Floresta e Ambiente 2018; 25(3): e20170465
https://doi.org/10.1590/2179-8087.046517
ISSN 2179-8087 (online)

Original Article

Silviculture

Phytoremediation Capacity of Forest Species to Herbicides in Two Types of Soils

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Abstract

The present study aimed to evaluate the potential of forest species for herbicide phytoremediation. The experiment was conducted in a greenhouse with a randomized block design and a 2x3x3 factorial scheme, using two soils (Red-Yellow Latosol - RYL and Quartzarenic sandy soil - QN), three herbicide solutions (without herbicides/water, 2,4-D and atrazine), and three forest species (*Cecropia hololeuca, Eucalyptus grandis* x *Eucalyptus urophylla* and *Hymenea coubaril*), with four replications. After the experiment, *Cucumis sativus* was cultivated in order to investigate possible herbicide residues in the soils. The evaluated forest species reduced atrazine and 2,4-D residues in most treatments, except for the *Jatobá* (*Hymenaea coubaril*) cultivated in the RYL soil. Eucalyptus was the species that showed the greatest tolerance to herbicide action, demonstrating the potential for phytoremediation of atrazine and 2,4-D. *Cecropia hololeuca* and *Hymenaea coubaril* presented the greatest potential for 2,4-D and atrazine, respectively.

Keywords: leaching, eucalyptus, *Jatobá*, *Embauba*.

1. INTRODUCTION

The State of Mato Grosso is an important contributor to national grain production. Studies have shown that the state is the largest national producer, representing approximately 24% of soy production in 2016 (IBGE, 2016). On the other hand, it is known that adequate management of pests, diseases and weeds is necessary in order to obtain high yields. In this context, there has been an increase in pesticide use in the region. Of these, herbicides stand out, which are chemicals that act by killing or suppressing weed development (Oliveira, 2011).

After application, herbicides can be absorbed by the aerial part of plants or reach the soil. When they reach the soil, redistribution and breakdown processes occur, which can be a short process in the case of simple, non-persistent molecules, or last for months or years for persistent compounds (Filizola et al., 2002). According to Pires et al. (2003), when the product remains for longer periods in the soil without being adsorbed by colloids, degraded and/or mineralized, the possibility of leaching is greater.

Molecules that present characteristics such as high profile displacement potential (leaching), high persistence, low to moderate water solubility and moderate adsorption by organic matter have contaminating potential of water resources (Almeida et al., 2006). Atrazine and 2,4-D are among the herbicides that are potentially capable of leaching.

Atrazine belongs to the triazine class and is classified as a selective and systemic herbicide that acts on inhibiting photosynthesis for the control of broadleaf-weeds. It is widely used in agriculture due to its low cost. It is a potential water contaminant due to its high potential for mobilization in relation to other molecules, high persistence in soils, slow hydrolysis, low to moderate solubility in water and moderate adsorption by organic matter and clay (Cerdeira et al., 2005; Arantes & Lima, 2006).

2,4-D is a hormonal latifolicide of the synthetic auxin group, which is highly efficient in controlling broad-leafed weeds (Rodrigues & Almeida, 2005), presenting moderate persistence in soils (Amarante et al., 2002). According to Primel et al. (2005), this herbicide has low potential for surface water contamination; however, it has the potential to contaminate underground water.

Intense use of these herbicides has been a significant source of contaminating water bodies by run-off and percolation throughout the soil profile (leaching) (Correia & Langenbach, 2006), not only threatening water resources, but also ecosystem integrity (Ludovice et al., 2003).

When considering the sustainability of agricultural systems, phytoremediation represents an important tool to be investigated, as it is a technique that accelerates the breakdown of these molecules in the environment, allied to the biodiversity and favorable climatic conditions in Brazil.

Since not all plant species can develop in contaminated environments, the first step is to identify species that, in addition to being adapted to local conditions, can tolerate the contaminant. Therefore, it is desirable that the species used present characteristics such as rapid growth, high biomass production, competitiveness, vigor and tolerance to pollution (Lamego & Vidal, 2007).

