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Pulp mill sludge-based organomineral fertilizer: performance evaluation on the early growth of *Eucalyptus globulus*

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Abstract. This study aimed to evaluate the performance of an innovative pulp mill sludge-based organomineral fertilizer (OrgM) in comparison with a conventional mineral fertilizer (Min). We also assessed its combination with a controlled-release fertilizer (CRF) and potassium sulfate (K). A greenhouse trial was conducted in 50 L pots, utilizing three fertilization treatments (Min, OrgM, and OrgM+CRF+K), to evaluate their effects on the early growth of *Eucalyptus globulus* and nutrients leaching.
The highest plant growth was obtained with OrgM, compared to mineral fertilization (Min). After five months, total plant biomass was 662.5 g/plant and 439.6 g/plant in the "OrgM" and "Min" treatments, respectively. This trend was consistent across the other growth parameters measured. During the same period, the "Min" treatment caused the greatest loss of nutrients through leaching (5 g N, 2.2 g P, and 3.3 g K/pot), which was significantly higher than that observed in the "OrgM" treatment (0.61 g N, 0.10 g P, and 0.54 g K/pot). The combination of OrgM with CRF and K had no relevant effect. Results show that the nutrients in the pulp mill sludge-based organomineral fertilizers were used more efficiently, resulting in greater growth of *Eucalyptus globulus*.

Keywords: pulp mill sludge, organomineral fertilizer, fertilizer efficiency, nutrients leaching

1. Introduction

The pulp and paper industry is one of the world's largest, and it is estimated that in Europe alone, the pulp and paper industry generates around 11 million tonnes of waste each year (Amandio et al., 2022). Portugal produces around 0.6 million tonnes (Biond, 2022), which mainly comprises wood waste, ash and, mostly, sludge (around 60%). Nowadays, the social and legislative pressure on the transition to the green economy in this specific industrial field is high. As a result, companies increasingly seek opportunities to invest in new technologies, within the circular economy concepts (Amandio et al., 2022).

In order to find a sustainable alternative to the proper disposal of sludges, AGRISTARBIO has developed an innovative system for the production of organomineral fertilizers from pulp mill sludge from the ALTRI group. This recycling of organic waste promotes the circular economy and provides a sustainable source of nutrients that will feed plants and act as a tool to reintroduce organic matter into soils (Sakrabani, 2024).

This study aimed to evaluate the effect of a pulp mill sludge-based organomineral fertilizer, compared to a 100% mineral fertilizer, on the initial growth (first 5 months) of *Eucalyptus globulus*, and nutrients leaching.

2. Materials and Methods

The experiment was carried out in a greenhouse located at Quinta do Furadouro, Óbidos, Portugal (39°20'30.7"N 9°13'32.0"W). It utilized 50 L pots filled with washed sand, with one plant per pot. Three fertilization treatments were tested: i) 150 g/pot of mineral fertilizer (8-24-8, "Min"); ii) 267 g/pot of pulp mill sludge-based organomineral fertilizer (4.5-15.9-7.5, "OrgM"); iii) OrgM + 42 g/pot of potassium sulfate + 25 g of controlled-release fertilizer (9:20:8, "OrgM+K+CRF").

A drip irrigation system was installed. During each irrigation, pots were leached with a volume corresponding to about 20% of the irrigation supply. The leachates were collected, quantified, and analyzed.

On May 10, one plant was planted per pot. On October 16 (five months after planting), four plants per treatment were harvested for biomass component (roots, stems, and leaves) evaluation. Samples were dried at 65 °C to a constant weight and subsequently weighed.

The data obtained were subjected to an analysis of variance (ANOVA) followed by a comparison of means using the LSD test (least significant difference) at α=5%.

3. Results and discussion

3.1. Plant growth

Five months after planting, total biomass (Table 1) in plants fertilized with mineral fertilizer ("Min") was significantly lower, at 439.6 g/plant. In contrast, higher

growth was observed in plants fertilized with pulp mill-based organomineral fertilizer (OrgM) (662.5 g/plant), representing a 51% increase in biomass compared to the "Min" treatment. Supplementation with potassium sulfate and controlled-release fertilizer ("OrgM+K+CRF") had no significant effect on plant growth when compared to OrgM.

It was observed that the pattern of variation in the biomass components (roots, stems, and leaves) was similar to that of the total biomass (Table 1).

Table 1. Biomass average value (dry matter at 65°C) of each component (root, stem, and leaves) and of the entire plant (total), for each fertilization treatment.

Fertilization treatment	Biomass (g dw/plant)			
	roots	stems	leaves	total
Min	74.4[a]	163.1[a]	202.1[a]	439.6[a]
OrgM	129.7[b]	237.6[b]	295.2[b]	662.5[b]
OrgM+K+CRF	140.8[b]	210.6[b]	257.0[b]	608.3[b]

In each column, the same letter means not statistically different (α=5%.)

For plant height and stem diameter (Table 2), superior performance was likewise observed in the "OrgM" treatment. This confirms the enhanced growth of plants under this fertilization treatment when contrasted with the mineral fertilizer ("Min").

Table 2. Average values of plant height (cm) and stem diameter (mm), for each fertilization treatment

Fertilization treatment	Plant heigh (cm)	Stem diameter (mm)
Min	135.8[a]	20.1[a]
OrgM	145.7[b]	22.6[b]
OrgM+K+CRF	149.7[b]	22.7[b]

In each column, the same letter means not statistically different (α=5%.)

3.2. Nutrients leaching

Considering nutrient leaching from the pots during the same period, the mineral fertilizer ("Min") treatment caused the greatest loss of nitrogen, with 5 g N/pot leached, as well as significant losses of P (2.2 g/pot) and K (3.3 g/pot) (Table 3). This leaching was significantly higher than that observed in the treatments with organomineral fertilizers: "OrgM" and "OrgM+K+CRF".

Table 3. Average values of nitrogen (N), phosphorus (P) and potassium (K) leaching (mg/pot) for each treatmen.t

Fertilization treatment	Nutrients leaching (mg/pot)		
	N	P	K
Min	4989[b]	2243[b]	3280[b]
OrgM	613[a]	103[a]	537[a]
OrgM+K+CRF	288[a]	43[a]	356[a]

In each column, the same letter means not statistically different (α=5%.)

In organomineral fertilizer granules, the surface functional groups and micro- and nanopores of the organic fraction help bind and adsorb chemical fertilizer molecules, retaining nutrients for longer. This allows for slow nutrient release and increased efficiency (Uddin et al., 2025).

Organomineral fertilizers contain organic compounds, and a positive interaction exists between these organic matrices and the physical, chemical, and biological components of the soil (Qiao et al., 2020). Applying organomineral fertilizers to soil significantly increases its organic matter content compared to soil treated solely with NPK (Viana et al., 2025). Due to its absorption characteristics, soil organic matter becomes a natural reservoir that accumulates inorganic nutrients and some organic elements, creating a sponge effect in the soil (Bouhia et al., 2022). Consequently, organomineral fertilizers have the ability to improve the soil's mineral retention capacity.

Thus, these effects at the level of the fertilizer granule and soil organic matter explain the results obtained in this trial, specifically: i) the reduction of nutrient loss through leaching; and ii) increased plant growth due to greater nutrient use efficiency.

4. Conclusions

With pulp mill sludge-based organomineral fertilizers, nutrients were used more efficiently. This led to less nutrient loss through leaching and promoted greater initial growth of *Eucalyptus globulus*.

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