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Articles

Coppice management in *Eucalyptus*: a comparison between chemical and mechanical control of lateral sprouts

Manejo de talhadia em *Eucalyptus*: comparativo entre o controle químico e mecânico de brotações laterais

Pábulo Diogo de Souza[I], **Leandro Roberto da Cruz**[II], **Antônio dos Santos Júnior**[III], **Rinaldo Costa Félix**[I], **Leonardo David Tuffi Santos**[IV]

[I]Celulose Nipo-Brasileira S.A., Belo Oriente, MG, Brazil
[II]Instituto Federal de Educação, Ciência e Tecnologia de Mato Grosso, Sorriso, MT, Brazil
[III]Universidade do Estado de Minas Gerais, Ituiutaba, MG, Brazil
[IV]Universidade Federal de Minas Gerais, Montes Claros, MG, Brazil

ABSTRACT

The objective was to evaluate the growth of *Eucalyptus*, managed in a coppice system and subjected to either mechanical or chemical control of lateral sprouts. The trial was conducted in a commercial plantation of Celulose Nipo-Brasileira, located in the municipality of Belo Oriente – MG, Brazil, using the *Eucalyptus grandis* x *Eucalyptus urophylla* clone. The experimental design was arranged in randomized blocks with four repetitions. The experimental units consisted of plots with 64 eucalyptus plants spaced 3 m x 3.33 m. Sprout control was carried out either by manual removal with a digging tool or by applying glyphosate at doses of 360, 720, 1,080, or 1,440 g ha^{-1}. For the chemical control treatments, intoxication in the selected sprouts was assessed 15 days after herbicide application during early sprout thinning. For all treatments, height and diameter increments, and wood production, were measured at 72 months. Glyphosate intoxication was observed in the managed sprouts, and a reduction in wood production was noted, particularly at higher doses. The use of glyphosate for lateral sprout control reduces the growth and production of *E. grandis* x *E. urophylla* in a coppice system, especially when applied at high doses.

Keywords: Silviculture; Glyphosate; Forest production; Herbicide; Forest management

RESUMO

Objetivou-se avaliar o crescimento de *Eucalyptus*, conduzido em sistema de talhadia e submetido ao controle mecânico ou químico de brotações laterais. O ensaio foi desenvolvido em um plantio comercial da Celulose Nipo-Brasileira município de Belo Oriente – MG, Brasil, manejados em sistema de talhadia e composto pelo clone *Eucalyptus grandis* x *Eucalyptus urophylla*. O delineamento experimental foi disposto em blocos casualizados, com quatro repetições. As unidades experimentais foram compostas por parcelas de 64 plantas de eucalipto no espaçamento 3 m x 3,33 m. O controle das brotações foi realizado por meio de deslocamento com cavadeira ou aplicação de *glyphosate* nas doses de 360, 720, 1.080 ou 1.440 g ha^{-1}. Para os tratamentos com controle químico foi avaliada a intoxicação nos brotos selecionados na desbrota precoce aos 15 dias após a aplicação do herbicida. E para todos os tratamentos foram mensurados os incrementos em altura e diâmetro e a produção de madeira aos 72 meses. Foi observada intoxicação por *glyphosate* nos brotos manejados e houve diminuição da produção de madeira, principalmente nas doses mais altas. O uso de *glyphosate* para o controle de brotações laterais reduz o crescimento e produção de *E. grandis x E. urophylla* conduzido em sistema de talhadia, principalmente se utilizado em altas doses.

Palavras-chave: Silvicultura; *Glyphosate*; Produção florestal; Herbicida; Manejo florestal

1 INTRODUCTION

Planted forests are important sources of supply to meet the growing global demand for forest products. Globally, about 1.15 billion hectares are managed for the extraction of timber and non-timber products (FAO, 2020). Brazil is a global reference due to its high productivity in high-density, short-rotation stands, such as *Eucalyptus* forests (Ferraz Filho et al., 2014; Payn et al., 2015). The country has approximately 7.4 million hectares of *Eucalyptus* forests, representing 29% of the world's planted forests (Silva et al., 2020). This significance in the forestry sector is associated with Brazil's comparative advantages in terms of edaphoclimatic conditions and genetic improvement, as well as the refinement of silvicultural management techniques (Ramos et al., 2024).

