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Forestry performance of *Bertholletia excelsa* Humn. & Bonpl Lecythidaceae under different fertilizers after two years of planting

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Abstract

Bertholletia excelsa is a species is frequently used in reforestation due to its high degree of adaptability and its excellent initial growth. Thus, this work aimed to study the growth of *B. excelsa* according to different types and concentrations of fertilization, seeking to contribute to the silvicultural development of this species. For this purpose, seedlings of *B. excelsa* were planted in the Madre de Dios region on a property near the province of Puerto Maldonado in Peru. The seedlings were selected when they presented an average height of 22 cm for all treatments, being T1: Dolomite + SPT; T2: Dolomite + NPK; T3: Dolomite + SPT + Agricultural plaster; T4: Dolomite + NPK + Agricultural plaster, and T5: A control treatment without fertilization modifications. The experimental design was randomized blocks with five treatments and four replicates of six seedlings each. Once the ANOVA assumptions were met, the data were subjected to analysis of variance, with significant differences between the data, the means were compared using the Tukey test ($p < 0.05$). Survival (%) was evaluated from the number of live individuals in two years of measurement. The treatment T4 presented great silvicultural potential, as the fertilization provided the development in height and diameter. Treatments T1 and T3 did not perform well when compared to the control, presenting the lowest growth rates in height and diameter, and the lowest survival rate. The control treatment did not differ statistically from T4, thus concluding that pre-plant fertilization of *B. excelsa* is not necessary.

Keywords: Brazil nut; initial growth; tree seedlings; survival.

Desempenho silvicultural de *Bertholletia excelsa* Humn. & Bonpl Lecythidaceae sob diferentes adubações após dois anos de plantio

Resumo

A espécie *Bertholletia excelsa* é frequentemente utilizada em reflorestamentos pelo alto grau de adaptabilidade e seu ótimo crescimento inicial. Com isso, esse trabalho objetivou estudar o crescimento de *B. excelsa* de acordo com diferentes tipos e concentrações de adubação, buscando contribuir para o desenvolvimento silvicultural dessa espécie. Para isso, foram plantadas mudas de Bertholletia excelsa na região de Madre de Dios em uma propriedade próxima a província de Puerto Maldonado no Peru. As mudas foram selecionadas quando apresentaram altura média de 22 cm para todos os tratamentos, sendo T1: Dolomita + SPT; T2: Dolomita + NPK; T3: Dolomita + SPT + Gesso agrícola; T4: Dolomita + NPK + Gesso agrícola e o tratamento controle sem modificações por adubação. O delineamento experimental utilizado foi em blocos ao acaso com cinco tratamentos e quatro repetições de 6 plântulas cada. Uma vez atendidos os pressupostos da ANOVA, os dados foram submetidos à análise de variância, havendo diferenças significativas entre os dados, as médias foram comparadas pelo teste de Tukey ($p <0,05$). A sobrevivência (%) foi avaliada a partir do número de indivíduos vivos em dois anos de medição. O tratamento T4 apresentou grande potencial silvicultural pelo que a adubação proporcionou ao desenvolvimento em altura e em diâmetro. Os tratamentos T1 e T3 não obtiveram um bom desempenho quando comparado ao controle, apresentando as menores taxas de crescimento em altura e em diâmetro, e as menores taxa de

sobrevivência. O tratamento controle obteve um bom resultado não diferindo estatisticamente de T4, assim concluindo que não é necessário a adubação pré-plantio de *B. excelsa*.
Palavras-chave: Castanheira-do-Brasil; crescimento inicial; sobrevivência; mudas florestais.

1. Introduction

Bertholletia excelsa is considered a promising species for reforestation of degraded areas due to its high survival rates, as well as its robustness, tolerance to degraded soils, excellent growth in high conditions of light. This justifies the *B. excelsa* enrichment planting in areas close to human occupations. As a consequence of traditional itinerant agricultural practices, such as shifting cultivation and landscape management, anthropogenic ecosystems are predominant in these areas, generally in a state of secondary regeneration with medium or high exposure to sunlight (SCOLES; GRIBEL, 2021).

For Dionisio *et al.* (2017), exploitation of renewable resources in this region is related to slash-and-burn agriculture, where the forest cover is eliminated for the introduction of annual and perennial crops, later being replaced by pastures, resulting in degradation of these areas.

