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# DEVELOPMENT OF FOREST SPECIES IN THE ATLANTIC FOREST USING CONTROLLED-RELEASE FERTILIZER IN A PERMANENT PRESERVATION AREA

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**Resumo**

*Desenvolvimento de espécies florestais da Mata Atlântica com uso de Fertilizante de Liberação Controlada em Área de Preservação Permanente.* Este trabalho avaliou o desenvolvimento inicial de espécies florestais nativas da Mata Atlântica sob doses de Fertilizante de Liberação Controlada (FLC) na adubação de plantio, visando a recuperação florestal de uma área de mata ciliar historicamente utilizada na agricultura. O experimento foi realizado em São Bento do Sul – SC. O delineamento foi em blocos casualizados em parcela subdividida, com três repetições. Na parcela foram alocadas as doses do FLC de 0, 40, 80 e 120 g por cova e na subparcela as espécies nativas (*Handroanthus albus; Alchornea glandulosa; Inga marginata; Ocotea puberula; Campomanesia xanthocarpa; Allophylus edulis).* Aos 24 meses após a implantação foi avaliada a sobrevivência das plantas, altura, diâmetro do colo e de copa. O percentual de sobrevivência das espécies foi semelhante entre as doses e diferiu entre as espécies. A sobrevivência de *O. puberula* foi de 66,67%, e acima de 87% para as demais. Em geral, as doses do fertilizante de liberação controlada aplicadas em cova apresentaram efeito semelhante na sobrevivência e desenvolvimento das espécies. A ausência de respostas significativas a adubação pode ser atribuída as condições pré-existentes de fertilidade do solo, cujo histórico de uso pela agricultura promoveu ou manteve a fertilidade do solo em níveis medianos que tendem a ser satisfatórios para as espécies nativas da Mata Atlântica. O uso do fertilizante de liberação controlada, em projeto de recuperação de área de preservação permanente no bioma mata atlântica, não resultou em melhor desenvolvimento inicial das espécies arbóreas florestais nativas estudadas.
*Palavras-chave*: Fertilizante de Liberação Lenta, Restauração, Zona ripária.

**Abstract**

This study evaluated the initial development of native forest species of the Atlantic Forest under Controlled Release Fertilizer (CRF) doses in planting fertilization, aiming at forest recovery of an area of riparian forest historically used in agriculture. The experiment was carried out in São Bento do Sul - SC. The design was in randomized blocks in a subdivided plot with three replications. In the plot, CRF doses of 0, 40, 80 and 120 g per hole were allocated and, in the subplot, native species (*Handroanthus albus; Alchornea glandulosa; Inga marginata; Ocotea puberula; Campomanesia xanthocarpa; Allophylus edulis*). 24 months after implantation, plant survival, height, collar diameter and crown diameter were evaluated. The survival percentage of the species was similar between the doses and differed among the species. The survival rate of *O. puberula* was 66.67% and above 87% for the others. In general, the doses of controlled-release fertilizer applied in the hole had a similar effect on the survival and development of the species. The lack of significant responses to fertilization can be attributed to pre-existing soil fertility conditions, whose history of use for agriculture promoted or maintained soil fertility at medium levels that tend to be satisfactory for native species of the Atlantic Forest. Using controlled-release fertilization technology in a permanent preservation area recovery project in the Atlantic Forest biome did not result in better initial development of the native forest tree species studied.
*Keywords*: Slow-Release Fertilizer, Restoration, Riparian zone.

## INTRODUCTION

Riparian forests provide numerous ecological functions, such as protection against silting, pollution and eutrophication of watercourses, aquifer recharge, habitat and food for various organisms (CASTILHO *et al.*, 2021). Despite their importance, in the tropics alone, it is estimated that millions of hectares of deforested areas need to be restored. However, the cost involved in this process is critical to its implementation (JIANG *et al.*, 2024). Techniques such as nucleation have been used to accelerate the recovery process of areas, with a good cost-benefit ratio compared to plant species in the entire area (PROCKNOW *et al.*, 2023). In parallel with these

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techniques, the importance of soil physical and chemical conditions for reintroducing native species is discussed (ROBINSON *et al.*, 2023). While fertilization at planting can boost plant development, the sustainability of the recovery process can also be critical, considering the increased costs, the origin of the fertilizers, and the lack of adequate response of the species of interest (SILVA *et al.*, 2022).

