins et al., 2025; Freitas et al., 2026). The present study aims to address these gaps by evaluating the effect of a biosolid produced from sewage sludge and plant residues on the early development of sunflowers in a Dystrophic Red Argisol under tropical conditions.

2. Materials and methods

The experiment was conducted under field conditions in the city of Araruama, Rio de Janeiro (Figure 1), which is located in a climatic transition zone characterized by the presence of different climate zones, such as the Tropical and Mild Tropical zones. Average annual precipitation ranges from 900 mm to 1,300 mm, with the heaviest rainfall occurring during the summer months. There are more pronounced dry spells during the winter, which require management practices that optimize soil water retention (Fialho & Machado, 2024).

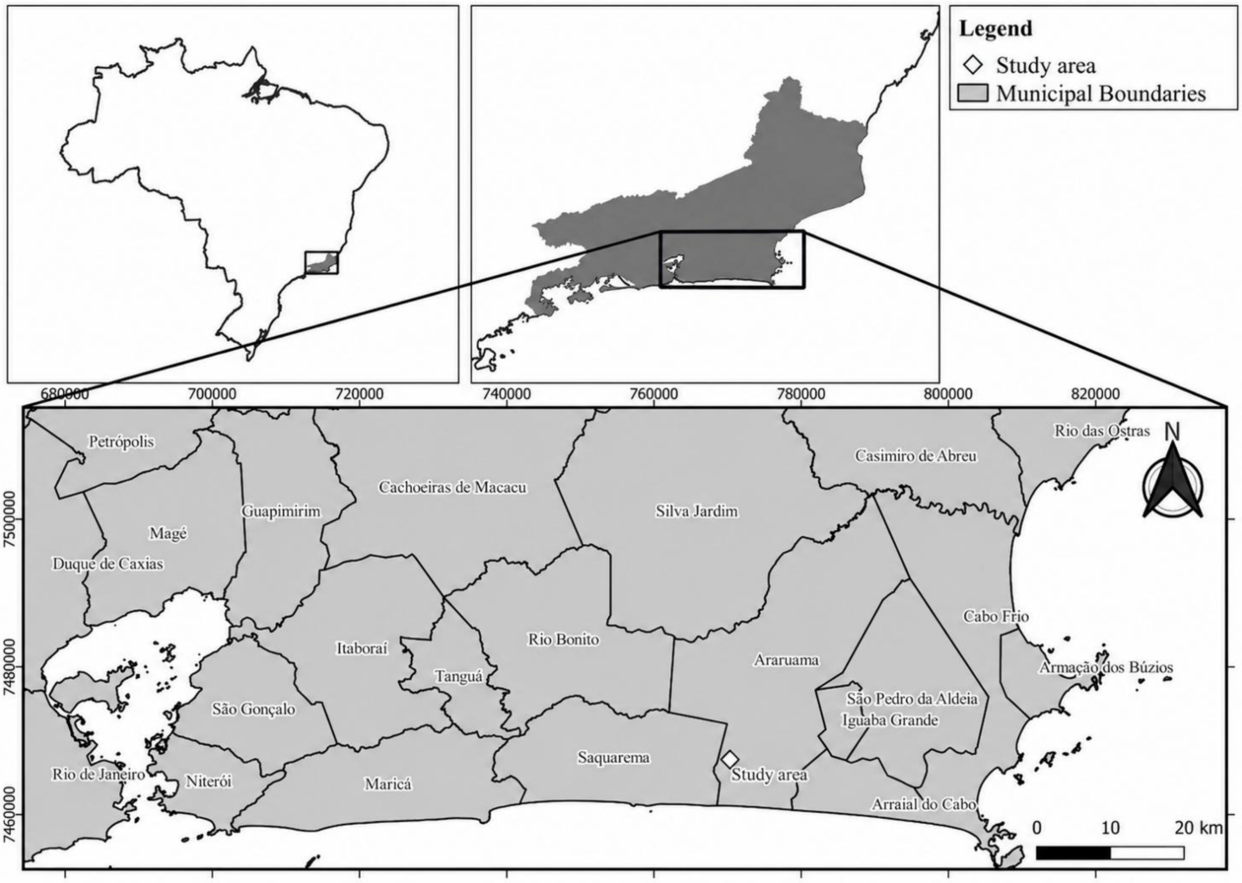

Figure 1. Location of the study area

Average annual temperatures range from 22°C to 25°C, with ample sunlight throughout the year. The soil in the study area was classified as Dystrophic Red Argissol, according to the criteria of the Brazilian Soil Classification System (Santos et al., 2018). Data from the National Institute of Meteorology (Inmet) were used to monitor local climate variations. The parameters considered were temperature, relative humidity, and radiation, which were monitored every five days, all at 10:00 a.m., over an 80-day period following sunflower sowing. In addition, precipitation data were used; in this context, the results represent the sum of precipitation from the previous five days.

