# PIG SLURRY IMPROVES THE PRODUCTIVE PERFORMANCE OF EUCALYPT AND EXCEEDS THE MINERAL FERTILIZATION

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ABSTRACT – The nutrients contained in the liquid pig slurry (PS) make this residue a potential organic fertilizer for the cultivation of tree species for the production of wood, which can promote the circular economy. This research aimed to evaluate soil chemical parameters, nutritional status, and development of hybrid eucalyptus clone urograndis from PS application for three consecutive years. The treatments evaluated were without fertilization (C); mineral fertilization (NPK) – 300 kg $ha^{-1}$ $year^{-1}$ of the 02-30-10 formulation; fertigation with PS of 200 $m^3$ $ha^{-1}$ $year^{-1}$ (FPS200); and fertigation with PS of 400 $m^3$ $ha^{-1}$ $year^{-1}$ (FPS400). Macronutrients and micronutrients from leaves and soil were evaluated. Tree development was analyzed using stem diameter at breast height (DBH) and total height (Ht). PS treatments resulted in leaves with higher accumulation of K and P and lower accumulation of N, Ca, M, S, Cu, and Fe. The treatments FPS200 and FPS400 presented DBH and Ht equal or superior to the mineral fertilization. Fertilizations with NPK, FPS200, and FPS400 resulted, respectively, in DBH increments 16, 27, and 30% higher than the control. Regarding the chemical attributes of the soil, the use of PS reduced the pH of the soil and increased the levels of P in comparison with the other treatments. The micronutrient values were adequate for fertility and no accumulation of potentially toxic elements at a level considered harmful was observed. The application of PS in eucalyptus hybrid urograndis proved to be an attractive alternative to increase wood production.

Keywords: Circular Economy; Eucalyptus hybrid urograndis; Organic fertilization.

## *DEJETO DE SUÍNO MELHORA O DESEMPENHO PRODUTIVO DO EUCALIPTO E SUPERA A ADUBAÇÃO MINERAL*

*RESUMO – Os nutrientes contidos nos dejetos líquidos dos suínos (PS) fazem desse resíduo um potencial adubo orgânico para o cultivo de espécies florestais destinado a produção de madeiras, podendo promover a economia circular. Essa pesquisa objetivou avaliar parâmetros químicos do solo, status nutricional e desenvolvimento de um clone de eucalipto híbrido urograndis em função da aplicação de PS por três anos seguidos. Os tratamentos avaliados foram sem adubação (C); adubação mineral (NPK) – 300 kg $ha^{-1}$ $ano^{-1}$ da formulação 02-30-10; fertirrigação com PS de 200 $m^3$ $ha^{-1}$ $ano^{-1}$ (FPS200); e fertirrigação com PS de 400 $m^3$ $ha^{-1}$ $ano^{-1}$ (FPS400). Macronutrientes e micronutrientes das folhas e do solo foram avaliados. O desenvolvimento das árvores foi analisado por meio do diâmetro do caule à altura do peito (DAP) e da altura total (Ht). Os tratamentos com PS resultaram em folhas com maior acúmulo de K e P e menor acúmulo de N, Ca, M, S, Cu e Fe. Os tratamentos FPS200 e FPS400 apresentaram DAP e Ht igual ou superior à adubação mineral. As adubações com NPK, FPS200 e FPS400 resultaram, respectivamente, em incrementos de DAP 16, 27 e 30% superiores ao controle. Em relação aos atributos químicos do solo, o uso de PS reduziu o pH do solo e elevou os teores de P em comparação com os outros tratamentos. Os valores de micronutrientes foram adequados para a fertilidade e*




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*não se observou acúmulo de elementos potencialmente tóxicos a um nível considerado nocivo. A aplicação de PS em eucalipto híbrido urograndis mostrou-se uma alternativa atrativa de ampliação de produção da madeira.*

*Palavras-Chave: Economia circular; Eucalipto híbrido urograndis; Adubação orgânica.*

## 1. INTRODUCTION

Pig worldwide production was 97,757,000 tons in 2020, and China (38.9%), the European Union (24.5%), the USA (13.1%) and Brazil (4.5%) were the countries with the highest production percentages. In Brazil, pork production increased from 3,237,000 tons in 2010 to 4,436,000 tons in 2020. This has positively impacted the country's economy, since only the export of 2020 (1,024,000 tons) yielded about 2,269 billion dollars to the country (Abpa, 2021).

Despite the economic benefits, pig farming requires large volumes of water and generates expressive amounts of organic wastes from animal defections and the stalls' hygiene. These wastes known as pig slurry (PS) can be reused in agriculture as organic fertilizer. Its reuse is interesting from both under the economic and an environmental point of view, since it represents an internal resource of rural properties and agro-industries that can be used for application in the soil in the same properties or in properties of the region for grain production, adapting to the nutrients circular economy (Valve et al., 2019).

The efficient reuse of nutrients from organic wastes presents economic and environmental advantages over mineral fertilizers. The most consumed mineral fertilizers come from non-renewable sources and their production largely depends on the use of fossil fuels (Woods et al., 2010). And most important, they do not provide a solid basis for development of sustainable agricultural production systems precisely because they are devoid of organic matter which is essential to maintain soil quality and to promote greater use of nutrients (Cai et al., 2019).

Thus, the use of PS has a key role for sustainable agriculture due to the possibility of using these wastes both for soil fertilization and for reduction of ecological impacts caused by its improper accumulation in the environment (Couto et al., 2015). Therefore, the problem of inadequate disposal of these materials is minimized and contributes to an ecological based production, which aims to conserve natural resources.