In first-rotation *Eucalyptus* stands, after clear-cutting, it is common to conduct a second rotation of the stand through the adoption of the coppice system, which is very frequent in the reality of the Brazilian forestry sector (IBÁ, 2017; Drake et al., 2009). In this system, a new stand is formed by managing the sprouts to develop new stems.

The main advantage of coppicing is the reduction in forest production costs compared to stand renewal (Gadelha et al., 2015; Rode et al., 2015).

In the initial phase, *Eucalyptus* managed in a coppice system, even after early sprout thinning, exhibits a high emission of lateral sprouts that can compete for resources with the main sprout, hindering the production of wood in desirable dimensions for harvest (Ferraz Filho et al., 2014). In this context, silvicultural management is necessary to control these sprouts. Mechanical control using a digging tool is the primary method employed in the forestry sector.

The current scenario in the national agricultural sector has been facing difficulties in recruiting labor for fieldwork. Thus, the process of continuous improvement requires the development of alternatives to enable the implementation of silvicultural management. In this regard, the use of chemical weed control technologies may be an alternative for controlling lateral sprouts in *Eucalyptus* managed in a coppice system.

Glyphosate is a systemic herbicide from the glycine group and is commonly used for weed management in the forestry sector. Although it is not selective for *Eucalyptus*, it is unclear whether using this herbicide could be effective in controlling lateral sprouts while not negatively affecting the growth and production of *Eucalyptus* managed in a coppice system. Therefore, the objective of this research was to evaluate the growth and production of *Eucalyptus* in a coppice system, subjected to either mechanical or chemical control of lateral sprouts.

2 MATERIALS AND METHODS

The study was conducted in a commercial plantation area of Celulose Nipo-Brasileira, located in the municipality of Belo Oriente – MG, with 1.79 ha managed in a coppice system, using the *Eucalyptus grandis* x *Eucalyptus urophylla* clone. The region has an Aw climate classification, with an average annual precipitation of 1,108 mm and an average annual temperature of 23.8ºC (Beck et al., 2018).

Four months after the clear-cutting of the forest, the best sprout in terms of size and position was selected for each stump, and the remaining sprouts were eliminated through mechanical control using a digging tool. Six months after the clear-cutting of the stand, when the remaining sprouts averaged 2.6 m in height, the control methods proposed in this research were applied. These methods consisted of removal with a digging tool, application of four doses of glyphosate-based herbicide (360, 720, 1,080, 1,440 g a.e. ha^{-1}, respectively), and a control (maintenance of all sprouts). The experimental design was arranged in randomized blocks with four repetitions. The experimental units consisted of plots with an area of 640 m^2, containing 64 eucalyptus plants, spaced 3 m x 3.33 m, with a usable area of 360 m^2 and 36 central plants.

The application of glyphosate was targeted at the lateral sprouts. A backpack sprayer with a single boom equipped with a TTI110015 nozzle tip was used, maintaining constant working pressure through a regulator valve at 200 KPa, with an estimated spray volume of 100 L ha^{-1}.

Four months after the first control of the lateral sprouts, or 10 months after the clear-cutting of the stand, a second intervention was carried out using the same treatments in the corresponding plots.

2.1 Effectiveness of sprout control and intoxication in the main sprout

Fifteen days after the application of the treatments (DAA), the effectiveness of sprout control was evaluated for all proposed control methods. This procedure involved visually inspecting all stumps to determine whether lateral sprout control was effective. For the treatments subjected to glyphosate application, visual assessments of intoxication were conducted on the sprout being managed to form the new stem. These assessments involved assigning scores from 0 to 100 to each plant analyzed, where 0 indicated the absence of intoxication and 100 indicated death due to glyphosate intoxication (ALAM, 1974).

2.2 Evaluation of eucalyptus growth and productivity

At 4, 10, and 18 months after the first application of treatments, the height and diameter at breast height (DBH) at 1.3 m above ground level were measured for all plants. A continuous forest inventory was also conducted at 10, 18, 33, 46, 58, and 72 months of stand age. In all measurements, the adopted procedure was a census of height and DBH for all trees in the usable area of the plots.

2.2 Evaluation of eucalyptus growth and productivity

The data on the intoxication of the main sprout was subjected to analysis of variance ($p \leq 0.05$), and in the case of significant differences between treatments, a regression analysis was performed. This process was carried out using the stats package of the R Studio statistical program (R Core Team, 2022).