2.1 Experimental design

The study was conducted between September 2022 and March 2023. Specifically, to vary the rates of biosolids applied to the soil, an experimental design with five treatments was used. Each plot was demarcated with dimensions of 9 m in length along a single row of plants. Thus, each treatment consisted of 30 holes, allowing for a comparison of the different biosolid ratios.

The soil-and-biosolids mixtures were prepared in advance based on volumetric ratios, with biosolids ratios of 0:1 (control), 1:1, 2:1, 3:1, and 1:0 (biosolids only), and were subsequently incorporated into the previously scarified strip of each plot. Considering the volume of the scarified strip for each treatment (9.0 × 0.20 × 0.30 m) and the defined ratios, the total volume of biosolids used in the experiment was 1.575 m^3. Since biosolids have a density of 0.8 g cm^{-3}, 1,260 kg of material were used. Initially, procedures were carried out for composting with sludge; this included analyzing the biosolids to be used, preparing the soil, and sowing sunflowers to subsequently monitor germination and plant growth and verify the results.

2.2 Preparation and analysis of biosolids

The sewage sludge was treated through a composting process. Initially, the sludge was spread out and left to dry naturally on waterproofing sheets to mitigate soil pollution. The dewatering area was covered with translucent sheets, allowing sunlight to penetrate for thermal drying and protecting the sludge from rainfall. The process took 30 days to reduce the sludge's moisture content, after which it was compacted and then screened. From the screened material, compost piles were formed by mixing the sludge with shredded prunings of the macrophytic species *Cyperus alternifolius* and sugarcane bagasse in a 5:1:1 ratio, resulting in piles with a triangular cross-section and a volume of 7 m^3. In addition, the process was monitored for organic degradation and temperature conditions to ensure the efficient action of microorganisms during the 70-day composting cycle. In this way, the maturation phase can be achieved with high-quality biosolids.

The sanitization process was confirmed through laboratory analyses conducted on the biosolids. At the end of the composting stage, three samples of the product were collected and duly sent to an accredited laboratory. Parameters related to agricultural suitability were analyzed, in accordance with the requirements of CONAMA Resolution No. 498/2020: *Escherichia coli*, arsenic, barium, cadmium, lead, copper, chromium, mercury, molybdenum, nickel, selenium, and zinc (Brazil, 2020).

2.3 Soil preparation and seeding

The soil was prepared according to the recommendations of the Brazilian Agricultural Research Corporation (EMBRAPA, 2026), by scarifying it to a width of 20 cm and a depth of 30 cm and subsequently sieving it to remove coarse materials. After preparation, biosolids were mixed into the soil for each treatment in increasing proportions of biosolids to soil by volume: 0:1 (control), 1:1, 2:1, 3:1, and 1:0 (biosolids only).

Seeds were sown at 30 cm intervals and 5 cm deep, using three sunflower (*Helianthus annuus*) seeds per hole, which were subsequently thinned to one plant per hole after 15 days. Twenty liters of water per day were applied to each treatment, exclusively on dry days with no rainfall.

2.4 Monitoring and data collection

The parameters monitored were: plant height, number of leaves, leaf width, leaf area, stem diameter, and capitulum diameter. Measurements were taken weekly using a tape measure and a caliper. Specifically, to determine the plant's leaf area (LA), the nonlinear power model described by Maldaner et al. (2009) was used, as shown in Eq. 1:

$$LA = 1.7582 \times \mathrm{L}^{1.7067} \quad (1)$$

where L represents the leaf width. Stem diameter was measured 5 cm above the ground.