Resende *et al.* (1999) evaluated phosphorus doses on the development of species from different successional groups. They observed that fast-growing pioneer species tend to be more responsive to fertilization, while those from the climax successional group were little affected by fertilization. Considering NPK and limestone doses, Scheer *et al.* (2017) found that the doses caused varying effects on the development of forest species, reinforcing the particularity of response or not of each species under study. Other similar studies have also reported positive and, in some cases, null effects of conventional fertilizer doses on forest species (SILVA *et al.*, 2022).

In this context, the use of so-called Controlled-Release Fertilizers (CRF) has currently been considered a promising strategy for fertilizing crops more ecologically and effectively, mainly by reducing nutrient leaching and ammonia volatilization (FIRMANDA *et al.*, 2022; VEJAN *et al.*, 2021). These fertilizers are designed to decompose slowly, releasing the nutrients plants need over several months to several years, depending on the formulation and climate (VEJAN *et al.*, 2021).

In a review of the use of controlled-release fertilizers in the forestry sector, Cunha *et al.* (2021) concluded that the application of CRF in forest plantations is still incipient, and this is due to the scarcity of studies on the subject with forest species, despite there being favorable preliminary results (ROSSA *et al.*, 2013). Hypothetically, pioneer or secondary native forest species could benefit from this fertilization technology, thus enhancing riparian forest areas' recovery. On the other hand, the responses of each species to CRF within the field ecological context of deforested riparian forest areas still need to be evaluated. This study aimed to evaluate the initial development of native forest species under CRF doses in planting fertilization, aiming at forest recovery in an area of riparian forest historically used in agriculture.

## MATERIAL AND METHODS

### Soil and climate conditions of the environment

The biome is the Atlantic Forest, and the phytoecological region of the vegetation is the Submontane Dense Ombrophilous Forest, which has flat relief. The region's climate is of the Cfa type, constantly humid subtropical in the Köppen classification, with annual averages of temperature, precipitation and R.H. of 21 °C, 1,900 mm and 87.5%, respectively. The soil is of the haplic cambisol type, of clayey-sandy loam textural class, without compaction (Table 1). During the experimental period, the relative humidity was 85%, and the minimum, average and maximum temperatures were 15, 20 and 24 °C, respectively (EPAGRI, 2020). Precipitation was 1460 mm, lower than the region's historical average (1900 mm).

Table 1. Average chemical and physical characteristics of the soil (0-20 cm) at the time of the experiment.
Tabela 1. Média das características químicas e físicas do solo (0-20 cm) na implantação do experimento.

| pH ($H_2O$) | pH SMP | P (mg/dm³) | K (mmolc/dm³) | M.O (%) | Ca (cmolc/dm³) | Mg (cmolc/dm³) | S (mg/dm³) | H+Al (cmolc/dm³) |
|---|---|---|---|---|---|---|---|---|
| 5.3 | 6.1 | 23.5 | 6.7 | 2.85 | 3.7 | 1.4 | 10.4 | 3.8 |
| CTC pH7 (cmolc/dm³) | Al (cmolc/dm³) | V (%) | SB | Ca/Mg | Ca/K | Mg/K | m (%) | Na (mg/dm³) |
| 9.62 | 0.3 | 60.47 | 5.82 | 2.6 | 5.52 | 2.09 | 2.5 | 8.45 |

| B (mg/dm³) | Fe (mg/dm³) | Mn (mg/dm³) | Cu (mg/dm³) | Zn (mg/dm³) | Sand (%) | Clay (%) | Apparent density | Textural Class |
|---|---|---|---|---|---|---|---|---|
| 0.5 | 114 | 26 | 2 | 12.2 | 44.1 | 31 | 1.1 | Sandy Clay Loam |