For each treatment, the measurements taken at 4, 10, and 18 months after the experiment's implementation were analyzed for the mean periodic increment values of the DBH and height variables, using analysis of variance. In the case of significant mean differences, the data were subjected to the Scott-Knott clustering test with the help of the *ExpDes.pt* package (Ferreira et al., 2013) in the R Studio software (R Development Core Team, 2022).

As for the continuous forest inventory data, growth and production analyses were performed. In this process, the relationship between volume and age was assessed by fitting the Prodan model without an intercept, Equation (1).

$$V = \frac{Id^2}{(Id\ b_1 + Id^2\ b_2)} \quad (1)$$

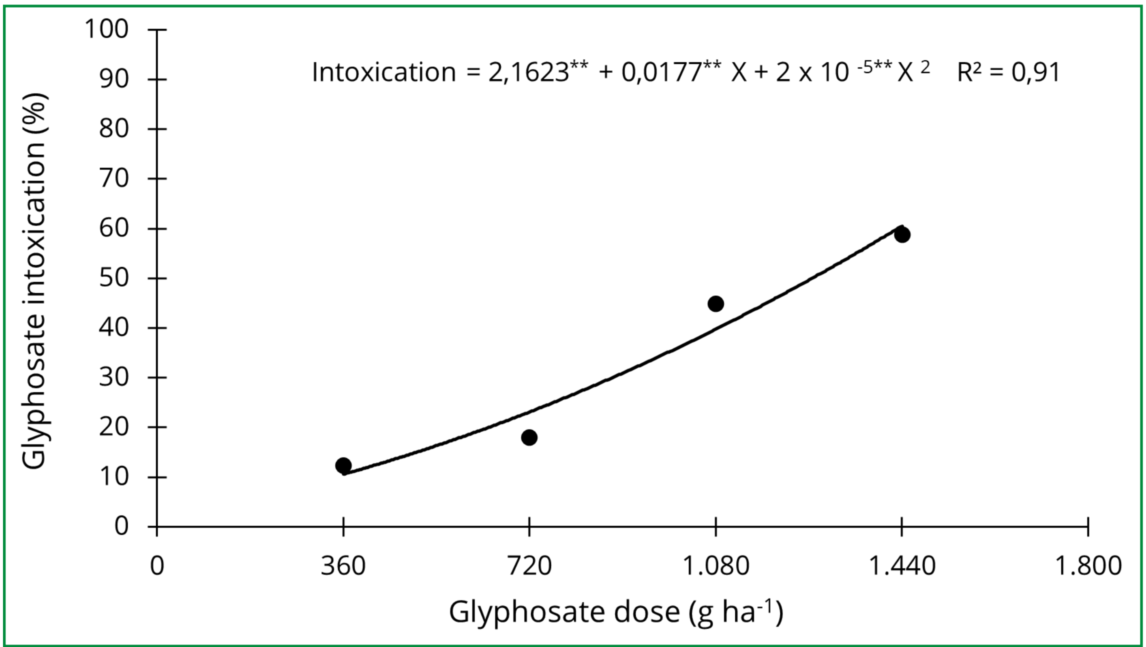
where: V = volume, in $m^3\ ha^{-1}$; Id = age, in months; b_i = coefficients of the model.

Growth curves were constructed and compared using the method proposed by Dette and Neumeyer (2001) (TN), which is similar to covariance analysis by Snedecor's method, as described by Schneider et al., (2009). However, the test applied in this research is not limited to linear models. These analyses were performed using the *fANCOVA* package (WANG, 2010) with the aid of the R Studio software (R Core Team, 2022).

3 RESULTS AND DISCUSSIONS

All methods were effective in controlling the lateral sprouts of *E. grandis* x *E. urophylla* in both interventions. However, the use of chemical control caused intoxication of the main sprout at 5 DAA, with averages ranging from 13% to 59% at doses of 360 and 1440 g ha^{-1} of glyphosate, respectively (Figure 1).

Figure 1 – Percentage of intoxication in the main sprout of *E. grandis* x *E. urophylla* 15 days after the application of glyphosate used for the control of unwanted sprouts in a coppice system



Source: Authors (2023)

In where: ** significant at $p < 0.01$.