However, there is concern about the use of this type of waste in food production due to the possibility of contaminants that may offer health risk (Zhang et al., 2016). In this sense, the application of PS to crops of tree species intended for wood production and industrial uses represents a safe alternative, since the product is not intended for food (Marron, 2015). The use of organic residues as fertilization in forest systems contributes to the replacement of expensive mineral fertilizers, to meet the crops nutritional needs, in addition to improving the natural fertility of the soil and increasing productivity (Leila et al., 2017).

The total area of trees planted in Brazil was 9.0 million hectares in 2019, which represented an increase of 2.4% over 2018. Only eucalypt cultivation accounted for 77% of this amount, i.e. 6.97 million hectares. The development of eucalypt cultivation was expanded in Brazil due to the edaphoclimatic characteristics favorable to these species, investments in research and demand for the pulp and paper, timber and energy sectors (Iba, 2020).

Therefore, it is essential to conduct experiments that evaluate the effects of the PS use on the soil and for the production of eucalypt species. Several studies have investigated the effects of the organic wastes application, such as sewage sludge, in forest production, with special attention to environmental effects (Florentino et al., 2019). But, few studies have investigated the effects of PS applications in relation to the agronomic effects on forest production, and most studies are focused on seedling production (Vanin et al., 2017) and not on tree development.

Therefore, this research aimed to evaluate soil chemical parameters, nutritional status, and development of hybrid eucalyptus urograndis as a function of PS application for three consecutive years.

## 2. MATERIAL AND METHODS

The study was carried out in a pig farming unit located in the municipality of Medianeira, Paraná, Brazil, at latitude 25°15’09” S, longitude 54°04’03” O and altitude of 396 m. About 2 ha of this property are intended for the cultivation of eucalypt clone hybrid urograndis (hybrid of *Eucalyptus urophylla* S.T. Blake and *Eucalyptus grandis* Hill ex Maiden).

The predominant climate in the area, according to the Köppen-Geiger classification, is subtropical, characterized by hot summers, with an average temperature of 20 °C and average rainfall of 1923 mm $year^{-1}$. Figure 1 shows the minimum, average and maximum temperatures, as well as the rainfall of Medianeira during the period during which the experiment was carried out (October 2018 to November 2019).

The soil of the area is classified as a typical Dystroferric Red Latosol (Embrapa, 2013), with 13 % sand, 18 % silt and 69 % clay. The soil chemical characteristics (0 to 0.2 m depth) of the reforestation area before the beginning of the experiment were: pH ($CaCl_2$) = 5.2; organic matter (OM) = 45.7 g $kg^{-1}$; P (Mehlich-1) = 5.9 mg $dm^{-3}$; H+Al = 4.7 cmol $dm^{-3}$; K (Mehlich-1) = 0.33 cmol $dm^{-3}$; Ca = 3.9 cmol $dm^{-3}$; Mg = 2.1 cmol $dm^{-3}$; S = 10.5 mg $dm^{-3}$; Al = 0.00 cmol $dm^{-3}$; cation exchange capacity (CEC) = 11.03 cmol $dm^{-3}$; V = 57.4 %; Cu = 6.8 mg $dm^{-3}$; Fe = 27.0 mg $dm^{-3}$; Mn = 89.9 mg $dm^{-3}$ and Zn = 16.4 mg $dm^{-3}$.

### 2.1. Pig slurry

Pig Slurry (PS) was obtained on the same property where eucalypt was grown. The unit had about 6,000 animals during fattening, which generated about 130 $m^3$ per day of slurries (excreta, urine, hygiene water of sheds, rest of animal feed and hair). The characteristics of PS were (average value, n = 6, two collections being carried out per year over three years): pH = 6.5; Chemical Oxygen Demand = 18,567.4; Total Kjeldahl Nitrogen = 428.5 mg $L^{-1}$; Total P = 117.4 mg $L^{-1}$; Total K = 156.9 mg $L^{-1}$; S = 226.6 mg $L^{-1}$; Ca = 136.8 mg $L^{-1}$; Mg = 81.2 mg $L^{-1}$; Fe = 11.8 mg $L^{-1}$; Cu = 0.4 mg $L^{-1}$; Zn = 1.7 mg $L^{-1}$; Mn = 0.9 mg $L^{-1}$; B = 0.4 mg $L^{-1}$. The PS total solids concentration varied between 3 and 6% over the six collections.

### 2.2.Treatments and configuration of the experiment

Four treatments were evaluated, with 20 repetitions each, totaling 80 experimental units. This number of repetitions was used to minimize the average variance in each treatment, allowing more data uniformity and precision. Each of the four plots consisted of 120 $m^2$ (10 m long by 12 m wide), containing 20 eucalyptus clone hybrid urograndis plants, with 2 m spacing between plants and 3 m between lines. Between one plot and another, eight lines were skipped to avoid overlapping treatments. The treatments evaluated were: control or without fertilization (C); mineral fertilization (NPK) – 300 kg $ha^{-1}$ $year^{-1}$ of the formulation 02-30-10; fertigation with pig slurry with 200 $m^3$ $ha^{-1}$ $year^{-1}$ (FPS200); and fertigation with pig slurry with 400 $m^3$ $ha^{-1}$ $year^{-1}$ (FPS400). Treatments were applied after 40 months of planting and occurred twice a year until the plants reached 77 months, i.e. in June and December 2018, 2019 and 2020, totaling six applications. The fertilizations were top dressing and the pig slurry was applied with the aid of a suction tank. Plant and soil