In recent years, research aimed at the propagation of native tree species has increased because of environmental issues that are increasingly present, such as deforestation and burning, which are soon linked to agricultural expansion, mining activities, and civil construction (OLIVEIRA *et al.*, 2013; DIONISIO *et al.*, 2019).

In addition to the ecological benefits, the reforestation of these areas would increase the wood supply the region, consequently increasing the rural properties incomes, thus spreading economic, social and environmental balance (REBOUÇAS *et al.*, 2018).

However, the reforestation of degraded areas using only highly productive exotic species, such as Pinus, Eucalyptus and Acacia, can result in a biological and land use simplification, not promoting the reestablishment of wood from native species with high commercial value (LAMB *et al.*, 2005).

The Brazilian nut tree (*B. excelsa*) is frequently used in reforestation due to its high degree of adaptability and its excellent initial growth, with the most developed grafted seedlings from reforestation being a good strategy for recovering degraded areas (SALOMÃO *et al.*, 2006; SCOLES *et al.*, 2011).

Being considered an example of the use of a non-timber forest product, the Brazilian nut tree, which belongs to the Lecythidaceae family, can reach two meters in diameter and 50 meters in height (DIONISIO *et al.*, 2017). Seen as a forest product of great importance in the Amazon, due to its excellent wood quality, its main use is through extractivism for the consumption of its nuts, being exploited by extractive communities, thus demonstrating its potential economic, social and ecological for the Amazon region.

One of the main factors for increasing forestry productivity is plant nutrition through fertilization and growth substrates. With this, studies are carried out in order to future plantings to have reductions in costs and processing acceleration, making the species more resistant and ready for good survival after planting, both to recover degraded areas and for their commercial use.

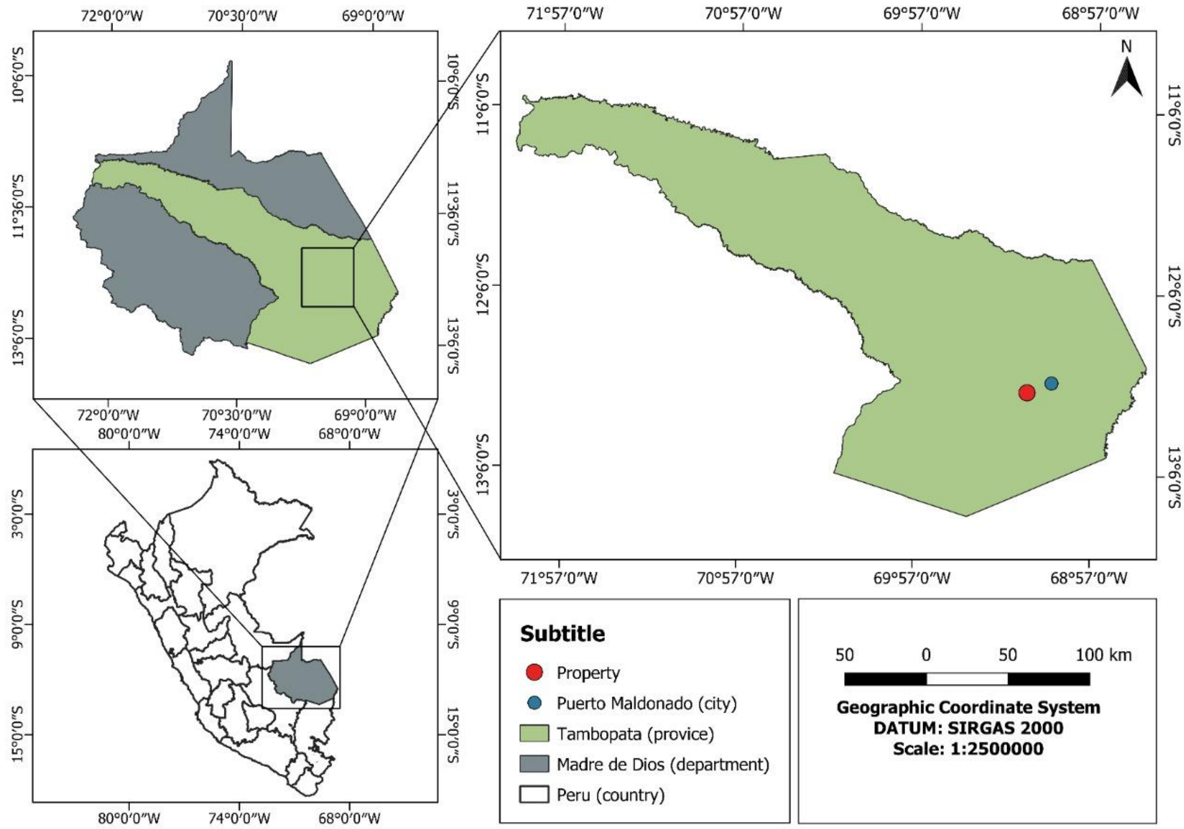
Thus, this work aimed to investigate growth in height and diameter, and the survival rate of *Bertholletia excelsa* under different types and concentrations of fertilization, seeking to contribute to the silvicultural development of this species. Thus, we tested the following hypothesis: Fertilization influences positively the initial growth of *B. excelsa* seedlings.

