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Effects of a Liquid Organic Biofertilizer from Rubber Seed Cakes on the Growth of Rubber Plants in the Nursery in Côte d'Ivoire

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Abstract

Rubber has a major role in the Ivorian economy. However, the production of seedlings in nurseries is limited by the scarcity of fertile substrates, leading to a high dependence on chemical fertilizers, the excessive use of which compromises environmental sustainability. With this in mind, the purpose of this study was to evaluate the effect of liquid biofertilizers formulated from rubber seed cakes on the growth of seedlings in nurseries. The experiment, conducted at the CNRA station in Anguédédou, was carried out using a randomized complete block design comprising five treatments: an absolute control (T0), a urea control (T1) and three liquid biofertilizers (T2: 1 kg of rubber seed cakes/10 L of water; T3: 2 kg of rubber seed cakes/10 L of water; T4: 1 kg of rubber seed cakes/10 L of water + 15 g of urea). Applications were made monthly for four months. The parameters observed were the diameter, the height, the growth rate and the vegetative vigour index. The results revealed that the T3 and T4 treatments significantly favoured the development of the plants, with higher diameters and heights as well as increased vigour compared to the controls. These performances reflect the agronomic efficiency of biofertilizers from rubber seed cakes, which are capable of improving growth while adding value to a local by-product. This strategy is a sustainable and environmentally friendly alternative to chemical fertilisers. However, further research is needed to adjust the doses and study the long-term effects after grafting and on the fertility of the substrate.

Keywords

Rubber, Biofertilizer, Rubber Seed Cakes, Growth, Nursery, Côte d'Ivoire

1. Introduction

The rubber tree (*Hevea brasiliensis*), a species native to the rainforests of the Amazon, is the world's main source of natural rubber [1]. Introduced in Côte d'Ivoire in 1953, its cultivation has developed rapidly thanks to its economic profitability, public incentive policies, and the effective structuring of the sector by the Association of Natural Rubber Professionals of Côte d'Ivoire, APROMAC [2]. Today, Côte d'Ivoire, with an estimated production of 1.68 million tons, is the leading African producer and the third largest in the world of natural rubber [3]. Rubber cultivation thus represents a strategic sector for the country's rural development, ensuring regular income for smallholders and contributing significantly to job creation in agricultural areas [4]. However, the expansion of rubber plantations to marginal agroecological zones comes with many challenges, both environmental and agronomic [5]. One of the main constraints encountered is the limited availability of quality substrates for nursery production. This situation leads many producers to resort to chemical fertilizers to stimulate the growth of young plants [6]. However, the intensive and often uncontrolled use of these chemical fertilizers is recognized for its harmful effects on soil quality and the environment [7]. In particular, these practices can alter the balance of soil microbial communities, reduce soil biological fertility, and increase plant susceptibility to disease [8].

In this context, the use of organic fertilisers, which are more respectful of ecological balances, is a sustainable alternative to chemical inputs. Among these biofertilizers, cakes from rubber seed oil, rich in organic matter and nutrients, appear to be a particularly promising option [9]. These by-products, which are still undervalued in production systems, could help improve plant growth and vigour while reducing dependence on mineral fertilizers. Thus, this study aims to evaluate the effect of an aqueous biofertilizer based on rubber seed cakes on the development of rubber plants in nurseries. More specifically, it involves:

1) Measure the effect of different treatments on the growth of young plants;

2) Analyze the vigour of the plants according to the fertilization methods;

3) Determine the relationship between plant height and diameter as a function of the treatments applied.

2. Study Site

The study was conducted at the Production Station of the National Center for Agronomic Research (CNRA) in Anguededou, located in the commune of Songon, District of Abidjan, between 5˚18'35" and 5˚18'55" north latitude, and 4˚9'15" and 4˚9'30" west longitude (**Figure 1**). The average annual temperature recorded between 2014 and 2024 at the CNRA station in Bimbresso is 28.8˚C. The annual rainfall is 1,545 mm. The climatic regime includes a long dry season from December to February, a long rainy season from March to July, a short dry season in August, and a short rainy season from September to November [10]. The soils of the Songon region are ferralitic on a tertiary sandy substrate, with a sandy-clayey texture [11]. Although potentially fertile, these soils are vulnerable to leaching and podzolization [12].