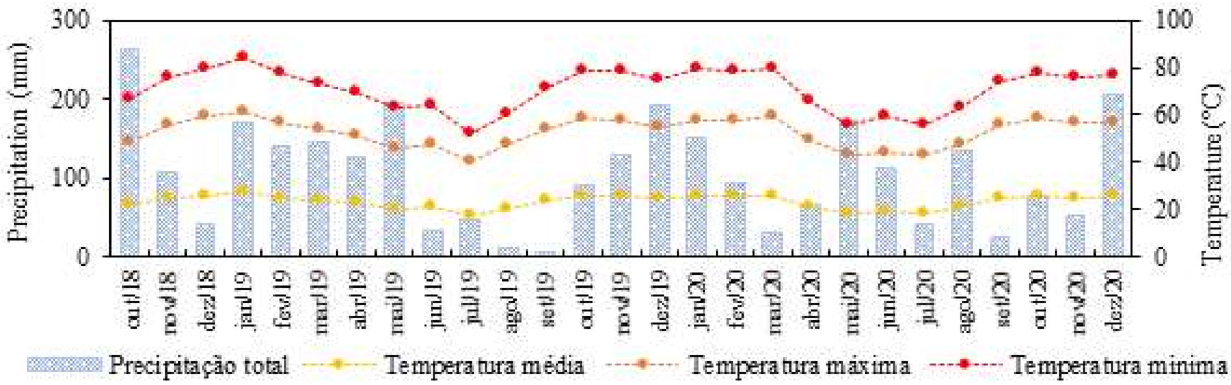


**Figure 1** – Total monthly precipitation and minimum, average and maximum experimental area temperatures during October 2018 until December 2020.

***Figura 1*** – *Precipitação mensal total e temperaturas mínimas, médias e máximas da área experimental durante outubro de 2018 até dezembro de 2020.*

attributes were analyzed at 52, 64 and 77 months of eucalyptus hybrid urograndis cultivation.

**2.3. Analytical methods of the plant**

Using a pruning shears, 15 fresh leaves of the primary branches of each plot plant were collected. The leaves were stored in paper bags and prepared for leaf analysis. Nitrogen concentrations (N) were carried out in digestion with concentrated sulfuric acid, followed by distillation and titration. The concentrations of P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn of the leaves were analyzed from nitric-perchloric digestion, according to Silva (1999). The plants development was analyzed by means of stem diameter at breast height (DBH) and total height (Ht). The DBH measurement was performed with the aid of a tape measure at a height of 1.30 m and the height was performed with the aid of a hypsometer.

**2.4. Analytical methods of soil and slurry**

Soil sampling was performed at 0.0–0.2 m depth using the Ducth auger hole. Each soil sample was conducted by taking twelve subsamples collected at random in the useful area of each plot along the rows of the plantation. The samples were then homogenized, air dried and sieved at 2.0 mm. The following chemical attributes were analyzed: pH ($CaCl_2$); P and K (Mehlich-1); exchange Ca, Mg and Al (KCl 1 mol $L^{-1}$); $SO_4^{2-}$ [$Ca(H_2PO_4)2$, 500 mg $L^{-1}$ of P in HOAc 2 mol $L^{-1}$]; Organic Matter (OM) (Walkley Black); and base saturation (V%) according to Pavan (1992); and micronutrients: Fe, Cu, Mn and Zn (Mehlich-1) according to Silva (1999). The micronutrient contents in the soil were analyzed in terms of comparison among control and mineral treatments, as well as for the evaluation of soil fertility, comparing them with reference values (RV) and to evaluate possible contamination in relation to the standard soil quality reference values (VSQ), since these elements are potentially toxic when at high concentrations. The soil quality reference standard values (Cetesb, 2016) establish the concentration of substances in the soil that defines it as clean or uncontaminated. One of the major concerns of the re-use of pig slurry in the soil is related to Cu and Zn contamination that can occur at high concentrations in PS (Legros et al., 2013; Benedet et al., 2019).

The chemical oxygen demand (COD) of pig slurry was determined according to the standard method (Baird and Bridgewater, 2017). Total Kjeldahl nitrogen (NTK) was determined by the samples digestion with sulfuric acid, followed by distillation using the Kjeldahl distiller and titration with $H_2SO_4$ (Baird and Bridgewater, 2017).

**2.5.Statistical analysis**

The experimental design was randomized blocks, with four treatments and twenty plots. The data obtained were submitted to ANOVA and the means were compared year by year using the Tukey test at 5% probability. Soil attributes and phytometric variables of commercial interest were studied using multivariate analysis techniques. Cluster analysis was applied to determine the similarity among the treatments. For the clusters formation the hierarchical cluster analysis of average linkage from the Euclidean distance matrix was used. The Principal Component Analysis (PCA) was used to summarize and interpret the relations among the effects of treatments on plant development. Accumulated explanation percentages above 60% were used as component selection criteria (Ferreira, 2011).

## 3. RESULTS

**3.1 Leaf content of nutrients**

The treatments influenced the leaf content of nutrients in all the evaluated years (Table 1). At 52 months of age, after the first applications of the treatments, higher N and P levels were observed for plants treated with FPS400 and higher Ca content in the treatments with mineral fertilization (NPK). The Mg content was lower only in the control treatment and the S and K contents did not show significant differences. The PS applications resulted in higher levels of B and Mn and lower Fe content. The FPS200 treatment resulted in higher Zn content, while the FPS400 presented plants with lower Cu content.

After the second year, at 64 months of age, no differences were observed in the leaf contents of N, P and Mg. K contents were higher in PS treatments regardless of the dose applied, whereas Ca and S levels were significantly higher in FPS400 treatments. Regarding the micronutrients, there was a higher concentration of Mn and Zn in FPS200 and FPS400 treatments, higher Fe content in the control treatment, and no difference was found between treatments for B and Cu contents (Table 1).