Monitoring and data collection began in January, following the thinning stage and once the plants had grown sufficiently to allow the use of hand tools. The results for each parameter were calculated as the simple arithmetic mean of three plants from the same treatment. After the plants were established, three individuals were randomly selected from each treatment for non-destructive monitoring of growth parameters throughout the experimental cycle. Using the same plants in all measurement campaigns allowed us to evaluate the temporal evolution of sunflower development under different biosolid ratios.

The parameters were monitored until the flowering stage, over a period of ten weeks, except for those related to the diameters of the plant's stem and flower head (which included six measurements), due to the sunflower's stage of development. These were monitored between February and March 2023, while the others were monitored from January through March 2023.

2.5 Statistical analysis

The data from the biosolids treatments were analyzed in R (v. 4.4.2), using the FSA, readxl, and ggplot2 packages. After importing and preprocessing the data (removing missing and infinite values), boxplots were generated for exploratory analysis. Since the data did not meet the assumptions of normality and homoscedasticity, the Kruskal-Wallis test ($p < 0.05$) was applied (Oliveira, Marriel, Resende & Coelho, 2023), followed by the Dunn test with Bonferroni correction for multiple comparisons (Santos et al., 2025). This approach allowed us to identify significant differences in sunflower development among the treatments.

3. Results and discussion

3.1 Climate variability

Based on data from Inmet regarding climate variation, Table 1 was compiled. In this context, the results reflect conditions recorded every five days, with data collected at 10:00 a.m. Specifically, each value reported for rainfall corresponds to the cumulative amount recorded over the previous five days.

Of particular note is the variation in air temperature between 22.6°C and 27.2 °C, with a downward trend throughout the crop cycle. During the first 20 days, a slight increase in temperature was observed, reaching a maximum of 27.2 °C on the 40th day. From that point on, the temperature fluctuated within a narrow range, ending the experiment at 22.6 °C.

Relative humidity fluctuated between 75% and 92%, remaining high most of the time, with peaks during the first 15 days. Global radiation, in turn, showed a high initial value (766.6 kJ/m^2 on the 5th day). However, overall, global radiation fluctuated and showed a downward trend over time.

Rainfall showed considerable variability during the experiment. In the first 10 days, the cumulative total was 95.2 mm, with a significant peak of 128.8 mm on the 15th day. During the experiment, heavy rainfall was observed between 40 and 50 days, reaching a maximum of 288.8 mm. Subsequently, rainfall decreased, with values ranging from 0 to 13 mm.

Table 1. Climate variation during the study period for sunflower germination and growth (December 27, 2022, to March 16, 2023)

Days after planting	Global Radiation (kj/m²)	Air Temperature (°C)	Relative Humidity (%)	Precipitation (mm)
5	766.6	23.6	82	76.8
10	165.7	23.4	89	18.4
15	297.5	23.0	92	128.8
20	600.0	26.3	77	16.2
25	722.6	25.8	79	33.4
30	488.1	24.6	90	67.4
35	303.8	23.9	87	4.2
40	324.6	27.2	83	4.0
45	426.7	24.2	87	288.8
50	267.6	23.8	86	43.2
55	163.0	24.4	85	13.0
60	286.8	25.1	77	3.0
65	341.3	23.4	81	0
70	206.5	22.9	84	5.2
75	227.5	24.0	75	0.6
80	266.6	22.6	83	2.4

3.2 Analysis of biosolids

The procedures applied and laboratory analyses conducted confirmed the quality of the biosolids for agricultural use in accordance with the requirements of CONAMA 498/2020, and quantitative testing was performed in accordance with the requirements for *Escherichia coli*, arsenic, barium, cadmium, lead, copper, chromium, mercury, molybdenum, nickel, selenium, and zinc. In this context, the three samples showed low concentrations of pathogens and controlled levels of heavy metals, complying with legal limits.

Specifically for the *E. coli* parameter, all results were below 1.8 grams per total solids (g^{-1} TS), thus meeting the most restrictive classification criterion of CONAMA 498/2020, which allows up to 10^3 *E. coli* per gram of total solids (g^{-1} TS) for Class A biosolids (Brazil, 2020).

Regarding the presence of heavy metals, the element with the highest relative concentration relative to the permitted limit was barium, reaching 24.57% of the maximum allowed for Class 1 biosolids in sample 2. The lowest relative concentration, on the other hand, was observed for nickel, which reached only 2.12% of the permitted limit in sample 3. Figure 2 shows the results of the chemical analyses, which met the most stringent regulatory limits, thereby classifying the biosolids as Class 1.