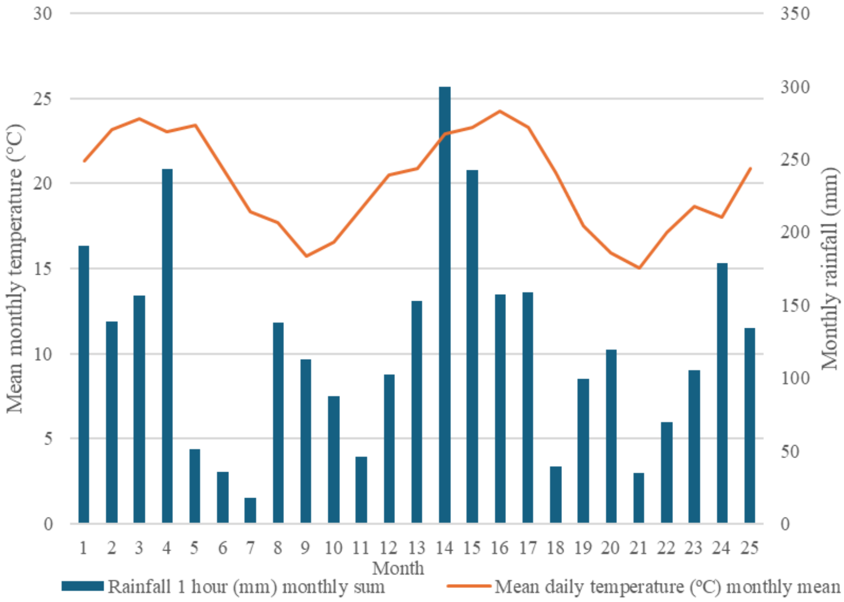


Figure 1. Climogram of monthly temperature and precipitation in the region for 2020 and 2021.
Figura 1. Climograma de temperatura e precipitação mensal na região dos anos de 2020 e 2021.

**History of the riparian forest area**

The deforestation of native vegetation occurred approximately 60 years ago to implement improvements and crops of dryland rice, corn and pasture to produce meat and milk for the family's subsistence purposes. Currently, the area is destined for banana farming. Adjacent to the area, there are remnants of secondary forest.

**Description of the experiment**

The experiment was conducted on a rural property in São Bento do Sul - SC (26°23'35.37S and 49°14'03.26W, alt. 100 m). The experimental design was in randomized blocks under a split-plot scheme with three replications. The different doses of CRF (0, 40, 80 and 120 g of CRF per hole, equivalent to 0, 277, 555 and 833 kg/ha, respectively) were allocated in the plot and the native species in the subplot (Table 2). Two individuals per species were used in the subplot, which was also used as a helpful subplot. The species used are native to the region and are suitable for forests with more humid soil in riparian forests with distinct ecological groups for ecological succession.

Table 2. Family and ecological group of native forest species under study.
Tabela 2. Família e grupo ecológico das espécies arbóreas nativas em estudo.

| Family | Species | Popular name | Ecological Group |
|---|---|---|---|
| Bignoniaceae | *Handroanthus albus* (Cham.) Mattos | Ipê-amarelo | Early secondary |
| Euphorbiaceae | *Alchornea glandulosa* Poepp. & Endl. | Tanheiro | Pioneer |
| Fabaceae | *Inga marginata* Willd. | Ingá-feijão | Pioneer |
| Lauraceae | *Ocotea puberula* (Rich.) Nees | Canela-guaicá | Early secondary |
| Myrtaceae | *Campomanesia xanthocarpa* (Mart.) O.Berg | Guabiroba | Early secondary |
| Sapindaceae | *Allophylus edulis* (A.St.-Hil. *et al.*) Hieron. ex Niederl. | Chal-chal | Pioneer |

The plots were located on the left bank of a tributary stream of the Braço Esquerdo River in a Permanent Preservation Area to be restored. A one-meter border was established from the typical riverbed and 1.5 meters between the plots to avoid edge effects. Before planting, the invasive exotic species (Brachiaria and elephant grass) were mowed, and the remaining banana clumps were removed. Usual silvicultural practices were carried out, such as controlling leaf-cutting ants by walking through the area in search of the ants and applying 150 g of granulated ant bait with a composition of Fipronil 0.01% along the ant trails and away from watercourses. The seedlings were purchased from a forest nursery in the region certified by RENASEM, measuring approximately 1 m and aged 1 year for pioneer species, 1 year and a half for secondary species and 2 years for *Ocotea puberula*. The seedlings were produced in plastic bags with a substrate in the following proportions: 50% red garden clay, 30% cured poultry manure, 20% carbonized rice husk, NPK 05-20-10 and limestone. The seedlings were planted manually using a hoe and shovel at a spacing of 1.20 x 1.20 meters in holes 40 cm deep and with a crown diameter of 80 cm. The tree seedlings were also mowed and crowned 5, 9 and 16 months after implantation.