**Table 1** – Macronutrient and micronutrient contents in eucalypt hybrid urograndis leaves in the year 2018 at 52 months of age, 2019 at 64 months of age, 2020 at 77 months of age, followed by applications of pig slurry in the soil (mean±standard deviation).
***Tabela 1*** – *Teores de macronutrientes e micronutrientes em folhas de eucalipto híbrido urograndis no ano de 2018 aos 52 meses de idade, 2019 aos 64 meses de idade, 2020 aos 77 meses de idade, seguido de aplicações de dejetos de suínos no solo (média±desvio padrão).*

| Treatment[1] | Age[2] | N | P | K | Ca | Mg | S | B | Cu | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | g kg⁻¹ | | | | | | mg kg⁻¹ | | | | |
| C | | 19.02±2.3 ab | 0.87±0.0 c | 5.00±0.6 a | 7.75±2.3 b | 1.59±0.1 c | 1.30±0.0 a | 25.53±3.5 b | 7.70±0.6 a | 205.05±31.3 a | 272.99±47.5 d | 11.21±0.8 bc |
| NPK | 52 | 18.01±1.7 b | 0.80±0.0 c | 5.02±0.7 a | 9.84±1.9 a | 1.71±0.1 bc | 1.31±0.0 a | 26.28±6.2 b | 7.23±0.6 ab | 200.42±58.8 a | 473.68±169.4 c | 12.80±1.3 ab |
| FPS200 | | 18.65±1.4 b | 1.16±0.3 b | 5.17±0.7 a | 7.04±2.1 bc | 1.88±0.2 ab | 1.25±0.1 a | 26.41±5.8 ab | 7.52±1.5 a | 94.60±20.5 b | 1434.28±298.9 b | 14.57±4.0 a |
| FPS400 | | 20.18±1.3 a | 1.81±0.4 a | 5.18±0.7 a | 5.42±0.9 c | 2.08±0.3 b | 1.25±0.0 a | 31.34±7.8 a | 6.44±1.1 b | 86.00±20.1 b | 2289.70±315.7 a | 10.68±1.5 c |
| C | | 20.61±1.9 a | 1.08±0.2 a | 7.35±2.0 b | 10.74±1.7 b | 2.36±0.5 a | 1.51±0.1 b | 35.92±8.1 a | 7.36±1.6 a | 141.55±38.7 a | 344.69±55.7 d | 14.85±1.9 c |
| NPK | 64 | 19.27±2.9 a | 1.15±0.3 a | 7.79±1.9 ab | 9.61±3.8 ab | 2.54±1.4 a | 1.45±0.1 b | 36.07±12.3 a | 7.33±2.4 a | 108.09±40.6 b | 681.67±197.6 c | 17.02±8.3 bc |
| FPS200 | | 19.48±2.3 a | 1.28±0.2 a | 8.79±1.6 a | 7.76±1.9 b | 1.91±0.3 a | 1.60±0.2 ab | 35.71±6.5 a | 7.26±1.3 a | 99.70±29.6 b | 1270.52±164.8 b | 22.18±13 ab |
| FPS400 | | 19.57±2.7 a | 1.28±0.2 a | 9.17±0.9 a | 11.01±5.2 a | 2.22±0.3 a | 1.74±0.3 a | 37.53±5.7 a | 7.62±1.1 a | 95.05±20.8 b | 1734.99±327.2 a | 25.89±5.2 a |
| C | | 23.05±2.6 ab | 1.26±0.1 b | 6.08±0.9 b | 13.14±4.7 a | 3.07±0.3 a | 2.09±0.2 a | 28.80±15 a | 5.04±1.4 b | 296.45±150 a | 439.73±110 d | 11.65±1.5 c |
| NPK | 77 | 23.51±2.1 a | 1.53±0.4 a | 6.64±1.4 b | 10.58±1.5 ab | 2.80±0.5 ab | 1.94±0.1 ab | 19.67±4.2 b | 6.84±1.4 a | 430.50±199 a | 725.97±109 c | 14.52±3.7 bc |
| FPS200 | | 23.72±1.5 a | 1.54±0.3 a | 7.01±1.2 ab | 9.23±1.4 b | 2.67±0.4 b | 1.97±02 ab | 18.25±5 b | 5.59±1.4 b | 318.88±260 a | 1041.60±80 b | 15.20±3.9 b |
| FPS400 | | 21.58±2.5 b | 1.71±0.1 a | 8.04±2.1 a | 8.94±3.8 b | 2.56±0.3 b | 1.81±0.2 b | 20.32±5.5 b | 4.92±0.4 b | 129.73±57 b | 1386.75±157 a | 22.42±6.0 a |
| VF[3] | | 13.5-18.0 | 0.9-1.3 | 9.0-13.0 | 6.0-10.0 | 3.5-5.0 | 1.5-2.0 | 30.0-50.0 | 7.0-10.0 | 150.0-200 | 400-600 | 0.5-1.0 |

Values followed by different lower-case letters in the column represent a significant difference by the Tukey test ($p<0.05$).
[1]Treatments: C indicates the control treatments without fertilization with manures or fertilizer; NPK indicates the treatments with mineral fertilization; FPS200 indicates the treatments in which 200 $m^3$/ha of PS were applied; and FPS400 indicates the treatments in which 400 $m^3$/ha of PS were applied.
[2]Age of plants in months.
[3]Reference values according to the Manual of fertilization and liming for the State of Paraná (SBCS/NEPAR, 2017).
*Valores seguidos de letras minúsculas diferentes na coluna representam diferença significativa pelo teste de Tukey ($p<0,05$).*
*[1] Tratamentos: C indica o tratamento de controle sem adubação com esterco ou fertilizante; NPK indica o tratamento com adubação mineral; FPS200 indica o tratamento em que foram aplicados 200 $m^3$/ha de PS; e FPS400 indica o tratamento em que foram aplicados 400 $m^3$/ha de PS.*
*[2] Idade das plantas em meses.*
*[3] Valores de referência de acordo com o Manual de Adubação e Calagem para o Estado do Paraná (SBCS/NEPAR, 2017).*

At 77 months, after the third year of application of the treatments, it was observed that less concentration of N and S was observed where the application of FPS400 was compared to the other treatments. P content was higher in plants that received both mineral and organic fertilization. The K content was higher in PS treatments, but the Ca and Mg contents were lower. The highest concentrations of Mn and Zn with FPS200 and FPS400 applications were observed again, and the highest Cu content was observed in the treatment with mineral fertilization.