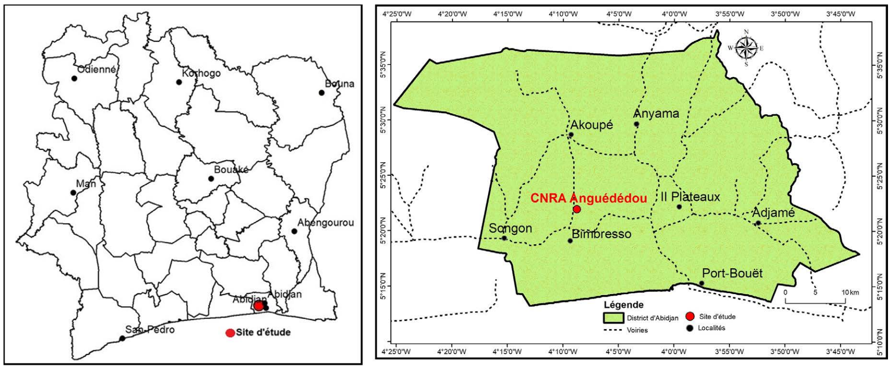


Figure 1. Location of the study site.

3. Study Material and Methodology

3.1. Material

The plant material used in this study consists mainly of rubber seed cakes (**Figure 2** and **Figure 3**), a solid residue obtained after mechanical extraction of the oil from the seeds. This rubber by-product, rich in organic compounds, has interesting potential for various agronomic applications.

Figure 2. Rubber seeds.

Figure 3. Rubber seed cakes.

3.2. Methods

3.2.1. Production Method of Aqueous Biofertilisers

The aqueous biofertilisers used in this study were formulated from rubber seed cakes, obtained after mechanical extraction of oil, water, and, for some treatments, urea. The preparation of the aqueous extracts began by crushing the rubber seed cakes into a fine powder, which was then mixed with water according to two mass ratios: 1 kg of rubber seed cakes to 10 liters of water, and 2 kg of rubber seed cakes to 10 liters of water. The mixtures thus formed were subjected to maceration for 15 days**.** Daily homogenization was performed during the first 14 days to promote the breakdown and release of nutrient compounds. On the fifteenth day, the suspensions were filtered through a fine 250 µm mesh sieve to remove solid debris and obtain a homogeneous liquid extract ready for use (**Figure 4**).

Three formulations of liquid biofertilizers were prepared from different proportions of rubber seed cakes and urea, according to the following treatments:

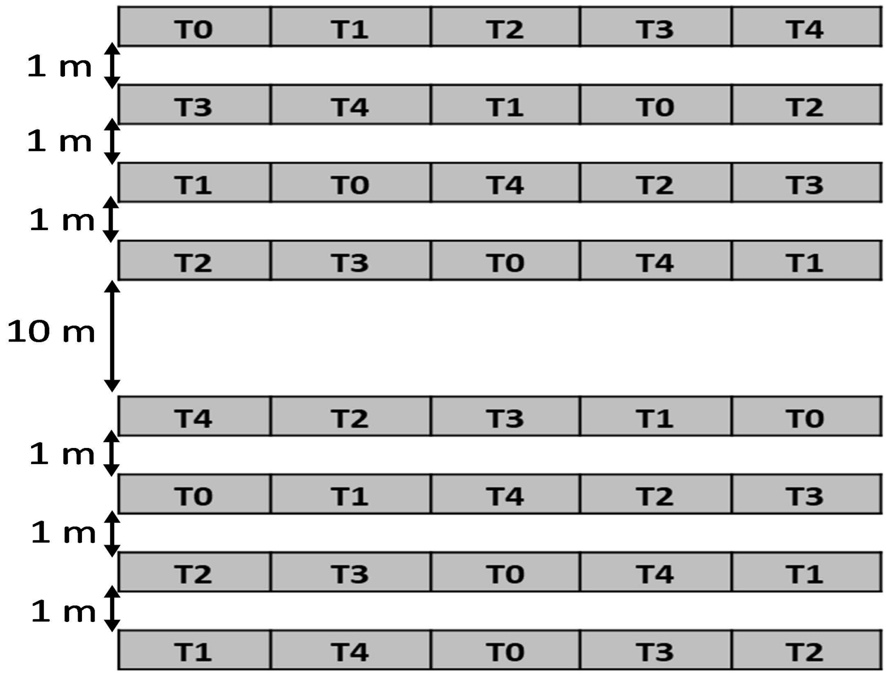
1) T2: 1 kg of rubber seed cakes + 10 liters of water.
2) T3: 2 kg of rubber seed cakes + 10 liters of water.
3) T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

Figure 4. Liquid biofertilizer based on rubber seed cakes collected in a bucket.