2. Material and Methods

2.1 Experimental design

The study area is located in the region of Madre de Dios, Peru, on a private property called Eddy Pastor farm, which is used mainly for agroforestry systems. The property is at coordinates 12º39’04” S, 69º19’17” W, 14 km from the city of Puerto Maldonado towards Cusco (Figure 1).

Figure 1. Map of Peru, the department of Madre de Dios and the province of Puerto Maldonado, with points indicating the location of the Eddy Pastor farm property where the studies on *B. excelsa* fertilization were carried out during the years 2018 to 2020, and of the city of Puerto Maldonado.



Seedlings of *B. excelsa* were selected 30 days after germination and transplanted to 115 cm^3 tubes with a substrate composed of sand + sawdust + carbonized sawdust in proportions (1:1:1 v/v). The plants for each treatment were previously standardized by size. After transplanting, the tubes were placed in a nursery covered by a mesh with 60% shading for five months.

Seedlings were previously selected by height for standardization and uniformity of the lots when they presented an average of 22 cm for all treatments. Five treatments with different fertilizers were used in the study (Table 1).

Table 1. Treatments that were used to evaluate the growth of *B. excelsa* plants in the field over a period of 2 years, in the region of Madre de Dios, from 2018 to 2020 on the Eddy Pastor farm.

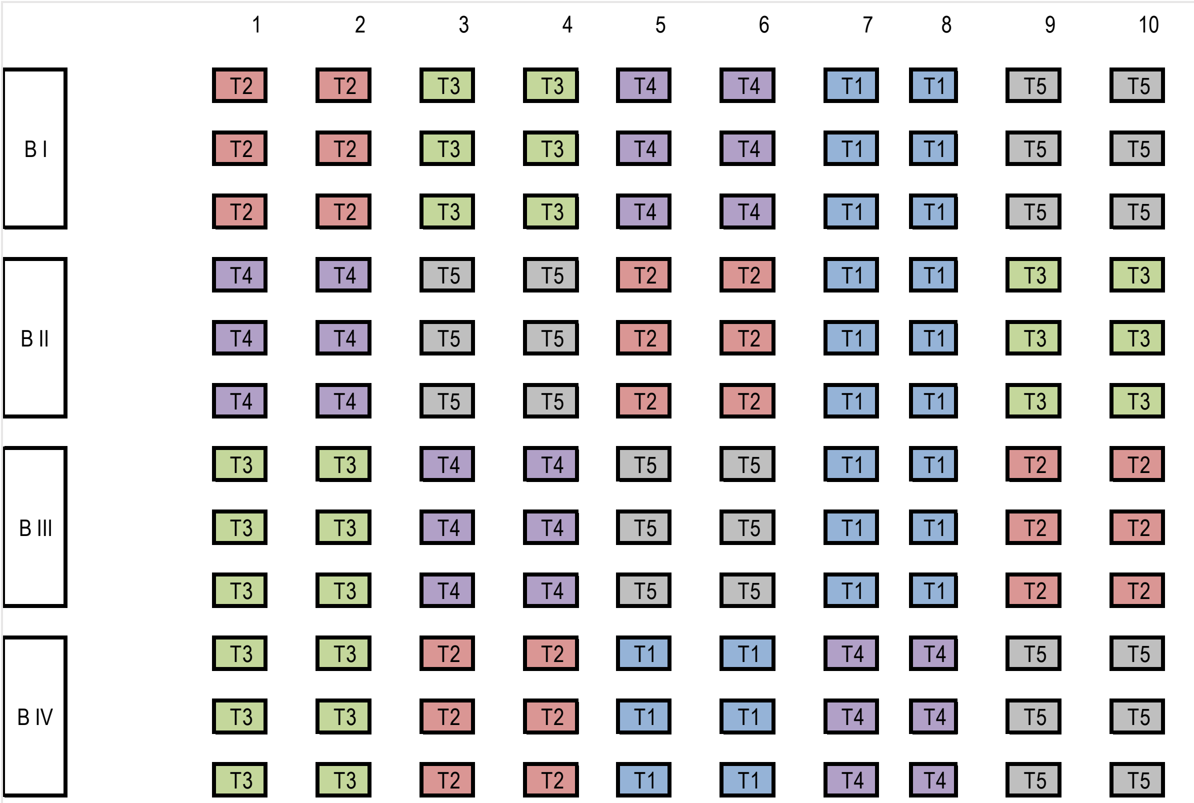
Treatments		**Quantity per pit**	**Application moment**	**Covering**
T1	Dolomite + SPT	200 g + 300 g	Pre-planting	SPT 300 g [sixth month]
T2	Dolomite + NPK	200 g + 40 g	Pre-planting	NPK 30 g [every three months]
T3	Dolomite + SPT + agricultural plaster	200 + 300 g + 100 g	Dolomite and base SPT and post-planting agricultural plaster	SPT 300 g [sixth month]
T4	Dolomite + NPK + agricultural plaster	200 + 40 g + 100 g	Dolomite and base NPK and post-planting agricultural plaster	NPK 30 g [every three months]
T5	Control	---	---	---