The Controlled-Release Fertilizer (CRF) used (Basacote® Plus 12) has a complete coating of the homogeneous granules with elastic polymer (Poligen®) and formulation with 15% total nitrogen, 8% neutral ammonium citrate and water-soluble phosphate, 12% water-soluble potassium oxide, 2% total magnesium oxide and 5% total sulfur. CRF was applied at four points around the seedlings (Figure 1). 24 months after the implementation of the experiment, plant survival was assessed punctually, and the height, collar diameter and crown diameter of the species were measured using a tape measure graduated in millimeters and a digital caliper. All seedlings presented similar size and quality at the implementation of the experiment. Therefore, the gain in growth over the period was not considered. The effect of CRF doses on the development of the species was analyzed using simple regression, and the development of the species at each dose was analyzed using least squares means. Statistica software was used to assist in the statistical analyses.

## RESULTS

### Seedling survival

At 24 months post-planting, no interaction between CRF doses and species was observed regarding plant survival. The dose levels did not influence post-planting mortality; the average survival rate was 88% (Table 3). On the other hand, differences between the species and three groups of averages were observed. The pioneer species *Allophylus edulis* and *Inga marginata* presented higher survival (> 95%). For the pioneer *Alchornea glandulosa*, and the initial secondary species *Handroanthus albus* and *Campomanesia xanthocarpa*, survival was at conventional levels (87.5–91.67%), while for the secondary species *Ocotea puberula*, the average survival was just above 66%.

Table 3. Percentage of species survival at 24 months post-planting under CRF doses per hole.
Tabela 1. Percentual de sobrevivência das espécies aos 24 meses pós-plantio sob doses de FLC por cova.

| Species/Doses | 0g | 40g | 80g | 120g | Average Species |
|---|---|---|---|---|---|
| | % plant survival | | | | |
| *Handroanthus albus* | 100 | 66.67 | 100 | 100 | 91.67 AB |
| *Inga marginata* | 100 | 100 | 100 | 100 | 100.00 A |
| *Alchornea glandulosa* | 66.67 | 100 | 100 | 83.33 | 87.50 AB |
| *Allophylus edulis* | 100 | 83.33 | 100 | 100 | 95.83 A |
| *Ocotea puberula* | 83.33 | 50 | 66.67 | 66.67 | 66,67 B |
| *Campomanesia xanthocarpa* | 83.33 | 83.33 | 100 | 83.33 | 87.50 AB |
| Average Doses (%) | 88.89 a | 80.56 a | 94.45 a | 88.89 a | |

* Means followed by the same lowercase letter in the row and uppercase letter in the column do not differ by the Tukey test (5%).

### Interaction between doses x species

The interaction between the Doses x Species factors occurred only at the 84% confidence level in the height variable (Table 4). The non-occurrence of interaction between the factors was evident for collar and canopy diameter. However, given the high variability of the field environment, it was decided to break down the interaction to understand the data better.

Table 4. Summary of the analysis of variance, mean square (MS) and significance by the F test of the sources of variation.
Tabela 4. Resumo da análise de variância, quadrado médio e significância pelo teste F das fontes de variação.

| FV | GL | Height MS | Colar diameter MS | Canopy diameter MS |
|---|---|---|---|---|
| Block | 2 | $0.3544^{ns}$ | 387.67 | 0.96 |
| Doses | 3 | $6.53^{*}$ | $726.02^{ns}$ | $2.33^{*}$ |
| Residue 1 | 6 | 0.78 | 753.39 | 0.44 |

| FV | GL | Height MS | Colar diameter MS | Canopy diameter MS |
|---|---|---|---|---|
| Species | 5 | 12.46 ** | 9192.85** | 7.09** |
| Doses x Species | 15 | 1.23ns P>0.16 | 613.22ns | 0.55 ns |
| Residue 2 | 40 | 0.83 | 723.47 | 0.43 |
| CV 1 (%) | | 24.69 | 47.31 | 30.94 |
| CV 2 (%) | | 25.42 | 46.36 | 30.50 |

**, * Significant by F test at 1 and 5% probability, respectively.
Ns Not significant by F test at 5% probability.

In the analysis of the effect of CRF doses on the development of each species, in general, no significant effects were observed, indicating a neutral behavior of CRF application at the doses under study. Particular behavior was observed only in the species *Inga marginata*, whose plant height and crown diameter were adjusted by a quadratic linear equation ($R^2$ = 23% and 96%, respectively) with negative b1 (Figure 2). For crown diameter, there was no effect of the doses in any of the species, and the means presented were (in mm): Ipê amarela = 37.64; Ingá = 77.07; Chal-chal = 49.20; Gabiroba = 33.83; Canela = 45.19; Tanheiro = 105.19.