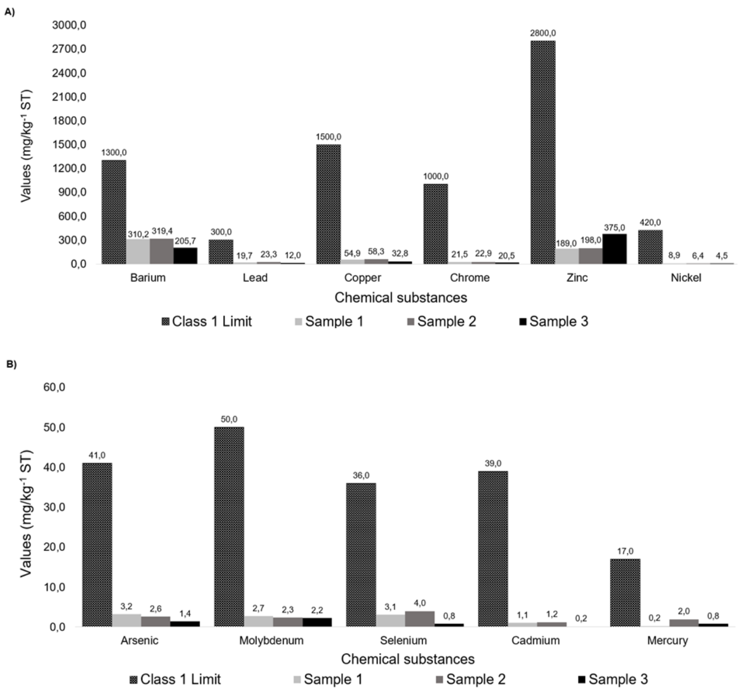

Figure 2. Results of chemical analyses for Class 1 biosolids: A) Barium, lead, copper, chromium, zinc, and nickel; B) Arsenic, cadmium, mercury, molybdenum, and selenium

3.3 Sunflower Germination

The results show significant differences in seed germination rates among treatments using different proportions of biosolids. Figure 3 illustrates the progression of germination over time. In the treatment with 100% biosolids (1:0), a germination rate of 43% was observed by the eighth day, while the control treatment showed only 7% by that same time. On the 10th day, the 1:0 treatment reached 77%, while the control treatment reached 40%, which was the final germination rate for the respective treatments. Treatment T4 showed the highest germination rate, with 80% of the seeds germinating.

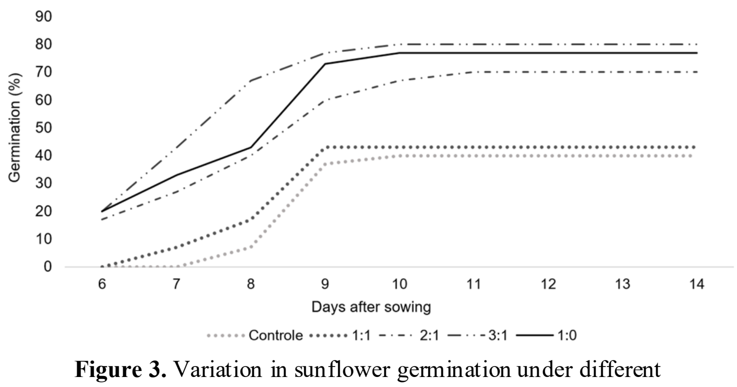

Figure 3. Variation in sunflower germination under different treatments involving biosolids to soil ratios: soil (T1 – control; T2 – 1:1; T3 – 2:1; T4 – 3:1); T5 - 1:0)

3.4 Sunflower Growth

Figure 4 summarizes the growth parameters evaluated: plant height (A), number of leaves (B), leaf width (C), leaf area (D), stem diameter (E), and capitulum diameter (F). It can be observed that the treatments with higher biosolid concentrations (1:0 and 3:1) exhibited higher means and greater variability in all analyzed parameters. In this regard, plant height in the 1:0 treatment was significantly higher compared to pure soil (control), with greater dispersion of values, reflecting an environment more favorable to growth. The treatment with pure soil exhibited lower mean values and limited variation across all parameters. Furthermore, the increase in the plants' aboveground biomass was directly proportional to the amount of biosolids.