Seedlings were planted in the field at 10 m x 10 m spacing in the month of October, in pits measuring 40 cm x 30 cm (depth and width) that were drilled with a mechanized drill for manual use with dimensions of 25 cm in diameter and 45 cm of length.

Agricultural plaster was applied at the time of planting and thereafter every six months. Superphosphate triple (SPT) at both T1 and T3 was applied in covering every six months, and NPK was applied every three months at T2 and T4. Seedlings were evaluated every six months for two years (2018-2020). To measure seedling diameter, a digital caliper (0.001 mm) was used, where seedling diameter was measured at 2 cm from the ground and the height was measured using a graduated ruler.

The experimental design used was randomized blocks with five treatments and four replicates of six seedlings each (Figure 2).

Figure 2. Test sketch used in the planting of *B. excelsa* seedlings, being T1: Dolomite + SPT; T2: Dolomite + NPK; T3: Dolomite + SPT + agricultural plaster; T4: Dolomite + NPK + agricultural plaster; T5: Control; in the region of Madre de Diós from 2018 to 2020, on the Eddy Pastor farm.



To verify the assumptions of the analysis of variance (ANOVA), the data were first checked for: a) normality with the Shapiro-Wilk test ($p > 0.05$), b) homoscedasticity by the Bartlett test ($p > 0.05$), c) independence of observations. Once these assumptions were met, the data were submitted to ANOVA, with significant differences between the data, the means were compared using the Tukey test ($p < 0.05$).

The absolute growth rate (AGR) was obtained by the following formula: AGR = M2 – M1 / T2 – T1; as M2 is the final measure of height or diameter, M1 is the initial measure of height or diameter and T2 – T1 is the time interval. The relative growth rate (RGR) was obtained by the formula: RGR= lnM2 – lnM1 / T2 – T1, where M2 is the final measure of height or diameter, M1 is the initial measure of height or diameter, T2 – T1 is the interval of time and ln is the neperian logarithm.