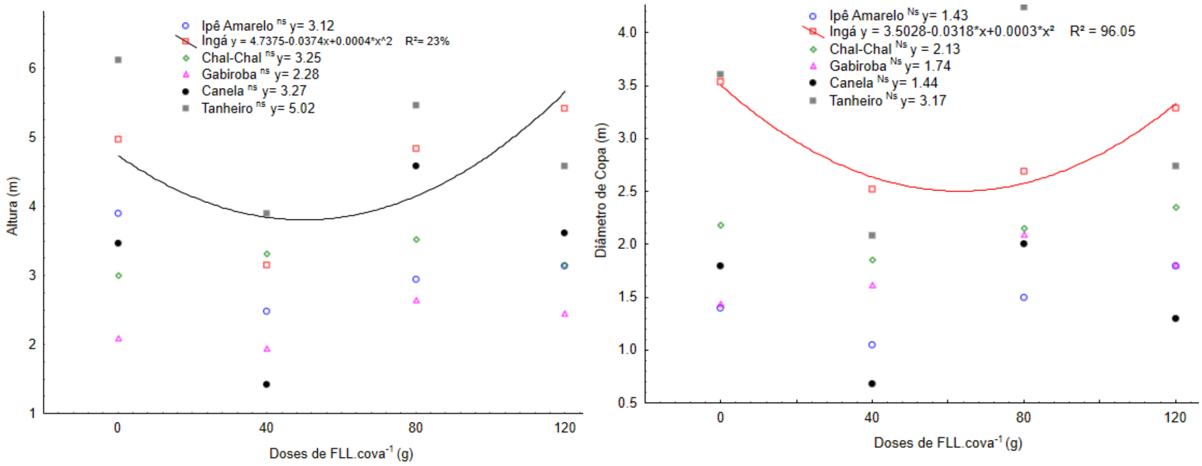


Figure 2. Height and canopy diameter of pioneer and secondary species, under the effect of CRF doses 24 months after planting.
Figura 1. Altura e diâmetro de copa das espécies pioneiras e secundárias, sob efeito das doses de FLC aos 24 meses do plantio.

Some specific interactions were observed when analyzing species' differences within each CRF dose. The height of the pioneer Tanheiro (*A. glandulosa*) was higher than that of the others, except for the pioneer Ing (*I. marginata*), which it resembled at the control dose, without CRF application (Figure 3). At the initial dose of fertilizer (40 g.cova$^{-1}$ of CRF), Tanheiro showed growth similar to the other species, superior only to Canela (*O. puberula*). With the increase in the dose (80 g.cova$^{-1}$ of CRF), the height of the Canela and Tanheiro plants was similar, and the latter grew more than the secondary species Ipê-amarelo (*H. albus*) and Gabiroba (*C. xanthocarpa*). At the highest dose (120 g.cova$^{-1}$ of CRF), the pioneer species Ingá resembled the secondary Canela and Tanheiro and stood out with superior growth. This behavior indicates a different response of the species in the riparian forest environment with the CRF dose inserted or not.

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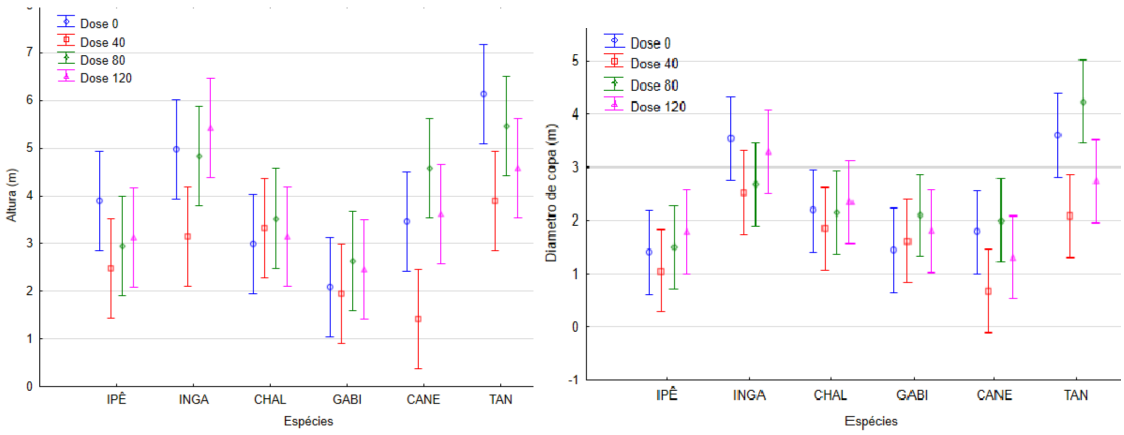