### 3.2. Influence of treatments on dendrometric characteristics

The evaluated treatments significantly influenced ($p<0,05$) diameter at breast height (DBH) (Figure 2A) and height (Ht) (Figure 2B) in the crop of eucalyptus hybrid urograndis cultivation. The PS application (FPS200 and FPS400) resulted in dendometric developments higher or equal to the NPK treatment, which may be related to higher nutrients availability, as observed in the nitrogen, phosphorus and potassium contents in the leaves (Table 1). This observation highlights the potential of using PS in eucalypt crops and reducing consumption of non-renewable fertilizers such as NPK.

### 3.3. Soil chemical properties

Some differences in soil properties were detected throughout the study. Significant reductions in soil pH values were observed with the application of slurry of up to 1.6 units compared to control and chemical treatments, mainly at 64 and 77 months of age (Table 2).

Similarly, significant reductions in soil OM content were observed, however, in this case, the greatest reduction was observed after FPS applications in the first two years of the experiment. FPS400 applications resulted in higher soil CEC compared to control treatment but did not show significant difference when compared to NPK treatment. On the other hand, the FPS200 treatment had little effect on the CEC, since it was closer to the values observed in the control treatment. The results indicate that PS applications increased Cu levels in the soil throughout the study (Table 2). No differences were found for Zn content during the first two years of study. However, after the third year of the study, the Zn content of the soil was reduced with the FPS400 treatment, which presented a 51% lower content than the control treatment.

### 3.3. Multivariate analysis

In the first year, the similarity level among all the treatments was higher than 90%, with C and NPK

Average values (n = 20) and bars represent standard deviation of average. Different letters represent statistically different treatments (Tukey with $p <0,05$).
*Valores médios (n = 20) e as barras representam o desvio padrão da média. Letras diferentes representam tratamentos estatisticamente diferentes (Tukey com $p<0,05$).*

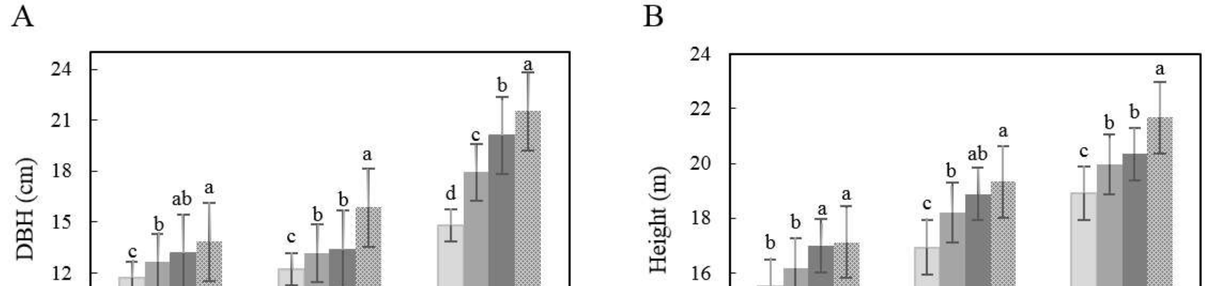


**Figure 2** – DBH (A) and height (B) of eucalypt hybrid urograndis culture measured in the years 2018, 2019 and 2020 when the trees were 52, 64 and 77 months old.
***Figura 2*** *– DAP (A) e altura (B) da cultura do híbrido de eucalipto urograndis medidos nos anos de 2018, 2019 e 2020 quando as árvores tinham 52, 64 e 77 meses de idade.*

**Table 2** – Soil chemical attributes in the study areas with eucalypt hybrid urograndis in the year 2018 at 52 months of age, 2019 at 64 months of age, 2020 at 77 months of age, followed by applications of pig slurry (mean±standard deviation).
***Tabela 2*** – *Atributos químicos do solo nas áreas de estudo com híbrido de eucalipto urograndis no ano de 2018 aos 52 meses de idade, 2019 aos 64 meses de idade, 2020 aos 77 meses de idade, seguido de aplicações de dejetos de suínos (média±desvio padrão).*

