SOCIEDADE BRASILEIRA DA CIÊNCIA DAS PLANTAS DANINHAS
SBCPD
PLANTA DANINHA
<http://www.sbcpd.org>
ISSN 0100-8358 (print)
1806-9681 (online)

Article

Physiological Characteristics of Trees Recommended for the Phytoremediation of Soils Contaminated with Herbicides

Características Fisiológicas de Espécies Arbóreas Recomendadas na Fitorremediação de Solos Contaminados com Herbicidas

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ABSTRACT - Herbicides are inputs with a high volume of use in agricultural production systems for weed management; however, the environmental contamination they cause is a reality. The objective of this research was to evaluate the tolerance of tree species used for the phytoremediation of herbicides in the soil, to atrazine, clomazone and 2,4-D, through the evaluation of photosynthetic indices. Thus, a randomized block design experiment was conducted with four replications, in a 4 x 5 factorial arrangement, where the first factor represented the herbicides atrazine, clomazone and 2,4-D and the control treatment without herbicide (water). The second factor consisted in the use of pre-selected tree species for the phytoremediation of soils with residues of the products [*Eremanthus crotonoides* DC. (candeia), - *Richeria grandis* Vahl (richeria), *Protium heptaphyllum* (Aubl) Marchand, (breu-branco) *Kielmeyera latrophyton* Saddi, Kew Bull, (pau-santo) *Calophyllum brasiliense* Cambess (guanandi)]. The herbicides were applied through dishes placed under the culture containers of the plants, when they presented eight months of development. After 15 days from the herbicide application, the visual intoxication, stomatal conductance (Gs), transpiration rate (E), CO_2 concentration in the substomatal chamber (Ci), and water use efficiency (WUE) were evaluated. The herbicides affected differently the physiological characteristics of the tree species; atrazine was the most harmful product. Individuals under the effect of 2,4-D and clomazone presented lower variation for their physiological characteristics, compared to the respective control treatments. Breu-branco, despite showing low visual intoxication provided by the herbicides, was the most affected species by the products. On the other hand, candeia was the most tolerant species to the action of the herbicides.

Keywords: photosynthesis, visual intoxication, atrazine, clomazone, 2,4-D.

*RESUMO - Herbicidas são insumos com grande volume de utilização nos sistemas de produção agrícola para o manejo de plantas daninhas; no entanto, a contaminação ambiental causada é uma realidade. Objetivou-se com esta pesquisa avaliar a tolerância de espécies arbóreas fitorremediadoras de herbicidas no solo, aos herbicidas atrazine, clomazone e 2,4-D, através da avaliação de índices fotossintéticos. Dessa forma, um experimento em delineamento de blocos casualizados foi montado com quatro repetições, em esquema fatorial 4 x 5. O primeiro fator representou os herbicidas atrazine, clomazone e 2,4-D e o tratamento controle sem herbicida (água). O segundo fator consistiu no uso de espécies arbóreas pré-selecionadas para fitorremediação de solos com resíduos dos produtos [**Eremanthus crotonoides** DC. (candeia) - **Richeria grandis** Vahl (richéria), **Protium heptaphyllum** (Aubl) Marchand (breu-branco), **Kielmeyera latrophyton** Saddi,*

Received: March 29, 2017
Approved: June 13, 2017

Planta Daninha 2018; v36:e018177021

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Doi: 10.1590/S0100-83582018360100114

Kew Bull (pau-santo), ***Calophyllum brasiliense*** *Cambess (landi)]. Os herbicidas foram aplicados em pratos de contenção sob os recipientes de cultivo das plantas, quando estas apresentavam oito meses de desenvolvimento. Quinze dias após o termino da aplicação dos herbicidas, foram avaliadas a intoxicação visual, condutância estomática (Gs), taxa de transpiração (E), concentração de* CO_2 *na câmara subestomática (Ci), taxa fotossintética (A) e eficiência do uso da água (EUA). Os herbicidas afetaram de forma diferenciada as características fisiológicas das espécies arbóreas, sendo o atrazine o produto mais prejudicial. Indivíduos sob efeito de 2,4-D e clomazone apresentaram menor variação para as características fisiológicas, comparados às respectivas testemunhas. O breu-branco, apesar de mostrar baixa intoxicação visual proporcionada pelos herbicidas, foi a espécie mais afetada pelos produtos. De maneira contrária, a candeia foi a espécie mais tolerante à ação dos herbicidas.*

Palavras-chave: fotossíntese, intoxicação visual, atrazine, clomazone, 2,4-D.