Figure 3. Height and canopy diameter of the species within each dose of CRF.
Figura 3. Altura e diâmetro de copa das espécies dentro de cada dose de FLC.

The crown diameter in the control treatment was similar for Ipê-amarelo, Chal-chal, Gabiroba and Canela (Figure 3). Tanheiro had a larger diameter than Ipê-amarelo, Gabiroba and Canela. The dose of 40 g.cova$^{-1}$ of CRF provided a similar crown diameter among the species, while at the dose of 80 g, Tanheiro had the most extensive crown. However, at the highest dose, the species had similar crown diameters.

The stem diameter at the control dose was similar to that observed for height, and the species Tanheiro and Ingá did not differ (Figure 4). However, at the dose of 40 g.cova$^{-1}$ of CRF, the stem diameter of Tanheiro was more significant than most species, resembling only Ingá. In the two highest doses, the species were similar in terms of neck diameter, and it can be inferred that there was a slight increase in the average development of the species (Ingá, Ipê-amarelo, Cha-chal, Canela) and a decreasing trend in Tanheiro, signaling a possible negative effect on their development.

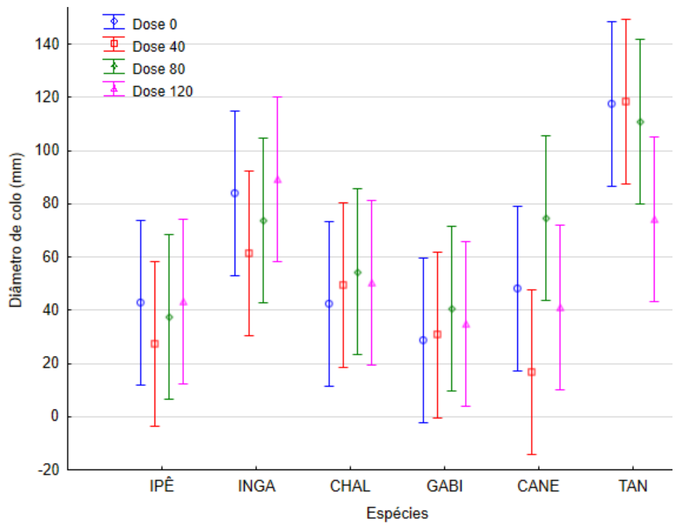


Figure 4. Stem diameter of the species within each dose of CRF at 24 months after planting.
Figura 4. Diâmetro de colo das espécies dentro de cada dose de FLC aos 24 meses após o plantio.

## DISCUSSION

The CRF under study releases its nutrients through a diffusion process, which ensures availability that minimizes losses due to leaching and possible harmful effects of salinity (FIRMANDA *et al.*, 2022; VEJAN *et al.*, 2021). The fertilizer in question is expected to be fully released within 12 months. For this reason, it was decided to evaluate 24 months.

The observed effect of soil fertilization with CRF on species survival indicates that the physical and chemical conditions of the soil, especially the availability of nutrients, were not a primary factor in the greater or lesser survival of the species. This finding regarding survival diverges from the initially established hypothesis that the recovery of riparian forest areas would be favored by fertilizing the species with CRF. In line with the previously established hypothesis and diverging from what was observed, Robinson *et al.* (2023), in conditions of soil (substrate) degraded after mining, identified that the location and substrate were 4 and 26 times more important, respectively, than the provenance of the species (*Banksia attenuata* and *Eucalyptus todtiana*) in explaining their survival.