| Treatment[1] | Age[2] | OM | pH $CaCl_2$ | K | Ca | Mg | Al | CEC | V | P | Cu | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | g dm³ | pH | cmol$_c$ dm³ | | | | | % | mg dm³ | | | | |
| C | 52 | 39.3±8.3$^{a}$ | 4.8±0.1$^{b}$ | 0.7±0.2$^{a}$ | 8.4±3.1$^{a}$ | 2.3±0.6$^{ab}$ | 0.1±0.1$^{bc}$ | 18.2±3.8$^{a}$ | 61.8±8.2$^{a}$ | 2.9±0.9$^{c}$ | 6.8±2.0$^{b}$ | 32.9±5.6$^{b}$ | 314±110$^{a}$ | 5.2±1.7$^{a}$ |
| NPK | | 37.5±11.4$^{a}$ | 5.1±0.1$^{a}$ | 0.7±0.1$^{a}$ | 8.9±2.5$^{a}$ | 2.5±0.5$^{a}$ | 0.0±0.0$^{c}$ | 17.4±2.5$^{ab}$ | 68.7±8.0$^{a}$ | 13.9±4.7$^{a}$ | 5.2±1.7$^{b}$ | 37.5±11.6$^{ab}$ | 293±110$^{ab}$ | 5.7±1.5$^{a}$ |
| FPS200 | | 34.7±11.5$^{ab}$ | 4.6±0.0$^{c}$ | 0.6±0.2$^{a}$ | 5.9±1.8$^{b}$ | 1.9±0.6$^{b}$ | 0.4±0.2$^{b}$ | 15.5±2.3$^{bc}$ | 52.6±9.3$^{b}$ | 6.6±1.7$^{b}$ | 7.3±3.1$^{a}$ | 37.7±7.8$^{ab}$ | 256±85$^{ab}$ | 4.8±1.6$^{a}$ |
| FPS400 | | 26.4±9.9$^{b}$ | 4.3±0.1$^{c}$ | 0.5±0.2$^{a}$ | 4.0±1.4$^{b}$ | 1.3±0.2$^{c}$ | 1.0±0.6$^{a}$ | 14.6±2.4c | 39.7±8.0$^{c}$ | 13.9±3.2$^{a}$ | 9.4±3.6$^{a}$ | 43.1±7.4$^{a}$ | 221±110$^{b}$ | 4.7±1.5$^{a}$ |
| C | 64 | 28.5±4.9$^{b}$ | 5.3±0.5$^{b}$ | 0.4±0.0$^{b}$ | 4.9±1.9$^{b}$ | 1.4±0.5$^{b}$ | 0.0±0.0$^{c}$ | 13.4±2.5$^{b}$ | 49.3±8.2$^{b}$ | 1.5±0.5$^{c}$ | 11.2±2.2$^{b}$ | 26.4±4.6$^{b}$ | 113±40$^{b}$ | 4.4±2.3$^{a}$ |
| NPK | | 39.9±19.4$^{ab}$ | 5.7±0.2$^{a}$ | 0.9±0.1$^{a}$ | 9.9±2.1$^{a}$ | 2.9±1.3$^{a}$ | 0.0±0.0$^{c}$ | 16.0±3.2$^{a}$ | 85.9±3.3$^{a}$ | 14.6±3.1$^{a}$ | 7.9±0.9$^{c}$ | 37.2±4.8$^{b}$ | 135±102$^{b}$ | 4.6±1.2$^{a}$ |
| FPS200 | | 30.3±4.0$^{b}$ | 4.2±0.1$^{c}$ | 0.4±0.0$^{b}$ | 2.9±0.8$^{c}$ | 1.2±0.3$^{b}$ | 1.5±0.5$^{b}$ | 13.9±0.9$^{b}$ | 32.5±6.2$^{c}$ | 5.1±1.9$^{c}$ | 13.0±2.4$^{a}$ | 27.8±6.0$^{b}$ | 155±40$^{ab}$ | 4.7±1.3$^{a}$ |
| FPS400 | | 48.1±22.3$^{a}$ | 3.7±0.1$^{d}$ | 0.5±0.2$^{b}$ | 1.5±0.6$^{d}$ | 0.6±0.2$^{c}$ | 2.1±0.3$^{a}$ | 17.2±1.4$^{a}$ | 15.2±5.6$^{d}$ | 13.2±3.6$^{a}$ | 14.3±14.9$^{a}$ | 55.9±24.9$^{a}$ | 204±57$^{b}$ | 3.8±1.5$^{a}$ |
| C | 77 | 79.2±10.1$^{a}$ | 5.1±0.2$^{b}$ | 0.7±0.0$^{b}$ | 5.6±1.3$^{b}$ | 3.6±1.0$^{a}$ | 0.2±0.2$^{c}$ | 14.8±2.9$^{b}$ | 65.8±5.0$^{b}$ | 2.2±0.7$^{c}$ | 8.1±1.2$^{b}$ | 28.4±4.8$^{c}$ | 184±44$^{a}$ | 6.5±1.0$^{a}$ |
| NPK | | 50.6±14.2$^{b}$ | 5.7±0.3$^{a}$ | 0.9±0.2$^{a}$ | 10.8±2.6$^{a}$ | 4.1±0.7$^{a}$ | 0.0±0.0$^{c}$ | 18.3±3.4$^{a}$ | 86.3±4.7$^{a}$ | 16.9±4.3$^{a}$ | 8.7±2.5$^{b}$ | 39.6±9.8$^{b}$ | 191±105$^{b}$ | 4.7±1.1b |
| FPS200 | | 50.8±9.6$^{b}$ | 4.5±0.1$^{c}$ | 0.5±0.4c | 7.1±2.5$^{b}$ | 2.4±0.6$^{b}$ | 1.5±0.4$^{b}$ | 16.2±2.2$^{ab}$ | 60.7±9.6$^{b}$ | 5.1±1.4$^{b}$ | 12.7±2.0$^{a}$ | 41.3±10.1$^{b}$ | 210±62$^{b}$ | 4.6±1.3$^{b}$ |
| FPS400 | | 71.8±14.2$^{a}$ | 3.7±0.1$^{d}$ | 0.6±0.2$^{b}$ | 2.7±0.8$^{c}$ | 1.0±0.3$^{c}$ | 1.8±0.2$^{a}$ | 16.7±2.9$^{ab}$ | 27.6±9.6$^{c}$ | 17.5±3.1$^{a}$ | 13.9±3.5$^{a}$ | 65.9±10.1$^{a}$ | 235±44$^{ab}$ | 3.3±0.6$^{c}$ |
| VF[3] | | 14.0-34.0 | 4.5-6.0 | 0.06-0.45 | 1.0-6.0 | 0.5-2.0 | 0-2.5 | 5.0-24.0 | 35.0-70.0 | 3.0-12.0 | 0.2-20.0 | nd | 15-200 | 1.3-10 |
| VSQ[4] | | nd | nd | nd | nd | nd | nd | nd | nd | nd | <35 | nd | nd | <60 |