INTRODUCTION

The herbicides are the agrochemicals with the highest application volume on plant production systems, accounting for 57.1% of the total amount sold in commercial products in 2012 (SINDAG, 2016). They are considered the main tool used in weed management due to their low cost, operational efficiency and high selectivity to crops (SINDAG, 2016).

A major problem faced by the use of herbicides is related to the environmental impacts caused by greater mobility residues, downstream from the application areas. Even when applied at technically recommended doses and with the correct technology, most molecules do not reach the target, and can be adsorbed to the soil or move within the environment. Herbicides have been a cause of concern in several areas of knowledge, since they have been causing adverse changes in the environmental quality (Melo et al., 2010).

The contamination degree of an herbicide in the environment is mainly related to its physical-chemical characteristics, which can determine its capacity of persisting in the soil and the contamination of non-target organisms (Spadotto, 2006). Some herbicide molecules, for being leachable, can reach forest species and be absorbed by the roots. This possibility of contact can occur due to the direct application in planting areas (between the furrows), on annual crops grown between tree species, intercropped or in bands, or by the residual effect together with the solution of groundwater coming from applications in areas downstream from agricultural fields.

Among the herbicides already reported as potential water contaminants due to their high potential for leaching and volatilization, there are atrazine, clomazone and 2,4-D. Atrazine belongs to the triazine group and is suitable for maize, controlling annual, broadleaf weeds. Clomazone, in turn, belongs to the chemical group of isoxazolidinones, and is widely used on cotton, rice, potato, sugarcane, among others, and acts by inhibiting the synthesis of carotenoids. Finally, 2,4-D, which is hormonal, is used for rice, maize, wheat, sugarcane and pastures (AGROFIT, 2015).

In this sense, the mitigation of the impacts of eventual herbicide residues in non-target areas, especially in the case of riparian zones, contributes favorably to the restoration of environmental quality (Gregory et al., 1991). Planting tree species that have phytoremediation potential for contaminated soils is a recovery alternative used in areas that have a compromised resilience (Resende et al., 2015). Recently, this practice has been proposed as a technological innovation in the remediation of areas with leachable residues of herbicides (Cabral and Santos, 2016; Fiore et al., 2016). Therefore, it is essential to search for information about the behavior of these plants when they are implanted in contaminated areas.

In studies about herbicide selectivity, it is fundamental to analyze the intoxications, as well as the effects on growth (Negrisoli et al., 2004; Galon et al., 2009). However, the damage caused by herbicides is often not apparent and the evaluation time is not enough for the poisoning caused by the product to occur (Ferreira et al., 2015). Thus, photosynthetic analyses can help understanding the development of plants in contaminated environments, because chlorophyll has high relation with the yield of plants (Smeal and Zhang, 1994).

From the few studies evaluating the potential of tree species to remedy sites with herbicide residues, atrazine and 2,4-D (Fiore, 2016) and the joint evaluation of atrazine, clomazone and 2,4-D stand out (Aguiar, 2015).

In the light of the aforementioned, the objective of this study was to evaluate the characteristics related to the photosynthetic activity of phytoremediating tree species (*candeia*, *richeria*, *breu-branco*, pau-santo and guanandi) on the sensitivity of these species when planted in soils contaminated with atrazine, clomazone and 2,4-D.

MATERIAL AND METHODS

The experiment was conducted in a nursery and a greenhouse belonging to the Faculdade de Ciências Agrárias da Universidade Federal dos Vales do Jequitinhonha e Mucuri, Diamantina - Minas Gerais campus. The seedlings used in the study were produced in the nursery of the Forest Engineering Department, and consisted in the forest species *candeia* - *Eremanthus crotonoides*, *richeria* - *Richeria grandis*, *breu-branco* - *Protium heptaphyllum*, pau-santo - *Kielmeyera latrophyton*, and guanandi - *Calophyllum brasiliense*. Approximately six months after being sown in a nursery, the seedlings were transplanted and cultivated in polyethylene pots with a volume capacity of 8 dm^3. The substrate used in the experiment consisted of a dystrophic Red Latosol, with sandy texture, and with 56.2% of sand, 36% of clay and 7.8% of silt, duly fertilized.

The experiment was implemented in a randomized block design, in a 4 x 5 factorial arrangement, with four replications. The first factor consisted in atrazine, clomazone and 2,4-D and soil without herbicide, and the second one consisted in the tree species, totaling 20 treatments and 80 experimental units.