3.2.2. Study Methodology

The study was conducted in a nursery using a randomized complete block system consisting of two blocks, separated by a distance of 10 meters (**Figure 5**). Each block consisted of five treatments, each repeated four times. The T0 treatment corresponded to the absolute control, without the application of fertilizer, while T1 (Urea) served as the reference control, presenting the common practice in rubber nurseries. The three treatments based on liquid biofertilizers were tested: T2 (1 kg of rubber seed cakes + 10 L of water), T3 (2 kg of rubber seed cakes + 10 L of water), and T4 (1 kg of rubber seed cakes + 10 L of water + 15 g of urea).

Before application, each biofertilizer was diluted to 50% with water. Each plant was then given 100 mL of nutrient solution, consisting of 50 mL of biofertilizer and 50 mL of water. The control treatments received no fertilizer (T0) or 1.5 g of urea dissolved in 50 mL of water per plant (T1), respectively. All treatments, whether biological or chemical, were applied monthly for a total of four applications during the experimental period.



Note: T0: Absolute control; T1: Urea, relative control; T2: 1 kg of rubber seed cakes + 10 liters of water; T3: 2 kg of rubber seed cakes + 10 liters of water; T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

Figure 5. Experimental plot configuration.

3.2.3. Data Processing Methods

1) Stage of development of the plants

The development of the seedlings was monitored through monthly measurements of height and diameter at the collar for all the treatments applied. These measurements made it possible to assess the growth and vegetative development of rubber plants, which are essential indicators of the condition of the nursery. The joint analysis of the height and diameter at the crown was used to characterize the growth dynamics of the plants as a function of the treatments. For each observation period, the mean height and diameter values were used to assess the comparative effect of different treatments on the development of bagged plants.

2) Seedling development rate

The speed of development is the ratio between the variation in the diameter at the neck and the duration of the treatment. This parameter was evaluated on the basis of the diameter, considered as a decisive criterion for grafting. Indeed, a rubber tree plant is suitable for grafting when its diameter at the collar reaches 10 mm within a maximum period of six (06) months. The measurement of the speed of development thus makes it possible to assess the speed of seedling growth according to the cultivation conditions applied. The development rate (VD) was calculated according to the following formula: $VD = \left[(Pf - Pi) / (tf - ti) \right]$ with VD = Development rate (cm/month), Pf = Final diameter at the collar (cm), Pi = Initial diameter at the neck (cm), tf = final time, and ti = initial time.

3) Seedling vegetative vigour index (IVV)

The vegetative vigour index (IVV) of the seedlings was determined from the diameter (D) and the total height (H) of each seedling. It was calculated according to the following formula: $IVV = \log\left(\left(pi \times D^2 \times H \right) / 4 \right)$ with $pi = 3.14$.

4) Correlation between plant diameter and height by treatment

The relationship between the diameter and the total height of the plants was analysed in order to assess the correlation between these two growth parameters according to the different treatments applied. Prior to the analysis, the data were subjected to the Shapiro-Wilk normality test and the variance homogeneity test, in order to verify the validity of the conditions for applying the correlation test. For each treatment, the Pearson linear correlation coefficient (r) was calculated to determine the direction and intensity of the relationship between plant diameter and height. The interpretation of the strength of the correlation was carried out according to the classification proposed by [13]: low ($0.10 \le R^2 \le 0.30$), moderate ($0.30 \le R^2 \le 0.50$), and strong ($R^2 \ge 0.50$). All statistical analyses were carried out using the XLSTAT software, version 7.0.

5) Comparison of Means

A one-way analysis of variance (ANOVA) was performed to evaluate the effects of biofertilizers on the vegetative growth parameters of rubber plants. When the treatment effect was found to be significant, the comparison of means was performed using Fisher's test of the smallest significant difference (*LSD*), at the 5% probability level ($\alpha = 0.05$).