Values followed by different lower-case letters in the column represent a significant difference by the Tukey test ($p<0.05$).
[1]Treatments: C - control treatments without fertilization with manures or fertilizer; NPK - treatments with mineral fertilization; FPS200 indicates - treatments in which 200 m³/ha of PS were applied; and FPS400 - treatments in which 400 m³/ha of PS were applied.
[2]Age of plants in months. nd: means not determined.
[3]Range of reference values according to the Manual of fertilization and liming for the State of Paraná (SBCS/NEPAR, 2017).
[4]Reference standard values for the quality of substances in the soil (Cetesb, 2016). nd: means not determined.
*Valores seguidos de letras minúsculas diferentes na coluna representam diferença significativa pelo teste de Tukey ($p<0,05$).*
*[1]Tratamentos: C - tratamento controle sem adubação com esterco ou fertilizante; NPK - tratamento com adubação mineral; FPS200 - tratamento no qual foram aplicados 200 m³/ha de PS; e FPS400 - tratamento no qual foram aplicados 400 m³/ha de PS.*
*[2]Idade das plantas em meses. nd: significa não determinado.*
*[3]Faixa de valores de referência conforme Manual de Adubação e Calagem para o Estado do Paraná (SBCS/NEPAR, 2017).*
*4Valores de referência para a qualidade das substâncias no solo (Cetesb, 2016). nd: não determinado.*

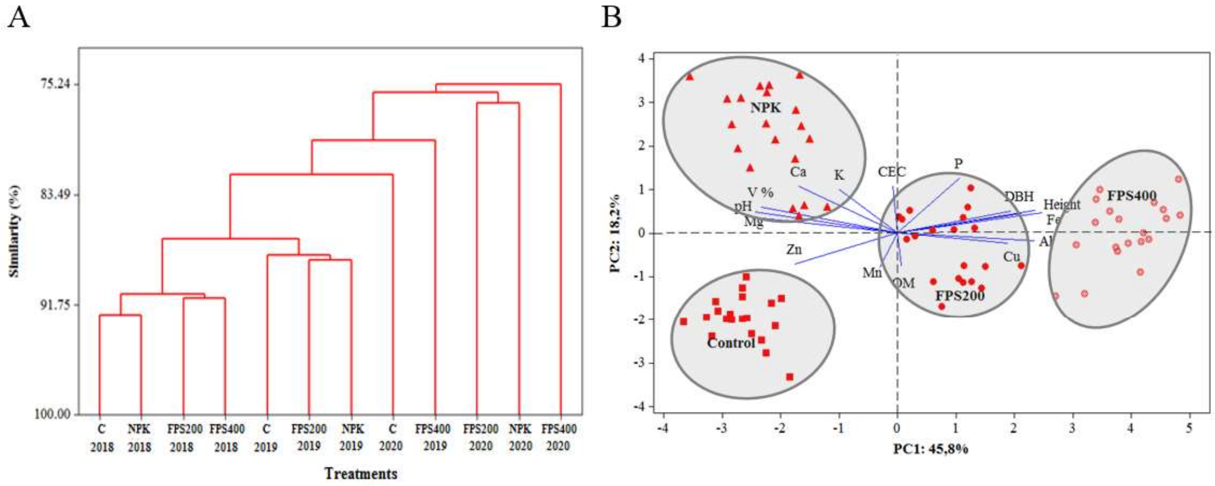


**Figure 3** – Multivariate analysis Cluster grouping based on the similarity of the treatments over the three years of experiment conduction (A) and Biplot charts generated from two main components (PC1 and PC2), showing the loads of soil and dendrometric attributes evaluated in 2020 (B).

***Figura 3*** – *Análise multivariada de agrupamento de clusters baseado na similaridade dos tratamentos ao longo dos três anos de condução do experimento (A) e gráficos Biplot gerados a partir de dois componentes principais (CP1 e CP2), mostrando as cargas de atributos do solo e dendrométricos avaliados em 2020 (B).*

being 92.3% similar and FPS200 and FPS400 90.8% (Figure 3A). This high level of similarity among the different treatments can be explained by the beginning of late applications, that is, when the individuals were already 52 months old. In the third year, the degree of similarity among the treatments reduced and varied between 75 and 86%, which shows the most pronounced effects of the treatments in the medium and long term due to the cumulative effects.

The analysis of the main components confirmed the degree of similarity among the treatments, since the treatments FPS200 and FPS400 were grouped between quadrants I and IV, while the other treatments were more separated, i.e., NPK in quadrant II and Control in quadrant III. The first two main components explained 64% of the variability of soil data (Figure 3B). The variables pH, Mg, Al, Zn, Cu, Fe, V%, DBH and height were explained predominantly by the first main component (PC1: 45.8%), while P, OM, K, Mn, and CEC were explained mainly by the second main component (PC2: 18.2 %). Ca was explained by the two components.

## 4. DISCUSSION

The highest concentrations of N, P, B and Mn found on the leaves are due to the high concentrations of these elements in PS. Moreover, due to the high organic load that is mineralized by soil microorganisms, releasing these elements that are readily absorbed by the plants (Thirkell et al., 2016). Nitrogen is the nutrient that is found in higher concentrations in higher plants, its participation in metabolism is one of the elements that most influence plant growth, which can be observed in the greater trees development. P through its reaction catalyzing function (Schachtman et al., 1998) also has a positive effect on the dendrometric growth of eucalypt. Studies point out that the adequate supply of P can promote gains of up to 97% in volume of wood produced (Fernandez et al., 2000).