Six applications of the herbicides atrazine, clomazone and 2,4-D were performed at 10 day intervals, each application corresponding to one third of the commercially recommended dose (AGROFIT, 2015): 2.5 kg ha^{-1}, 0.720 kg ha^{-1} and 0.806 kg ha^{-1}, respectively.

At 55 days after transplanting the seedlings and 15 days after the last herbicide application, physiological evaluations were carried out on the five tree species treated with herbicides. The evaluations were made on the last adult leaf in full physiological maturity (fourth to fifth leaf, counting from the apical bud to the lower end). The used equipment was an ADC infrared gas analyzer (IRGA), model LCA PRO (Analytical Development Co. Ltd, Hoddesdon, UK). The stomatal conductance (Gs - mol m^{-1} s^{-1}), transpiration rate (E - mol H_2O m^{-2} s^{-1}), CO_2 concentration in the substomatal chamber (Ci - µmol mol^{-1}), photosynthetic rate (A - µmol m^{-2} s^{-1}) and water use efficiency (WUE = A/E - mol CO_2 mol H_2O^{-1}) were determined. These evaluations were carried out between 7 and 9 am on a clear day and with artificial lighting of 1,200 µmol m^{-2} s^{-1}, so that the homogeneous environmental conditions were maintained during open house vegetation evaluations, allowing the free movement of air. Grades on visual intoxication were also given, varying from 0 to 100%, where values close to 0% indicate the absence of herbicide effects and 100% indicates plant death.

The obtained data were transformed in percentage in relation to the control treatment, since they are different species and, therefore, with different developmental characteristics. The variables presented in the study were photosynthetic rate percentage (A%), stomatal conductance percentage (Gs%), internal carbon percentage (Ci%), transpiration rate percentage (E%) and water use efficiency percentage (WUE%).

Subsequently, the analysis of variance was performed, and the means between the species under the effect of each herbicide, when significant, were submitted to the Tukey's test at 5% of error probability.

RESULTS AND DISCUSSION

Data were significant, and interaction between species and tested herbicides was observed; thus, each independent variable was unfolded. Tree species submitted to atrazine showed a reduction in the percentage of the photosynthetic rate (A%), being breu-branco and guanandi the species most negatively affected by the herbicide (Table 1). Atrazine has a direct action on

Table 1 - Photosynthetic rate (A - %) of tree species (candeia, richeria, breu-branco, pau-santo and guanandi) subjected to the application of herbicides

Herbicide	Photosynthetic rate / A - % (μmol m^{-2} s^{-1})				
	Specie				
	Candeia	Richeria	Breu-branco	Pau-santo	Guanandi
Control treatment	100.00 A (16.77)	100.00 A (10.84)	100.00 A (10.49)	100.00 A (10.83)	100.00 A (9.19)
Atrazine	76.97 a B	70.88 a B	25.33 b B	65.86 a B	33.89 b B
Clomazone	118.82 a A	46.32 b B	57.83 b B	114.71 a A	106.11 a A
2,4-D	119.41 a A	66.32 b B	57.41 b B	102.71 a A	120.09 a A
CV (%)	17.95				

Means followed by the same letter, lowercase on the line and uppercase in the column, do not differ from each other by Tukey's test at 5% of error probability. Numbers in parentheses refer to gross values.

the photosynthetic apparatus, inhibiting the transport of electrons from photosystem II to photosystem I (Ross and Childs, 1996); thus, the reduction in the photosynthetic rate occurs rapidly in plants that are sensitive to this herbicide.

Atrazine is easily absorbed by roots and leaves; its intoxication symptoms in tree species are characterized by foliar chlorosis followed by necrosis, beginning with the leaf edges. When used in post-emergence, intoxication symptoms may appear in a restricted form or be more pronounced at the contact points of the herbicide with the leaves. It is worth mentioning that, in this work, the absorption of atrazine by the tree species occurred through the root system. There is the possibility of a reduction in the photosynthesis by the plant, leading to a decrease in growth, which corresponds to the intensity of the intoxication suffered by it on the leaf blade (Barela and Christoffoleti, 2006).