4. Results

4.1. Plant Stage of Development

4.1.1. Diameter of the Plants under the Effect of the Different Treatments

Statistical analysis of the data on the application of the different biofertilizers on rubber plants in the nursery reveals a significant variation in the diameter of the plants (p-value = 0.015). Of the five treatments tested, the T3 and T4 treatments stand out for the highest average diameters, at 11.20 and 11.05 mm, respectively (**Table 1**). Conversely, the absolute control treatment (T0) has the lowest average diameter (9.28 mm). The T1, relative control, and T2 treatments show intermediate values, between 10.38 and 10.70 mm. These results highlight the particular effectiveness of the T3 treatment, formulated from 2 kg of rubber seed cakes diluted in 10 L of water, and the T4 treatment, consisting of 1 kg of rubber seed cakes diluted in 10 L with the addition of 15 g of urea. These two formulations appear to be promising biofertilizers to stimulate the growth in diameter of rubber plants in nurseries.

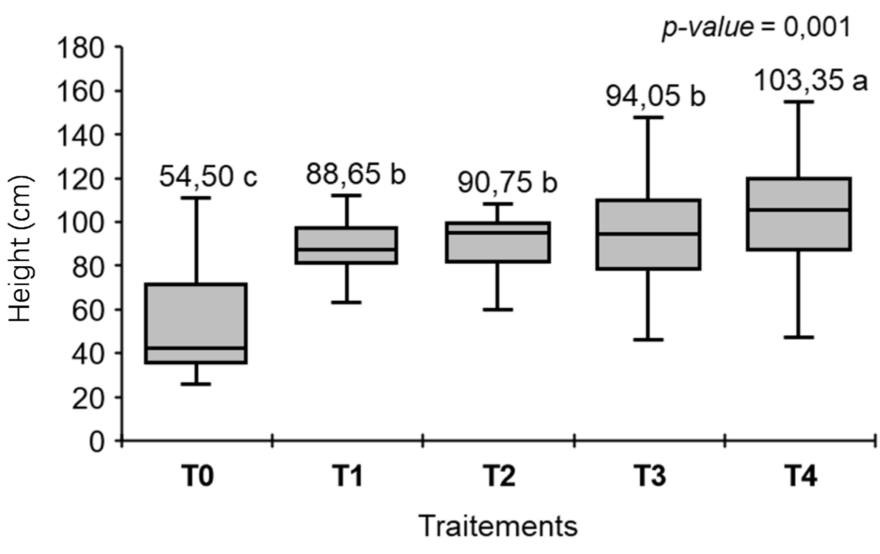
Table 1. Average diameters of differently treated rubber plants.

Treatments	Block 1	Block 2	Average of Blocks
T0	8.93 c	9.63 b	9.28 b
T1	10.30 b	10.45 ab	10.38 ab
T2	9.80 b	**11.60 a**	10.70 ab
T3	**11.60 a**	10.80 ab	**11.20 a**
T4	**11.35 a**	10.75 ab	**11.05 a**
p-value	0.0012	0.023	0.015

Note: T0: Absolute control; T1: Urea, relative control; T2: 1 kg of rubber seed cakes + 10 liters of water; T3: 2 kg of rubber seed cakes + 10 liters of water; T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

4.1.2. Average Heights of Rubber Plants

The evaluation of the average heights of rubber plants revealed highly significant differences between the treatments applied (p-value = 0.001). The T4 treatment recorded the highest average height (103.35 cm), reflecting a better performance in terms of vertical growth (Figure 6). It is followed by treatments T3 (94.05 cm), T2 (90.75 cm), and T1 (88.65 cm). In contrast, untreated plants (T0) had the lowest average heights. The T4 treatment, made from an aqueous biofertilizer composed of 1 kg of rubber seed cakes, 10 liters of water, and 15 g of urea, has therefore proven to be the most effective in stimulating the growth of plants in height.



Note: T0: Absolute control; T1: Urea, relative control; T2: 1 kg of rubber seed cakes + 10 liters of water; T3: 2 kg of rubber seed cakes + 10 liters of water; T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

Figure 6. Average heights of differently treated rubber plants.