Absolute and relative growth rates in height and diameter were submitted to analysis of repeated measures over time (ANOVA) using the R program version 4.0.2 and, with significant differences between the data, the means were compared by Tukey test ($p < 0.05$). Survival (%)

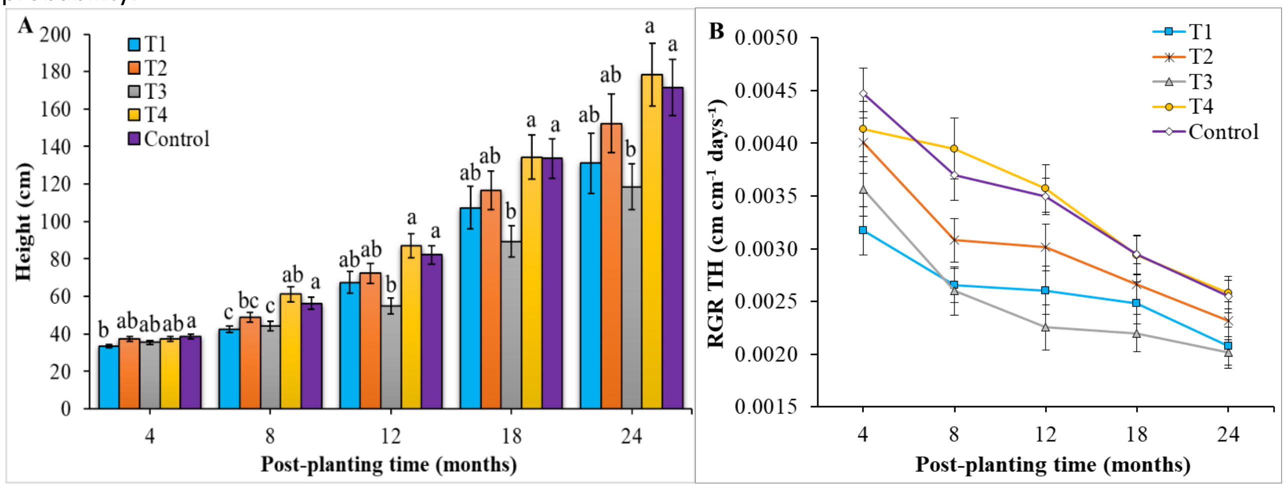
was evaluated from the number of live individuals in the two years of measurement, and the survival rate for each treatment and the overall survival rate were calculated.

3. Results and Discussion

3.1 Height growth (cm)

The treatments T2 (37.3 cm ± 1.2 cm), T3 (35.5 cm ± 1.2 cm) and T4 (37.3 cm ± 1.3 cm) presented no statistical differences for the variable height in the period of four months post-planting. The control treatment (38.6 cm ± 1.1 cm) had higher average height in the same period when compared to the T1 treatment (33.5 cm ± 0.9 cm) four months after planting. In the eighth month after planting, T4 (61.2 cm ± 4.1 cm) had the highest average height, and the lowest rate in the same period were presented by the treatments T3 (44.2 cm ± 2.7 cm) and T1 (42.6 cm ± 1.6 cm), which did not differ statistically from each other. After 12 months of planting, T4 and control showed the highest averages, differing significantly only from T3, which presented the lowest average height growth until the end of the period and evaluation. At 24 months after planting, treatments T4 (178.4 cm ± 16.9 cm) and control (171.6 cm ± 15.0 cm) did not differ statistically from each other (Figure 3A).

Figure 3. Average (±SD) height (A), relative growth rate (B) of B. excelsa seedlings as a function of time after planting, during the period 2018 to 2020 at Eddy Pastor farm, in the region of Madre de Dios, Peru. Lowercase letters indicate height differences in the same measurement in ANOVA with Tukey's test at 5% probability.