Clomazone provided a reduction in the photosynthetic rate (A%) of richeria and breu-branco species, and these decreases were higher than 50%. In the other species, an increase in this variable was observed. Candeia and pau-santoshowed an increase of A% by 18.82% and 14.71%, respectively, differing from the other treatments for clomazone (Table 1). Clomazone acts specifically on younger leaves, inhibiting the production of carotenoids. However, in this work, the evaluations were performed on adult leaves; this may explain the reduced effect of this herbicide on the species candeia, pau-santoand guanandi. In sensitive species, the A% reduction may be due to the photo-oxidation of carotenoids or to the lack of them (Bramley and Pallet, 1993). Clomazone is translocated from the roots to the leaves, inhibiting the formation of other carotenoids (Brauman et al., 2007) which are responsible for protecting chlorophyll from light. Carotenoids indirectly influence the production of chlorophyll, since, in the absence of them, it undergoes degradation and, consequently, there is a fall in the photosynthetic rate.

As for 2,4-D, it was verified that richeria and breu-branco presented lower values of A% with the presence of the product, with decreases of approximately 35% and 40%, respectively (Table 1). On the other hand, candeia had an increase in the photosynthetic rate with the presence of this herbicide. Considering that plants were submitted to low doses of 2,4-D, which has a similar effect to auxin, a hormone linked to plant growth, it is possible that low doses of the product stimulated the growth of more tolerant species.

When evaluating the effect of the herbicides within each species, it was verified that the photosynthetic rate of candeia plants was negatively affected by atrazine, differing from the other treatments. Clomazone and 2,4-D promoted an increase of approximately 18% in the A% of candeia plants. All the tested herbicides promoted a reduction in the photosynthetic rate of richeria and breu-branco plants, differing from the plots without herbicide application. Pau-santoand guanandi showed a reduction in the mean values of A% when submitted to the application of atrazine, differing from the other treatments. The photosynthetic rate evaluated in the plots without herbicide application ranged from 16.77 to 9.19 μmol m^{-2} s^{-1} among the five species, with the highest photosynthetic rate (Table 1).

Atrazine, clomazone and 2,4-D adversely affected the stomatal conductance (Gs%) of all the evaluated species, especially breu-branco, which showed the greatest reductions in the values of this variable with the presence of atrazine, differing from candeia and richeria. Different species present variations in quantity, size, distribution and shape of the stomata, which, in turn, interfere with their photosynthesis. The behavior of stomata is also influenced by abiotic conditions (Larcher, 1986). In stress situations, such as under the effect of herbicides, plants promote the closure of their stomata in order to avoid water loss, leading to increased resistance and consequently reducing stomatal conductance (Taiz and Zeiger, 2013). In breu-branco and pau-santo plants, a Gs% reduction was observed, differing from the other species treated with clomazone and 2,4-D (Table 2).

The absolute values of stomatal conductance in the control treatments were 0.34 mol m^{-1} s^{-1} for candeia, 0.48 mol m^{-1} s^{-1} for richeria and 0.45 mol m^{-1} s^{-1} for breu-branco. As for pau-santoand guanandi, these values were 0.48 and 0.29 mol m^{-1} s^{-1}, respectively. Candeia plants presented greater Gs% reduction under the effect of atrazine. All the other evaluated species were negatively affected by atrazine, clomazone and 2,4-D (Table 2).

Breu-branco showed the lowest average values of internal carbon percentage (Ci%), without, however, differing from candeia and pau-santowhen submitted to atrazine. It is interesting to highlight that richeria, pau-santoand guanandi plants treated with atrazine showed an increase of approximately 49%, 32%, and 109%, respectively, in Ci% values (Table 3). The internal carbon has an indirect relation with the consumption of CO_2 and the photosynthetic rate; thus, lower photosynthetic rates are related to the increase of the internal carbon, that is, to a lower consumption of CO_2.

Table 2 **-** Stomatal conductance (Gs - %) of tree species (candeia, richeria, breu-branco, pau-santo and guanandi) submitted to the application of herbicides

Herbicide	Stomatal conductance (Gs - %) (mol m^{-1} s^{-1})				
	Specie				
	Candeia	Richeria	Breu-branco	Pau-santo	Guanandi
Control treatment	100.00 A (0.34)	100.00 A (0.48)	100.00 A (0.45)	100.00 A (0.48)	100.00 A (0.29)
Atrazine	83.77 a B	82.16 a B	41.64 b B	51.99 ab B	55.63ab B
Clomazone	92.69 a AB	67.81 ab B	40.41 bc B	22.77 bc B	29.28 c B
2,4-D	96.14 a A	89.52 a B	33.90 b B	33.64 b B	29.98 b B
CV (%)	32.02				

Means followed by the same letter, lowercase on the line and uppercase in the column, do not differ from each other by Tukey's test at 5% of error probability. Numbers in parentheses refer to gross values.