4.2. Speed of Development of Rubber Plants

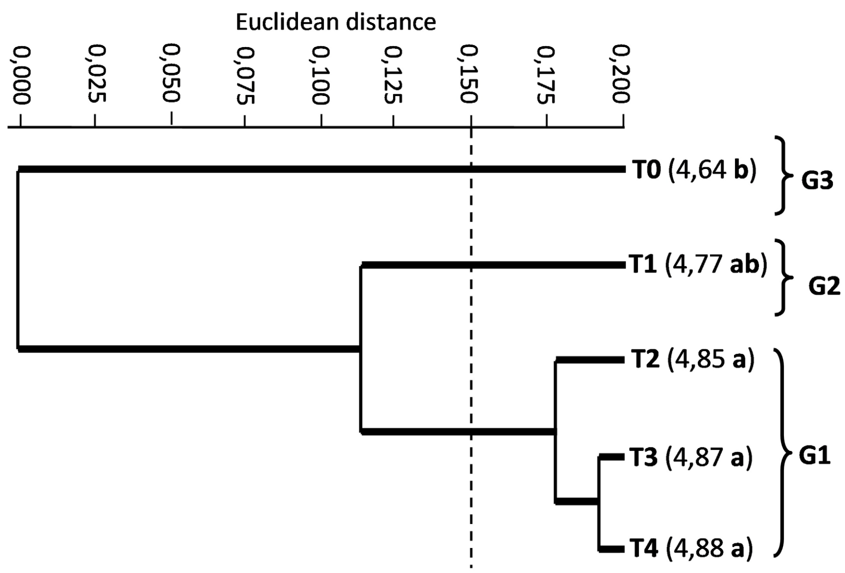
The evaluation of the development rate of rubber plants subjected to five separate treatments was carried out on the basis of the averages obtained in the two experimental blocks. Statistically significant differences were observed between the treatments, both within each block (p-value = 0.0006 for Block 1; p-value = 0.0461 for Block 2) than for the average of the two blocks (p-value = 0.0489). Among the treatments tested, T3 (1.59 mm/month) and T4 (1.56 mm/month) induced the highest growth rates (Table 2). The T0 control treatment showed the lowest growth, with a monthly mean of 1.14 mm/month. These results indicate that T3, an aqueous biofertilizer formulated from 2 kg of rubber seed cakes mixed with 10 L of water, and T4, consisting of 1 kg of rubber seed cakes, 10 L of water, and 15 g of urea, stand out as the most effective in stimulating the growth and development of young rubber plants in nurseries.

Table 2. Average growth rate of differently treated nursery rubber plants (mm/month).

Treatments	Block 1	Block 2	Average of Blocks
T0	1.02 ± 0.08 b	1.25 ± 0.34 b	1.14 ± 0.02 b
T1	1.28 ± 0.19 ab	1.26 ± 0.13 b	1.27 ± 0.00 ab
T2	1.02 ± 0.22 b	1.42 ± 0.26 a	1.22 ± 0.16 b
T3	**1.60 ± 0.33 a**	**1.59 ± 0.17 a**	**1.59 ± 0.02 a**
T4	**1.53 ± 0.30 a**	**1.59 ± 0.19 a**	**1.56 ± 0.00 a**
p-value	0.0006	0.0461	0.0489

Note: T0: Absolute control; T1: Urea, relative control; T2: 1 kg of rubber seed cakes + 10 liters of water; T3: 2 kg of rubber seed cakes + 10 liters of water; T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