Suppose survival was not impacted by the soil fertility conditions offered by the CRF. In that case, it can be assumed that the physical-chemical conditions of the soil in the riparian area under study (Table 2) were satisfactory for the development of the species, given the importance of the substrate/soil in the development of plant species (CASTILHO *et al.*, 2021; GONZÁLEZ *et al.*, 2015; ROBINSON *et al.*, 2023; SCHEER *et al.*, 2017).

The different survival rates among species indicate a specific relationship with the ecological group to which they belong, since of the total number of dead plants, considering absolute numbers, approximately 78% were species from the secondary ecological group, and the minority were pioneer species. A similar behavior was observed by Zanon *et al.* (2021), who identified lower mortality rates among pioneer species when evaluating the development of these and native secondary species from the Atlantic Forest in riparian forest areas. The predominance of the effect of the ecological group on species survival is corroborated by what was observed by Esposito *et al.* (2018). According to the authors, pioneer species have greater oxidative stress tolerance than non-pioneer species, which have a less efficient antioxidant metabolism.

When analyzing the meteorological data, the average monthly rainfall in the first three months (92 days) was 161 mm. However, no rainfall was recorded for 51 days (a little over half of the period), which could also partially explain the different survival rates between species. Fontana and Bündchen (2015), evaluating the survival of species in an area of riparian forest in a Mixed Ombrophilous Forest in the Erval Velho region of Santa Catarina, observed similar and higher survival results (94%) for the species, even without the use of planting fertilizer. According to the authors, the high rate was due to the appropriate species selection and was favored by the short evaluation period (30 days). In this study, if the same time horizon were considered, the average survival would be around 90%, already more impacted by the mortality of the species *O. puberula*. Insfrán Ortiz *et al.* (2022), after evaluating the establishment of forest species in the Paraguayan Atlantic Forest, concluded that the species factor was more important in survival and relative growth than the agronomic systems and types of planting carried out.

These observations reinforce the existence and importance of species-environment interaction when planning the recovery of forest areas. In-depth analysis between studies becomes complex because it is necessary to consider the ecological particularities of each environment in interaction with the species under study (PROCKNOW *et al.*, 2023). In a review of scientific works published over 25 years on restoring riparian forest areas, González *et al.* (2015) indicated the non-uniformity of the characteristics evaluated and the distinct and short study periods as some of the main obstacles to advancing the subject.

Analyzing species' growth within each dose helps identify possible specific interactions between a given species and the CRF doses. Such interactions may not be detected in the primary variance analysis. Naturally, since the species are genetically distinct, significant differences between them are to be expected. However, the objective in this case is to verify whether, at a given dose, there was a change in the relative behavior of the species as a function of the presence or absence of fertilizer. The absence or non-linearity of response to CRF doses in one or more species may be associated with the ecological complexity of the field environment. Controlled experimental environments allow better isolation of the factors under study. However, they disregard the multiple ecological interactions that occur in the forest environment existing in nature (INSFRÁN ORTIZ *et al.*, 2022; PROCKNOW *et al.*, 2023).

Some hypotheses can be listed to discuss the results of species development as a function of CRF doses. Among the main ones is the area's history with crops in the last 60 years, whose fertility conditions were improved to meet the high agricultural crop productivity demands. The slightly acidic soil pH (5.3) and the median levels observed for P, K, Ca, Mg and Organic Matter may have satisfied the demand for nutritional resources of the species – which are rustic and adaptable because they belong to the biome of the experimental region – thus not respond 24 months after implantation.

Although the study area is considered ecologically degraded, the same understanding cannot be attributed to the soil regarding its fertility (JIANG *et al.*, 2024). In practical terms, the observation shows that if the area's soil to be recovered is not degraded, the area's ecological recovery may reduce its fertilization costs.

Like what was observed in this study, but under more controlled environmental conditions, Knapik *et al.* (2011) did not obtain a response to fertilization for height and stem diameter of the species *A. edulis* (Chal-chal) at four months of age. According to the authors, the species has low nutritional requirements in the seedling stage. It is also considered that the species under study are native to the Atlantic Forest, whose soil pH in Brazil is at acidic levels, which suggests a physiological adaptation of these species to lower levels of nutrient availability. In other words, the increase in nutrient availability through fertilization with CRF in the soil may not translate into gains in the growth of the species if their physiology is not adapted to make use of this extra supply, however, throughout their development, they may present more remarkable performance, when compared to other unfertilized individuals of the same species.