Table 3 **-** Internal carbon (Ci - %) of tree species (candeia, richeria, breu-branco, pau-santo and guanandi) submitted to the application of herbicides

Herbicide	Internal carbon (Ci - %) (μmol mol^{-1})				
	Specie				
	Candeia	Richeria	Breu-branco	Pau-santo	Guanandi
Control treatment	100.00 A (342.58)	100.00 B (224.39)	100.00 A (390.49)	100.00 B (125.20)	100.00 B (192.07)
Atrazine	111.75 b A	149.12 a A	99.22 b A	132.10 b A	208.88 a A
Clomazone	85.49 b B	133.61 b A	98.70 b A	209.04 a A	117.41 b B
2,4-D	87.56 b B	154.17 a A	99.26 b A	182.13 a A	112.11b B
CV (%)	26.71				

Means followed by the same letter, lowercase on the line and uppercase in the column, do not differ from each other by Tukey's test at 5% of error probability. Numbers in parentheses refer to gross values.

Clomazone provided negative effects on the Ci% of candeia and breu-branco, with a reduction in the values of this variable by 15% and 2%, respectively; on the other hand, breu-branco showed a 109% Ci% increase in relation to the control treatment. 2,4-D negatively affected the percentage of other treatments (Table 3).

When evaluating the effect of the herbicides within each tree species in terms of Ci%, it was verified that candeia and guanandi plants were negatively affected by clomazone and 2,4-D. As for the richeria, breu-branco and pau-santospecies, no differences were observed as for Ci% between herbicide and control treatments (Table 3).

Plants treated with atrazine showed a reduction in the values of the transpiration rate (E%), which were lower than 100%, emphasizing that the species that had been most negatively affected by atrazine was breu-branco. Clomazone and 2,4-D provided higher reductions of E% in breu-branco and verawood, while 2,4-D promoted an 11.25% increase in the E% of guanandi (Table 4).

Table 4 **-** Transpiration rate (E - %) of tree species (candeia, richeria, breu-branco, pau-santo and guanandi) subjected to the application of herbicides

Herbicide	Transpiration rate (E - %) ($mol\ H_2O\ m^{-2}\ s^{-1}$)				
	Specie				
	Candeia	Richeria	Breu-branco	Pau-santo	Guanandi
Control treatment	100.00 A (3.89)	100.00 A (4.33)	100.00 A (5.03)	100.00 A (5.41)	100.00 A (3.27)
Atrazine	98.39 a A	81.03 a A	41.56 b B	51.47 ab B	55.05 ab B
Clomazone	93.05 a A	66.87 ab A	40.34 b B	29.39 b B	95.64 a A
2,4-D	96.51 a A	76.49 ab A	33.84 b B	43.57 b B	111.25 a A
CV (%)	36.68				

Means followed by the same letter, lowercase on the line and uppercase in the column, do not differ from each other by Tukey's test at 5% of error probability. Numbers in parentheses refer to gross values.

Stomatal closure reduces perspiration, and stomatal conductance is responsible for the CO_2 inflow and water outflow through the stomata; the lower its opening, the greater the stomatal resistance and, consequently, the decrease in perspiration (Taiz and Zeiger, 2013). Auxinic herbicides can act on the stomatal closure through lower water absorption by the root system (Machado et al., 2006), reducing leaf turgescence and leading the plant to reduce water losses with the stomatal closure. It is worth mentioning that breu-branco and pau-santoshowed a reduction in the values of the transpiration rate when treated with 2,4-D, which were approximately 65%. However, guanandi showed an increase by approximately 11% in the transpiration rate, which shows different effects from 2,4-D on the evaluated species. Breu-branco and guanandi showed different strategies regarding the herbicide effect: while the former showed a decrease in the photosynthetic rate and a reduction in transpiration, the latter showed an increase in these variables (Tables 1 and 4). It is also important to note that guanandi showed higher values of visual intoxication by 2,4-D (Table 6).

The species candeia and richeria did not show E% variation among the treatments. Breu-branco and pau-santoshowed a reduction in the mean values of this variable under the effect of the tested herbicides, emphasizing that clomazone was the product that most negatively affected the E% of these two species. Guanandi presented the lowest E% values when submitted to the application of atrazine, differing from the other treatments (Table 4).