4.3. Vegetative Vigour Index of Rubber Plants

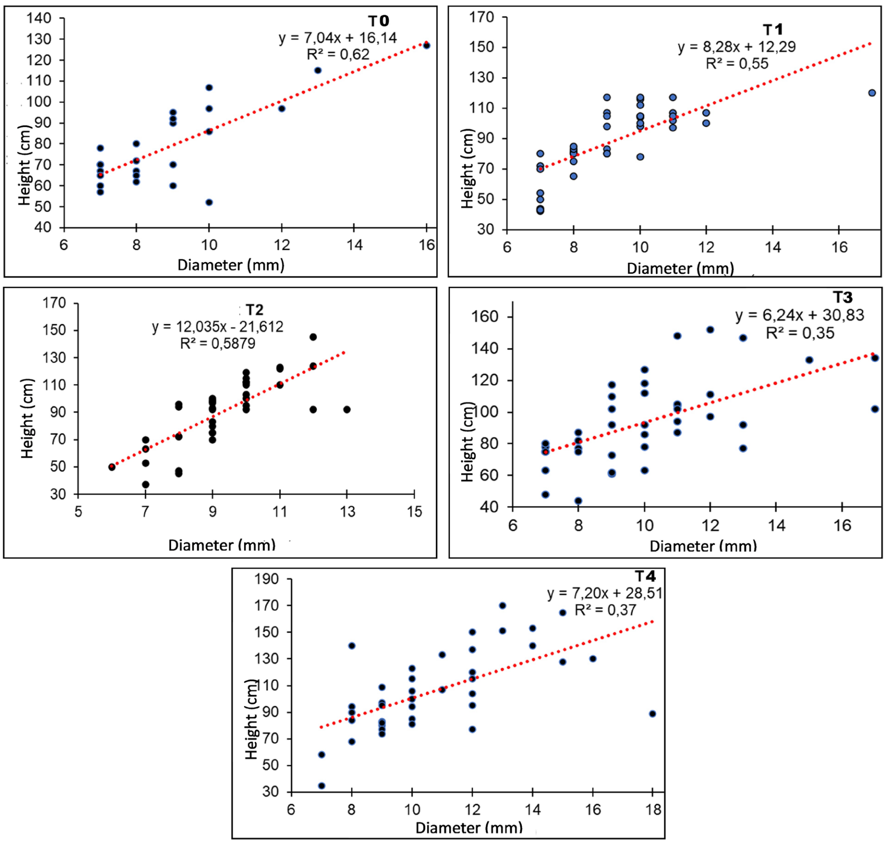


Note: T0: Absolute control; T1: Urea, relative control; T2: 1 kg of rubber seed cakes + 10 liters of water; T3: 2 kg of rubber seed cakes + 10 liters of water; T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

Figure 7. Histogram showing the difference in treatments.

The grouping of the different treatments according to the vegetative vigour index of rubber plants, based on a hierarchical classification based on the Jaccard similarity matrix and supplemented by an analysis of variance, made it possible to identify three distinct groups of treatments. The highest vigour indexes, with values between 4.85 and 4.88 (**Figure 7**). The second group (G2) consists of the relative control treatment (T1, Urea), which has a vigour index of 4.77. Finally, the third group (G3) is the absolute control treatment (T0), characterized by the lowest vigour index at 4.64. These results show that T2, T3, and T4 treatments significantly promote the vegetative vigour of young rubber plants in nurseries, reflecting their effectiveness in stimulating growth.

4.4. Correlation between Plant Diameter and Height by Treatment



Note: T0: Absolute control; T1: Urea, relative control; T2: 1 kg of rubber seed cakes + 10 liters of water; T3: 2 kg of rubber seed cakes + 10 liters of water; T4: 1 kg of rubber seed cakes + 10 liters of water + 15 g of urea.

Figure 8. Correlation curves between plant diameter and height according to treatments.

Analysis of the relationship between crown diameter and plant height shows a positive correlation for all treatments. This trend reflects a classic physiological behaviour of vegetative development, where an increase in diameter is usually accompanied by an increase in height, thus indicating vigorous and balanced plant growth. However, the intensity of this correlation varies between treatments, as shown by the coefficients of determination (R^2), ranging from 0.35 to 0.62 (**Figure 8**). The T0 (R^2 = 0.62), T1 (R^2 = 0.55), and T2 (R^2 = 0.58) treatments have the highest values, indicating harmonious growth between the height and diameter of the rubber plants in the nursery. In other words, the aqueous biofertilizers used in these treatments promote a proportional development in height and diameter. In contrast, the T3 (R^2 = 0.35) and T4 (R^2 = 0.37) treatments show weaker correlations, suggesting that, under these conditions, diameter growth is not strictly related to elongation of the plants. These results reflect a tendency for the plants concerned to thicken more than to grow tall.