Although the herbicide application was targeted at the lateral sprouts, intoxication occurred in the sprout selected to form the main sprout. This was directly proportional to the dose of herbicide used. This can be explained by the fact that, in the early growth stages, *Eucalyptus urograndis* is more sensitive to the action of the herbicide (Castro et al., 2019; Junior et al., 2020; Santos Junior et al., 2015).

The periodic height increment, referring to the interval between zero and four months after the first application of treatments, was influenced ($p \leq 0.05$) by the sprout control methods. The highest increment was observed in the plants subjected to mechanical control using a digging tool; however, this did not differ from the control and the treatment with 360 g ha^{-1} of glyphosate (Table 1). In subsequent evaluations, no significant differences in height increment were observed. This result indicates that at higher doses, lateral sprout control with glyphosate delays the initial growth of the main sprout of *E. grandis* x *E. urophylla.*

Table 1 – Height increment for *E. grandis* x *E. urophylla* after control of unwanted sprouts at measurement intervals of 0-120, 120-300, and 300-540 days after glyphosate application (DAA)

Treatments	Height increment (m)		
	0 - 120 DAA	120 - 300 DAA^{ns}	300 -540 DAA^{ns}
Control	3.22 a	5.99	4.51
Digging tool	3.17 a	6.39	4.57
360 g ha^{-1} of glyphosate	3.13 a	6.13	4.41
720 g ha^{-1} of glyphosate	3.07 b	6.65	4.30
1,080 g ha^{-1} of glyphosate	3.07 b	6.35	4.15
1,440 g ha^{-1} of glyphosate	2.93 b	6.23	4.27
Mean	3.10	6.29	4.37
Coefficient of variation (%)	19.85	5.58	9.83

Source: Authors (2023)

In where: Means followed by the same letter in the column do not differ from each other by the Scott-Knott test at 5% probability. ns = Not significant at 5% probability by the F-test.

As for diameter, no significant differences were observed between treatments for periodic increments in any of the analyzed periods. However, it was noted that plants subjected to control with 1,440 g ha^{-1} of glyphosate initially showed slightly smaller diameter increments. Over time, however, this difference was no longer observed (Table 2).

Table 2 – Diameter at breast height increment for *E. grandis* x *E. urophylla* after control of unwanted sprouts at measurement intervals of 0-120, 120-300, and 300-540 days after glyphosate application (DAA)

Treatments	**Height increment (m)**		
	120 - 300 DAA^{ns}	**120 - 540 DAA^{ns}**	**300 - 540 DAA^{ns}**
Control	3.69	6.54	2.74
Digging tool	3.73	6.5	2.77
360 g ha^{-1} of glyphosate	3.78	6.76	2.98
720 g ha^{-1} of glyphosate	3.82	6.85	2.83
1,080 g ha^{-1} of glyphosate	3.95	6.91	2.89
1,440 g ha^{-1} of glyphosate	3.66	6.36	2.61
Mean	3.77	6.64	2.79
Coefficient of variation (%)	4.33	5.34	5.12

Source: Authors (2023)

In where: ns = Not significant at 5% probability by the F-test.

The results obtained in the height increment evaluations are explained by the mode of action of glyphosate, which, in addition to causing intoxication symptoms, can interfere with plant growth by impairing protein synthesis, which is essential for growth (Santos Júnior et al., 2019). Furthermore, young plants are more susceptible to herbicide's effects, with the damage tending to be noticeable in the apical meristem. The lack of interference in diameter is justified by the fact that *Eucalyptus* exhibits slow diameter growth during the initial growth phase (Gonçalves et al., 2013). Machado et al. (2019) also found no significant differences in the diameter of *Eucalyptus grandis* at 12 and 24 months, planted at different spacings on the same site.

The Prodan model was suitable for estimating production as a function of age. The fit statistics and coefficients of the obtained equations are presented in Table 3.

Table 3 – Coefficients of the equations obtained for estimating the standing wood volume of *E. grandis* x *E. urophylla* managed in a coppice system and subjected to different methods of lateral sprout control

Treatment	*b1***	*b2***	AIC	R^2	Standard error
Control	0.19568	0.00156	236.36	0.95	15.36
Digging tool	0.18051	0.00165	253.78	0.91	20.96
360 g ha^{-1} of glyphosate	0.21836	0.00184	216.60	0.97	10.79
720 g ha^{-1} of glyphosate	0.21627	0.00138	250.65	0.92	19.82
1,080 g ha^{-1} of glyphosate	0.23277	0.00166	235.62	0.94	15.16
1,440 g ha^{-1} of glyphosate	0.23873	0.00152	259.24	0.87	23.11

Source: Authors (2023)

In where: AIC = Akaike Information Criterion. ** significant at $p<0.01$.