Water use efficiency is characterized as the amount of water transpired by a species to produce a certain amount of dry matter. In case of measurements with IRGA (infrared gas analysis), the efficiency in the use of water is given by the photosynthetic/transpiration rate ratio. Thus, crops that are more efficient in the use of water can produce greater amounts of dry matter per gram of transpired water. Atrazine promoted a greater reduction of the mean values of water use efficiency percentage in the plots cultivated with guanandi, differing from the other treatments. However, clomazone and 2,4-D negatively affected the WUE% of richeria, highlighting that, for these two herbicides, WUE% values were higher than 100% in the other tested species (Table 5). There was a correlation between the high WUE% and the higher accumulation of dry matter of these species (data not shown).

Table 5 **-** Water use efficiency (WUE - %) of tree species (candeia, richeria, breu-branco, pau-santo and guanandi) submitted to the application of herbicides

Herbicide	Water use efficiency (EUA - %) ($mol\ CO_2\ mol\ H_2O^{-1}$)				
	Species				
	Candeia	Richeria	Breu-branco	Pau-santo	Guanandi
Control treatment	100.00 B (4.36)	100.00 A (4.01)	100.00 B (2.04)	100.00 B (2.09)	100.00 A B (4.00)
Atrazine	78.62 a C	59.39 ab B	79.31 a C	92.40 a B	42.65 b C
Clomazone	131.11 b A	43.96 c B	165.70 b A	281.51 a A	126.87 b A
2,4-D	123.67 b A	68.64 c B	182.57 a A	160.17 a A	93.91 c B
CV (%)	40.83				

Means followed by the same letter, lowercase on the line and uppercase in the column, do not differ from each other by Tukey's test at 5% of error probability. Numbers in parentheses refer to gross values.

Candeia and breu-branco showed an increase in WUE values when submitted to the application of clomazone and 2,4-D, differing from plots cultivated without herbicides: it is worth mentioning that atrazine provided a WUE% reduction in these two species. Richeria showed a reduction of the WUE average values in the three evaluated herbicides. Pau-santoplants treated with clomazone and 2,4-D showed an increase in WUE% values, differing from the other treatments. Atrazine, on the other hand, resulted in a reduction of WUE% in verawood. As for guanandi, WUE% was higher in plants treated with 2,4-D (Table 5). The water use efficiency is influenced by the type of carbon metabolism that the species possesses, as well as the characteristics of the related stomata, mainly quantity and opening, as well as the leaf appearance (Silveira et al., 2012).

Atrazine provided greater visual intoxication (PVI) in guanandi, reaching 47%. Under the effect of clomazone, the highest intoxication was observed in candeia. The herbicide 2,4-D affected guanandi more negatively, with PVI levels of 67.50% (Table 6).

Table 6 **-** Plant visual intoxication (PVI) on tree species (candeia, richeria, breu-branco, pau-santo and guanandi) submitted to the application of herbicides, 15 days after the sixth application

Herbicide	Plant visual intoxication PVI - %				
	Species				
	Candeia	Richeria	Breu-branco	Pau-santo	Guanandi
Atrazine	15.00	23.75	7.50	10.00	47.00
Clomazone	1.05	45.00	12.50	15.00	67.50
2,4-D	11.25	0.00	2.50	0.00	0.00

Candeia was the species that showed the lowest effects on its physiological characteristics when under the effect of the three herbicides, emphasizing that this species showed low levels of visual intoxication for the tested products. Thus, this species was more tolerant to the three products when considering the physiological aspects, which makes it promising for its use in phytoremediation projects of soils with herbicide residues.

Monteiro Aguiar (2016), working with eight tree species on soils contaminated with atrazine, clomazone and 2,4-D, verified that all the species evaluated during the experiment underwent some degree of intoxication, but some recovered from the symptoms. Tolerance, at more advanced stages, may be related to the increase of agents capable of detoxifying the plant, through reactions such as hydroxylation, dealkylation and conjugation (Silva et al., 2007). In this sense, the lower physiological effect in candeia plants submitted to the application of atrazine may be due to the decrease of intoxication over time. Some species detoxify this product through the conjugation process, making it possible not to present injuries (Oliveira Jr, 2011).

Atrazine, clomazone and 2,4-D affected differently the physiological characteristics of the evaluated tree species. Atrazine was the product that most negatively affected the species; 2,4-D and clomazone showed lower effects on their physiological characteristics.

Although breu-branco showed low visual intoxication provided by the herbicides, it was the species that showed the greatest negative effect on the studied physiological variables, whereas candeia was the least affected. It is worth mentioning that candeia was the most tolerant species to the tested herbicides, considering the physiological aspects.

ACKNOWLEDGMENTS

To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), for their financial support in conducting this study.

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