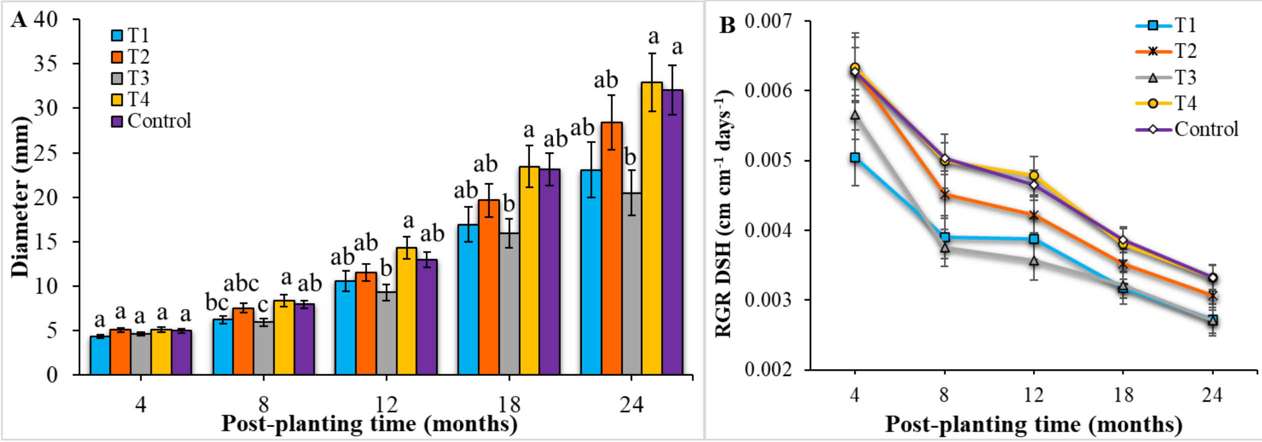


In relation to the relative growth rate, all treatments presented decreases over time, T4 and control had higher relative growth rates in all evaluations up to 24 months after planting. T2, T1 and T3 showed lower relative growth rates in all measurements over 24 months, respectively (Figure 3B).

3.2 Diameter growth (mm)

At four months post-planting there was no statistical difference between all treatments (p=0.05) for stem diameter. From the eighth month after planting, treatments T4 (8.3 mm ± 0.67 mm) and control (7.9 mm ± 0.41 mm) had the highest averages and did not differ statistically (p=0.05). T3 always presented the lowest average growth in diameter in every month that was measured. At 24 months post-planting, treatments T4 (32.9 mm ± 3.26 mm) and control (32.0 mm ± 2.80 mm) did not differ statistically (Figure 4A).

Figure 4. Average (±SD) in diameter (A), relative growth rate (B) of *B. excelsa* seedlings as a function of time after planting during the period 2018 to 2020 at Eddy Pastor farm, in the region of Madre de Dios, Peru. Lowercase letters indicate differences in diameter in the same measurement in ANOVA with Tukey's test at 5% probability.



Regarding the relative growth rate in diameter, all treatments obtained decreases over time (Figure 4B). T1 (0.003 cm.cm^{-1}.day^{-1} ± 0.0002 cm.cm^{-1}.day^{-1}) and T3 (0.003 cm.cm^{-1}.day^{-1} ± 0.0002 cm.cm^{-1}.day^{-1}) showed the lowest relative growth rate in 24 months after planting.

The growth in height and in diameter of the seedlings in which dolomite + NPK + agricultural plaster (T4) was applied was superior to the others since the eighth month after planting. The treatment in which only dolomite + NPK (T2) was applied also obtained a satisfactory result, showing good growth in height and diameter. The control treatment also had a positive result in height and diameter growth.

The NPK treatments shows greater plant development because of its functions performed by each nutrient (CAIONE *et al.*, 2012). However, for *B. excelsa* the fertilization had no positive effect, since the control treatment presented the same development as those who received fertilization. Thus, the treatment with the combination of dolomite + NPK + agricultural plaster (T4) did not differ statistically from the treatment without application of fertilizer.

The superphosphate triple (SPT) presented good performance in the development of seedlings of *Schizolobium parahyba* (Vell.) S. F. Blake (ADAMI; HEBIGLI, 2005). However, in the present work the results did not indicate good development with its use. One factor that can highlight the results of triple superphosphate treatments is the number of years of planting. According to Tonini *et al.* (2008) in a study applying 60 g of superphosphate triple, even with slow initial growth, *B. excelsa* obtained larger diameters from the fourth year of planting onwards.

In a study with *S. amazonicum* Huber ex Ducke in a greenhouse, Marques *et al.* (2004) verified that the absence of nitrogen caused lower plant height. This may also clarify why treatments with (SPT) triple superphosphate had much lower results when compared to those that received NPK fertilization.

As it does not differ statistically from the control treatment, it is not possible to affirm that the use of NPK combined with Dolomite in the long term performs better than a seedling planted without fertilization, thus requiring more research time for such affirmation. It is also not correct to rule out the use of superphosphate triple for the growth of *B. excelsa*. The studied plantation was two years old until the elaboration of this work, therefore giving room for the development in superphosphate triple to present better results afterwards.