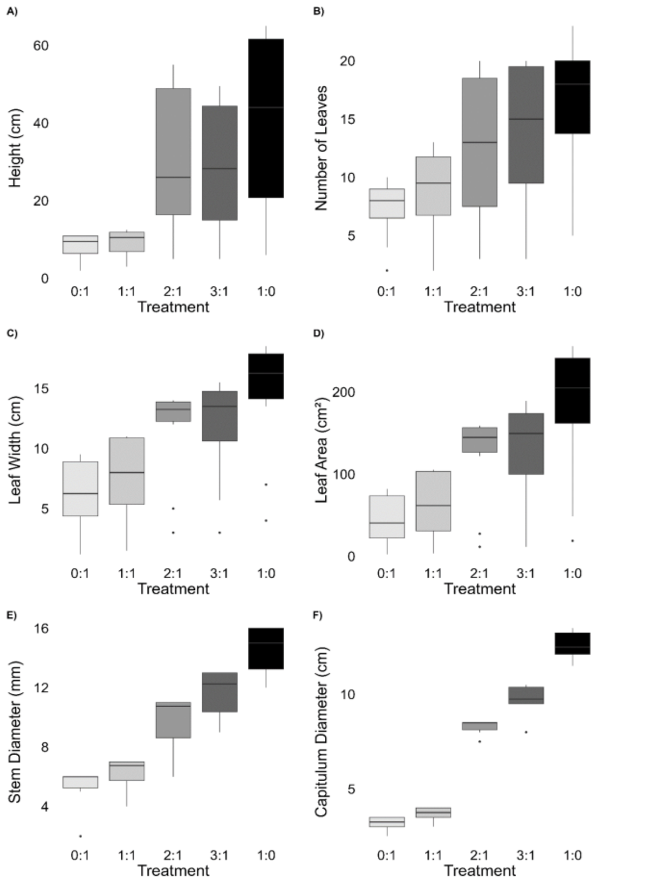

Figure 4. Variations in sunflower parameters under different treatments involving biosolids: soil (T1 – control; T2 – 1:1; T3 – 2:1; T4 – 3:1; T5 – 1:0): A) Height; B) Number of leaves; C) Leaf width; D) Leaf area; E) Stem diameter; F) Capitulum diameter

The results of the Dunn test showed significant differences in sunflower growth parameters depending on the proportions of biosolids applied. Table 2 lists the treatments that were found to be effective according to the adopted significance level ($p < 0.05$). For plant height, there was a significant difference between treatment T1 (pure soil) and T5 (pure biosolids), as well as between T2 (1:1) and T5, indicating that higher concentrations of biosolids promoted greater vertical growth. Regarding the number of leaves, the difference between T1 and T5 was statistically significant ($p = 0.0130$), suggesting that biosolids promote leaf development. Leaf width and leaf area also showed marked differences, especially between T1 and T5 ($p = 0.0009$), reinforcing the role of biosolids in increasing leaf surface area.

Stem diameter showed significant differences between T1 and T4, T1 and T5, and T2 and T5 ($p = 0.0035$), indicating that the use of biosolids directly impacted the plant's structural vigor. Regarding capitulum diameter, significant differences were observed between T1 and T4, and T2 and T5. Furthermore, the most significant difference ($p = 6.3601 \times 10^{-5}$) was observed for this parameter, indicating that the higher level of biosolid addition in treatment T5 resulted in a head diameter substantially greater than that observed in the treatment without biosolid addition.

Table 2. Results of the Dunn test for sunflower growth parameters up to the flowering stage with different biosolid-to-soil ratios (T1 – control; T2 – 1:1; T4 – 3:1; T5 – 1:0)

Comparison	Characteristic	*P*
T1 – T5	Height	0.0037
T2 – T5		0.0220
T1 – T5	Number of leaves	0.0130
T1 – T5	Leaf width	0.0009
T2 – T5		0.0071
T1 – T5	Leaf area	0.0009
T2 – T5		0.0071
T1 – T4	Stem diameter	0.0207
T1 – T5		0.0002
T2 – T5		0.0035
T1 – T4	Capitulum diameter	0.0147
T1 – T5		6. 3601 x 10-5

The results show that biosolids contributed to increased germination and development of sunflowers. The highest germination rates were observed in the 3:1 and 1:0 treatments (80% and 77%, respectively). This can be attributed to factors such as the positive impact of biosolids on soil moisture retention, temperature, and aeration—effects also reported by Yazdanbakhsh et al. (2020) and by Ribeiro et al. (2024) in studies using biosolids for sunflower cultivation. In comparison, the treatment without biosolids showed slower and more limited germination, indicating unfavorable conditions for the seed in dystrophic red argisol without the addition of organic matter.