5. Discussion

The results obtained from this study show that the application of biofertilizers significantly influences the morphological growth of young rubber plants in nurseries. Radial plant growth varied significantly across treatments (p-value = 0.015). The T3 (2 kg of rubber seed cakes diluted in 10 liters of water) and T4 (1 kg of rubber seed cakes in 10 liters of water with the addition of 15 g of urea) induced the highest diameters (11.20 and 11.05 mm). This performance could be due to the content of rubber seed cakes in essential nutrients such as nitrogen, phosphorus, and potassium, which would have promoted cell division, protein synthesis, and tissue elongation, key processes of primary growth [14].

The liquid formulation seems to have promoted a better availability and assimilation of nutrients, in agreement with the work of [15] and [16], who showed that organic inputs in liquid form stimulate root development and crown strengthening. Studies conducted in tropical areas have also confirmed the beneficial effect of organic amendments on early plant growth [17] [18].

The height of the plants also varied significantly between treatments (p-value = 0.001). The T4 treatment, combining rubber seed cakes and urea, produced the largest vertical growth (103.35 cm), followed by T3 (94.05 cm). This performance can be explained by better mineralization of the rubber seed cakes and a gradual release of nitrogen, supporting soil microbial activity and nutrient availability [19] [20]. Conversely, control plants (T0) had the lowest heights, highlighting the importance of a balanced nutrient supply in naturally poor substrates [21]. These trends are consistent with the observations of [22], which showed that well-decomposed organic amendments improve soil structure and nutrient use efficiency.

The monthly growth rate and the vegetative vigour index confirm the superiority of the T3 and T4 treatments, with 1.59 and 1.56 mm/month, respectively. This performance reflects an efficient assimilation of nutrients and sustained metabolic activity. The gradual release of organic compounds from the rubber seed cakes may also provide amino acids and bioactive substances that promote the growth of young tissues [23]. These results are consistent with those of [24], which showed that the combination of organic matter and mineral nitrogen optimizes nutrition and improves the vigour of Young plants in tropical environments. The positive correlation between height and diameter reflects a balanced allocation of resources between vertical growth and structural thickening, typical of woody species [25] and [26]. However, the moderate correlation coefficients obtained for the T3 and T4 treatments ($R^2 \approx 0.35 - 0.37$) indicate a slight priority given to thickening, an agronomic advantage in rubber nurseries. Indeed, a rubber plant in a nursery is suitable for grafting when its diameter reaches 10 mm within a maximum period of six months [27]. The liquid biofertilizers tested, therefore, appear to be particularly suitable for this purpose.

Overall, aqueous biofertilizers from rubber seed cakes appear to be an effective and sustainable alternative to mineral fertilizers for the production of seedlings in nurseries. Their use promotes growth, strengthens the vigour of the plants, and enhances a local by-product, thus contributing to circular and environmentally friendly fertilisation. However, this study was not exhaustive. The economic profitability study has not been conducted. This investigation will make it possible to estimate the benefit of the use of these aqueous biofertilizers compared to mineral fertilizers. In addition, soil analyses before and after treatment are carried out to assess the real impact of these aqueous biofertilizers on soil fertility and microbial dynamics.

6. Conclusions

The evaluation of the effects of liquid organic biofertilizers from rubber seed cakes on rubber tree growth in nurseries has highlighted their positive influence on the morphological development of young plants. The formulations tested significantly improved growth performance, confirming the agronomic interest of these organic inputs.

The T3 (2 kg of rubber seed cakes/10 L of water) and T4 (1 kg of rubber seed cakes/10 L of water + 15 g of urea) treatments were particularly distinguished by their favourable effects on the crown diameter, height, and growth rate of the plants. These treatments made it possible to obtain average diameters of more than 11 mm and heights exceeding 100 cm in five months of experimentation, reflecting balanced nutrition and increased vegetative vigour. The use of biofertilisers made from rubber seed cakes is therefore a sustainable, economical, and environmentally responsible alternative for the production of plant material. It allows the valorization of a local by-product while reducing dependence on mineral fertilizers, fully in line with a circular and sustainable fertilization logic.

However, further research is still needed to specify the optimal methods of application of these biofertilisers, to assess their impact on the post-grafting phase, and to monitor the evolution of the fertility of the substrate. These investigations will consolidate the scientific basis for integrated fertilization in rubber cultivation and develop strategies for sustainable nutrient management in rubber orchards.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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