Another hypothesis for the absence or non-linearity of responses to fertilization arises from the fact that in the riparian forest environments, species experience periods of flooding and high-water tables, which cause stomata to close and photosynthesis to drop dramatically (MARTINETTI *et al.*, 2021). In yellow Ipê (*Handroanthus chrysotrichus*), Bispo and Vieira (2022) observed a drastic reduction in growth and a slow recovery of physiological parameters after flooding stress. Under conditions of oxygen deprivation in the roots, the additional supply of nutrients has no effect due to the physiological impossibility of using it (JIMÉNEZ *et al.*, 2019).

Similarly, species' responses to fertilization are conditioned by the quantity and quality of solar radiation they receive during development (BALLESTRERI *et al.*, 2021). In the recovery conditions implemented in this study, intra- and interspecific shading is expected, considering the planting spacing used (1.2 x 1.2 m) and the natural expectation of repopulation of the riparian forest area as the forest recovery process progresses. Partial shading naturally reduces the demand for soil fertility since each plant's development rate is reduced as a function of time.

Under greenhouse conditions, Duarte *et al.* (2021), evaluating the development of the species *Campomanesia adamantium* (Gabiroba) at 120 days post-emergence, observed significant responses to phosphorus doses (0 to 400 kg/ha) and zero responses to nitrogen fertilization (0-200 kg/ha). This study studied NPK doses as a single factor, and the congener *C. xanthocarpa* was shown to be non-responsive to fertilization. The response observed by Duarte *et al.* (2021) for a soil with low P content (1.2 mg $dm^{-3}$), contrasting with the P content in this study (23.5 mg $dm^{-3}$), indicates the existence of minimum levels for the species to respond to fertilization, that is, for fertilization to be technically justified. Ornelas *et al.* (2022), evaluating the initial development of 22 native species of the Atlantic Forest under the effect of NPK fertilization associated or not with weed management, concluded that most species were not responsive to fertilization and intensification of treatments. According to the authors, the lack of response probably results from the recovery area having been used for decades with crops that increased soil fertility. In the present study, the lack of significant responses from different species to fertilization can be attributed to pre-existing soil fertility conditions, whose history of agricultural use promoted or maintained soil fertility at medium levels that tend to be satisfactory for native species of the Atlantic Forest. Therefore, prior analysis of soil fertility in the riparian forest area to be recovered may eliminate the need to plant fertilizers under conditions like this study's.

However, the conclusions of Ornelas *et al.* (2022) corroborate the results of this study and indicate that there is no need for soil fertilization in projects to recover ecologically degraded areas when, in their history, there has been an increase in soil fertility to median levels for crops. On the other hand, it is believed that in soils that are degraded in terms of fertility or naturally have low fertility (e.g., P of 1.2 mg $dm^{-3}$), responsive behavior to fertilization can be observed, as demonstrated by Duarte *et al.* (2021). Given this, fertilization of CRF plants can be justified by technical, economic and environmental factors, such as degraded soils with high acidity and very low fertility levels. From an economic perspective, although CRF initially has a higher acquisition value on the market when compared to conventional readily soluble fertilizers, it can generate savings over time due to the elimination of the need for topdressing fertilization operations, a lower seedling replanting rate, and a lower volume of handling, movement, and storage, resulting in reduced costs for the area recovery project, favoring its implementation in larger areas. Furthermore, as highlighted by Rossa *et al.* (2013), the technology presented by this class of fertilizers should be considered in terms of the capacity for gradual release of nutrients to the soil, reducing the environmental impact caused by contamination of the site and the water table by phosphorus ($P_2O_5$) and nitrate ($NO_3^-$), typically caused using highly soluble mineral fertilizers. Therefore, using CRF instead of conventional fertilizers - which may present excessive solubility and losses due to nutrient leaching, which may cause eutrophication of water bodies - can minimize environmental risks in the execution of recovery projects in permanent preservation areas.

Therefore, although this study's results demonstrate that there is no need for fertilization with CRF of the studied forest species, the success of a project to recover a riparian forest area also depends on the analysis of technical, environmental—mainly edaphological—and economic factors.

## CONCLUSIONS

- Using controlled-release fertilization technology in a permanent preservation area recovery project in the Atlantic Forest biome did not result in better initial development of the native forest tree species studied.

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