The Dette and Neumeyer (2001) test resulted in a TN value of 127.4 ($p<0.05$), indicating that at least one of the curves is statistically different from the others. The results suggested that, although the curves exhibit similar growth patterns, there is evidence to reject the nullity test, meaning they are statistically different from each other. This is justified by the rigor of the test (Miranda et al., 2015). The test was applied to all possible combinations of curve pairs (Table 4), and each treatment had its production estimated through its respective equation.

When comparing the mechanical control method (digging tool) with the chemical control using glyphosate (1,080 and 1,440 g ha^{-1}), the highest TN values were obtained. In contrast, comparing the treatments with chemical control methods yielded relatively low TN values. This indicates that these curves are the least different from each other (Miranda et al., 2015).

Figure 2 shows the volumetric growth curves for the evaluated treatments. It was observed that at 72 months, the digging tool method resulted in higher production compared to the other treatments. On the other hand, chemical control with the highest doses of glyphosate (1,080 and 1,440 g ha^{-1}) resulted in the lowest volumetric production.

Table 4 – Dette and Neumeyer (2001) test comparing the pairs of mean volume growth curves in *E. grandis* x *E. urophylla* subjected to different methods of lateral sprout control

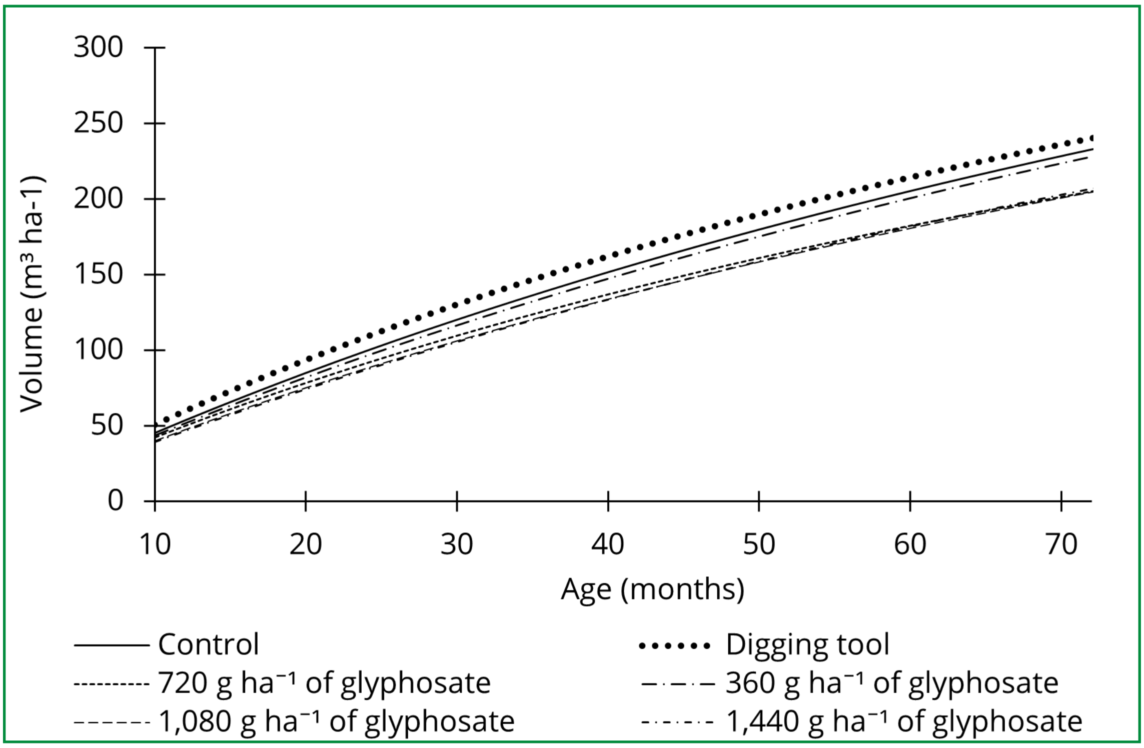
Treatment	T_N
Control – Digging tool	21.92*
Control - 360 g ha^{-1} of glyphosate	82.07*
Control - 720 g ha^{-1} of glyphosate	4.131*
Control – 1,080 g ha^{-1} of glyphosate	99.5*
Control – 1,440 g ha^{-1} of glyphosate	92.08*
Digging tool - 360 g ha^{-1} of glyphosate	171.9*
Digging tool - 720 g ha^{-1} of glyphosate	44.26*
Digging tool – 1,080 g ha^{-1} of glyphosate	205.9*
Digging tool – 1,440 g ha^{-1} of glyphosate	190.5*
360 g ha^{-1} of glyphosate - 720 g ha^{-1} of glyphosate	51.01*
360 g ha^{-1} of glyphosate – 1,080 g ha^{-1} of glyphosate	1.536*
360 g ha^{-1} of glyphosate – 1,440 g ha^{-1} of glyphosate	1.799*
720 g ha^{-1} of glyphosate – 1,080 g ha^{-1} of glyphosate	64.01*
720 g ha^{-1} of glyphosate – 1,440 g ha^{-1} of glyphosate	57.83*
1,080 g ha^{-1} of glyphosate – 1,440 g ha^{-1} of glyphosate	0.346*