The FPS400 treatment was the only one capable of resulting in sufficient levels of B on the leaves after the first applications, according to the reference values. Whereas the Mn values for plants treated with FPS were above the recommended maximum limit. Mn has several functions in the plant, among them it helps in chlorophyll synthesis and nitrate assimilation (Ducic and Polle, 2005), ans in excess can result in phytotoxicity, but eucalypt species present good tolerance to high Mn concentrations (Oliveira and Andrade, 2021). The higher content of these micronutrients could have resulted in superior plants development as observed in this treatment (Figure 2).

The FPS400 treatment was the only one that presented adequate K values on the leaves (SBCS/NEPAR, 2017). K is essential to ensure the the osmotic potential control in plants. In addition, it also plays a role in controlling the stomata opening and closing, allowing greater efficiency in the use of water (Taiz and Zeiger, 2013). Therefore, K is very important for water deficiency periods. Zn can also contribute to greater production in eucalypt plantations (Florentino et al., 2021).The higher concentration of Ca e S in the leaves with the use of manure may have influenced the higher development by the plants, since, according to Medeiros et al. (2020), they are important elements for the trees'trunk and bark formation.

Lower concentrations of macronutrients N, Ca, Mg and S observed in leaves are probably associated with translocations of these nutrients for the development of other parts of the plants, since the production values for the plants treated with slurry were significantly higher compared to the other treatments. The highest P content is related to soil fertilization, since the study soil presents naturally low P availability due to high adsorption of this element in clay, and its supplementation through mineral or organic fertilizer is necessary.

Considering the micronutrients, the use of PS for fertilization resulted in Mn and Zn accumulation, but not of Cu in the plants. The Fe levels were below the recommended level (Table 1). Therefore, the use of slurry in the soil may influence the nutritional status of metal micronutrients in eucalyptus hybrid urograndis, possibly due to changes in soil pH that may cause the Cu and Fe adsorption by transforming them into non-labile forms for the plants.

The treatments FPS200 and FPS400 resulted, respectively, in 27 and 30% DBH increments when compared to the control, while the NPK treatment showed an increase of 16% over the three years evaluated. The highest DBH observed in FPS200 and FPS400 treatments reveal great potential for PS recovery in order to increase yields with the commercialization of wood.

The height of the control treatments, NPK, FPS200 and FPS400 increased 3.4, 3.8, 3.3 and 4.6 m, respectively, during the evaluated period. Marron (2015) observed that the application of wastes such as sludge and animal manure significantly stimulates the growth of eucalypt, providing up to three times more growth when compared to mineral fertilization.

The K, Ca, Mg and OM contents in the soil were above the high fertility levels for latosols (SBCS/NEPAR, 2017). Soil acidification is consequence of an increase in the $Al^3$ concentration and, in particular, to the high levels of nitrogenous organic material contained in the slurry. The decomposition of these nitrogen compounds by means of nitrification releases H and the mineralization of organic matter produces organic acids, which causes pH reduction (Tian and Niu, 2015; Verma and Sagar, 2020).

After the third year of applications, there was an increase in the OM content indicating a probable stabilization of the compound. Studies point out that, generally, the highest soil content of OM is achieved with repeated applications of organic compounds (Diacono and Montemurro, 2011). This indicates that the beneficial effect of PS as a source of organic matter on the soil may take a longer time to be observed.

The levels of K, Ca and Mg and V% were lower in soils that received applications of slurry. In contrast, P concentration increased significantly with PS applications when compared to control treatment, as already observed in other studies (Conti et al., 2015; Boitt et al., 2018). All levels of Cu and Zn observed were within the range considered sufficient for soil fertility (SBCS/NEPAR, 2017) and below the critical level of contamination (Cetesb, 2016). Treatments with PS also increased the Fe levels in the soil and showed Mn values slightly higher than recommended, the higher concentration of these nutrients in the soil may be related to the low pH values recorded for the soil (Rengel, 2015).

Cluster analysis showed that throughout the three years of application of treatments (Figure 3A) the similarity among the treatments was progressively reduced due to the residual effect of treatments from one year to the next (Diacono and Montemurro, 2011). The principal component analysis biplot plot showed that, contrary to the expected, organic matter was not closer to treatment with the highest PS application (FPS400). This can be explained by the low solids content of this type of waste (Cândido et al., 2022). In addition, the low organic matter content may have been degraded in the soil, causing pH decline by volatilization or nitrification of ammonia and, consequently, an increase in soluble aluminum (Liu et al., 2020).

It was also possible to observe that although the FPS200 and FPS400 treatments resulted in soils with lower pH values and lower V%, the DBH exceeded the other treatments. This characteristic is explained due to the fact that eucalyptus hybrid urograndis is highly tolerant to acidity and not very demanding in relation to V% (25 – 30 %) (SBCS/NEPAR, 2017). In addition, the higher DBH of these treatments may be associated with higher availability of macro and micronutrients provided by the PS application. In general, fertirrigation with pig slurry presents advantages for forestry purposes as total or partial replacement of inorganic fertilizer, mainly P, K, Zn and Mn. The use of PS in forest systems can contribute to rational disposal of this residue in soil while helps to increase soil fertility and wood production.

## 5. CONCLUSION

The FPS applications in the cultivation of eucalyptus hybrid urograndis promoted greater stem diameter and plant height, when compared with mineral fertilization and with the control.

The FPS showed a tendency to reduce soil pH but did not promote the accumulation of potentially toxic elements such as Cu and Zn at a level considered harmful to the environmental quality of the soil within the analyzed period.

The results of FPS treatments are clearer from the medium term onwards due to the cumulative effect of the applications on the soil quality and on the greater trees' development.

## AUTHOR CONTRIBUTIONS

Anderson Rosa - sample collection, analysis, and scientifi c writing; Natália Pereira - statistical analysis, scientific writing, and review; Felippe Martins Damaceno - statistical analysis, scientific writing, review, and manuscript submission; Luiz Antônio Zanão Júnior - manager of research, and manuscript review.

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