The growth parameters monitored confirm that biosolid treatments yielded better results in terms of height, number of leaves, leaf width, leaf area, capitulum diameter, and stem diameter, with more vigorous and consistent development. This variability suggests that biosolids improve the physical and chemical structure of the soil, allowing for greater uniformity in plant growth. This can be attributed to improved nutrient concentrations in the soil, as reported in previous studies (Valadão et al., 2020; Amaral et al., 2024). Similar results from field plots indicated that the use of high proportions of sludge (0.75:1 by wet weight, equivalent to 900 t/ha of dry solids) promotes vigorous growth and increased aboveground biomass without causing a linear or dangerous increase in the uptake of heavy metals by the plant (Wang et al., 2024).

As for the analysis based on the Dunn test, the superior performance of treatment T5 (100% biosolids) compared to other treatments highlights the positive effect of organic matter on improving soil physical structure and water retention, which are critical factors for plant growth. Treatments with lower proportions of biosolids showed more limited growth, reinforcing the need for adequate doses to maximize the benefits to the plants.

The parameters of stem diameter and capitulum diameter showed three results with significant differences ($p < 0.05$), indicating that, in addition to T1, the treatment with the lowest biosolids addition (1:1) also yielded very limited results compared to T5 (1:0). Furthermore, the increase in stem and capitulum diameter suggests a direct impact on productivity, with the potential to increase seed and oil production.

Although no detailed chemical characterization of the soil was conducted prior to the start of the experiment, the experimental area was classified as a Dystrophic Red Argissol. This soil group belongs to the class of highly weathered tropical soils, typically characterized by pronounced acidity, low cation exchange capacity, and natural nutrient poverty (Basak et al., 2022; Santos et al., 2018). In sandy loam Argisols, nutrient dynamics are severely limited by the presence of minerals such as kaolinite and iron and aluminum oxides, resulting in low levels of plant-available nutrients (Castro et al., 2026). Thus, the positive response observed to the use of biosolids may be related to the addition of organic matter and nutrients to an originally low-fertility environment, which promotes biological cycling and increases the availability of labile fractions in the substrate (Castro et al., 2026; Silva et al., 2023).

The results obtained in this study not only confirm the fertilizing potential of biosolids but also fill a critical geographical gap in the literature, which still lacks robust data on the use of these wastes in South America (Hoang et al., 2026; Kumar et al., 2023). By demonstrating that field application accelerates germination and promotes vegetative vigor in Dystrophic Red Argisol, this study addresses the need for research that considers local edaphoclimatic characteristics and site-specific management (Desjardins et al., 2025; Freitas et al., 2026). Additionally, the use of regional waste as a structuring agent in composting reinforces a circular economy model applicable to other wastewater treatment plants in tropical regions, transforming an environmental liability into a strategic resource for oilseed cultivation (Araújo et al., 2022; Manea & Bumbac, 2024).

Despite the benefits, it is important to consider the limitations associated with the use of biosolids, such as the need to control contaminants and ensure proper management to prevent environmental impacts. Future studies should evaluate the long-term effects of biosolids on soil fertility, monitor sunflower seed production, and investigate the application of biosolids to other crops and regions.

4. Conclusions

The use of biosolids promoted increased germination and early development of sunflowers compared to soil without the addition of this material. The treatment with the highest concentration of biosolids, T5, containing only biosolids to a depth of 30 cm, achieved the best results for all growth parameters monitored. Regarding the germination rate, T4 (3:1) was the highest; however, the difference compared to T5 was only 3%.

Overall, increasing biosolid concentration was associated with improved moisture retention and soil aeration, favoring seed germination and subsequently enhancing sunflower growth through greater nutrient availability. These results highlight the potential of composted biosolids as a sustainable alternative for sunflower cultivation and for the agricultural use of wastewater treatment plants.

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