The control treatment in the present work obtained the best results in growth, both in height and in diameter, therefore agreeing with the observations of Tonini *et al.* (2006), by stating that *B. excelsa* has great potential for planting without the need of large amounts of inputs. In this way, aiming to reduce costs and have a good development, fertilization is not necessary according to the results found in the control treatment. However, the fertilizer dosage in other treatments must be taken into account; consequently, further studies are suggested with a higher rate of fertilization dosage in *B. excelsa*, in order to obtain better results.

In their study, comparing the performance of *B. excelsa* in a clear environment, scrubland and understory in a forest area, Scoles *et al.* (2011) found highly significant statistical differences between treatments. The clear treatment had an average increase in height (AICh) of 204.4 ± 115.4 cm in two years, obtaining the best performance. This fact corroborates with the height performance obtained in the present study, since its planting was performed in a clear area with high incidence of light, indicating a strong tendency for the planting of *B. excelsa* in open areas to present considerable height growth.

Also according to Scoles *et al.* (2011), the difference between treatments was also significant for growth in diameter, with the open field treatment again presenting the best performance compared to treatments with reduced light incidence, helping to justify the good performance of *B. excelsa* also in diameter when planted in open areas that have a lot of light.

3.3 Survival rate

The average survival rate for all treatments was 95.83%. All treatments showed good seedling survival rates in the field, and the control treatment was the only one to show 100% survival. T3 (91.66%) had the lowest survival rate in the field, with treatments T1, T2 and T4 presenting the same survival rate as seedlings in the field (95.83%) (Table 2). Seedling death (n=5) occurred 1 year and 6 months after planting in all treatments, except for the control treatment, which did not obtain live seedlings in the field.

Table 2. Survival rates of seedlings of *B. excelsa* in the field in different treatments, 24 months after planting, in the region of Madre de Dios in the period 2018 to 2020 at the Eddy Pastor farm.

Treatments	Discripition	Survival rate (%)
T1	Dolomite + SPT	95.8
T2	Dolomite + NPK	95.8
T3	Dolomite + SPT + Agricultural plaster	91.6
T4	Dolomite + NPK + Agricultural plaster	95.8
Control	---	100.0

In the two years of planting, the survival rate of 95.83% can be considered a relevant performance in relation to this variable. Tonini *et al.* (2008) found that at 5 years of age the survival rate of *B. excelsa* was 97.9%, demonstrating that the survival rate without any type of plant disturbance does not decline drastically. Scoles and Gribel (2021) evaluated survival of *Bertholletia excelsa* under different environmental conditions and levels of canopy openness within experimental plantations, where the survival rate was 85% ten years after planting. Garate-Quispe *et al.* (2020) evaluated survival and growth of *B. excelsa* seedlings planted in tree-fall gaps and found a survival rate of 75% after 12 months post-planting.

Over the years, survival can be affected by several factors. Machado *et al.* (2017), analyzing a 27-year-old *B. excelsa* plantation in the state of Amazonas, verified that the survival rate was 69%. The present work is lasting only two years and presented high performance in terms of survival rate. Additionally, monitoring the survival rate over the years in planting proves to be an important procedure in the long term.

Costa *et al.* (2009) observed that the survival of *B. excelsa* plants was lower, although a much larger planting spacing was established compared to the present study. This result is explained by the natural events that occurred in the research, such as winds and lightning, negatively impacting the survival of *B. excelsa*. This is another factor that can affect the survival rate over the years and that may explain the death of some plants in the present study.

It is possible to affirm that *B. excelsa* is easy to adapt and recommended for planting in degraded areas due to its high survival rate and the great performance without fertilization, showing itself as a resilient plant under the conditions offered.

4. Conclusions

Seedlings of *B. excelsa* without fertilization showed excellent development in the field up to two years after planting. The great initial performance of *B. excelsa* without fertilization suggests that seedling can be feeding partially from the reserves present in the almond. We suggest in future research to test such hypothesis and evaluate for how long almonds can feed seedlings in the field.

Two years after planting of *B. excelsa*, the seedlings still presented high survival rate. The NPK + agricultural plaster mixture should be better explored in future researches as it indicated potential for growth in diameter, height and survival rate in seedlings of *B. excelsa*.

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