Source: Authors (2023)

In where: * significant at $p<0.05$.

The difference between the growth curves of the digging tool control and the higher doses of glyphosate applied (1,080 and 1,440 g ha^{-1}) indicates that, even when targeted at lateral sprouts, the use of herbicide overdoses can negatively affect the growth of the sprout being managed and, consequently, reduce wood production at the end of the cycle. Under the experimental conditions of this study, it was observed that lateral sprout control using the digging tool resulted in higher wood production at 72 months compared to the glyphosate treatments, especially at the highest dose, where the difference was approximately 15%. Castro et al. (2019) used this herbicide at high doses for weed control in forest plantations and found that it reduced the dry matter gain of *Eucalyptus grandis* x *Eucalyptus urophylla* during the initial growth phase.

Figure 2 – Volumetric growth curves for *E. grandis* x *E. urophylla* managed in a coppice system and subjected to different methods of lateral sprout control



Source: Authors (2023)

The forestry sector requires the improvement of herbicide application techniques. In Brazil, chemical control using glyphosate has been recommended and used by companies in the sector at a dose of 720 g ha^{-1}. However, this research showed that under these experimental conditions, it is possible to reduce this input by 50% without compromising the early control efficiency of lateral sprouts. Montes et al. (2021) also achieved effective control of *Eucalyptus grandis* x *Eucalyptus urophylla* sprouts with the application of glyphosate.

Although the possibility of controlling lateral sprouts with glyphosate exists, it is important to note that even with a relatively low dose, the herbicide causes intoxication in the main sprout and impacts wood production.

4 CONCLUSIONS

The use of glyphosate for lateral sprout control induces intoxication during the initial growth phase of *Eucalyptus grandis* x *Eucalyptus urophylla* cultivated in a coppice system.

The use of glyphosate for lateral sprout control reduces the growth and production of *Eucalyptus grandis* x *Eucalyptus urophylla* managed in a coppice system, especially when used at high doses (1,080 and 1,440 g ha^{-1}).

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Authorship Contribution

1 Pábulo Diogo de Souza

Forest Engineer, Doctor in Forest Engineer

https://orcid.org/0000-0002-2446-8041 • pabulodiogo@gmail.com

Contribuition: Writing – original draft; Formal analysis; Writing – review & editing

2 Leandro Roberto da Cruz

Agronomist, Doctor in Crop Production

https://orcid.org/0000-0002-5673-6506 • leandrocruz2001@yahoo.com.br

Contribuition: Writing – original draft; Formal analysis; Investigation; Writing – review & editing

3 Antônio dos Santos Júnior

Agronomist, Doctor in in Phytopathology

https://orcid.org/0000-0002-5434-5034 • antonio_agronomia@yahoo.com.br

Contribuition: Writing – original draft; Investigation

4 Rinaldo Costa Félix

Biologist

https://orcid.org/0009-0009-5226-3754 • rinaldofelix@cenibra.com.br

Contribuition: Validation; Investigation

5 Leonardo David Tuffi Santos

Agronomist, Doctor in Phytopathology

https://orcid.org/0000-0002-9362-778X • ltuffi@ufmg.br

Contribuition: Supervision; Project administration; Writing – original draft

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