In the particular case of leachable herbicides such as atrazine and 2,4-D, a more promising proposal is rizofiltration, which consists in the adsorption or precipitation of the contaminant from an aqueous medium through the roots of tree species (Gratão et al., 2005) with deep-root systems developed downstream from agricultural areas, preferably near or contained in barriers in riparian forests. According to Santos et al. (2010) and Souto et al. (2013), the breakdown of these organic molecules can be facilitated by releasing root exudates that stimulate microbial activity in the soil.

Therefore, the objective of the present study was to evaluate the potential of forest species as herbicide phytoremediators.

2. MATERIAL AND METHODS

The experiment was carried out at the greenhouse of the Federal University of Mato Grosso (*UFMT*), in the municipality of Sinop/MT, Brazil.

Seedlings of three forest species were used: a eucalyptus hybrid (*Eucalyptus grandis X Eucalyptus urophylla)* referred to as clone H-13, *Embaúba* (*Cecropia hololeuca*) and *Jatobá* (*Hymenaea coubaril*) in the initial phase of growth between 06 to 08 months of age, purchased from a commercial nursery located in the municipality of Sinop-MT.

Two soil types were used as substrate: a clay texture Red-Yellow Latosol (RYL) and a sandy texture Quartzarenic sandy soil (QN). Collection was performed from the superficial layer of 0-20 cm of depth in two areas with no history of herbicide application, both in the municipality of Sinop/MT. Soil samples were air dried and passed through a 4 mm mesh sieve. The samples were subsequently separated and sent to the laboratory for chemical and physical analyses (Tables 1 and 2) where soil correction was initially performed, followed by fertilization after the limestone reaction (three months), according to recommendations by Malavolta (1980).

The seedlings were transplanted into polyethylene pots and the herbicide treatments (atrazine, 2,4-D and water) were applied after a period of 60 days. The recommended herbicide dose (atrazine and 2,4-D) was divided into three stages (at 60, 81 and 102 days after seedlings transplantation) in order to simulate the leached compound, totaling 1.24 $\mu L\ kg^{-1}$ and 3.3 $\mu L\ kg^{-1}$ of soil, respectively. The applications were carried out using micropipettes directly applied into the containment plates placed below the pots, with the purpose of simulating water absorption by the plant roots from an underground source contaminated by these herbicides. Irrigation was performed via the containment plates throughout the experiment, not exceeding their field capacity.

The growth and development variables evaluated were: stem diameter (SD) two centimeters away from the soil, measured with the aid of a pachymeter; plant height (PH), measured with a ruler from the stem base up to the insertion of the last leaf, the number of leaves (NL), chlorophyll *a* and *b* content (Cl*a* and Cl*b*) collected with the aid of a Falker® chlorophyll meter; and phytotoxicity (%) of the plants at 7, 14 and 21 days after each herbicide application. At the end, wet and dry shoot biomass (WSB and DSB) and root dry biomass (DRB) were determined.

The phytotoxicity evaluation was carried out visually according to the methodology and the score classification adapted from EWRC (1964). Phytotoxicity score classification was: score 1 (absence of phytointoxication); 1.5 (very mild); 2 (mild); 2.5 (moderate); 3 (average); 3.5 (almost strong); 4 (strong); 4.5 (very strong) and 5 (plant death).

For the wet and dry biomass assessment, the plants were sectioned at the stem base, separating them into shoot and roots, and then weighed and dried in a forced ventilation oven at 65°C for approximately 72 hours until reaching constant mass.

After removal of the forest species, the soil was turned and cucumber (*Cucumis sativus*) was planted to indicate the presence of atrazine and 2,4-D residues in the soil. Thirty (30) days after planting the bioindicator species, stem diameter (SD), plant height (PH), number of leaves (NL), chlorophyll *a* and *b* (Cl*a* and Cl*b*) and plant phytotoxicity were evaluated.

The experimental design was in randomized blocks according to a 2x3x3 factorial design corresponding to two soils (Red-Yellow Latosol and Quartzarenic Neosol), three forest species (*Cecropia hololeuca, Eucalyptus grandis x Eucalyptus urophylla* and *Hymenea coubaril*) and three herbicide solutions (atrazine, 2,4-D and water), with four replicates.

Data referring to the growth characteristics of the forest species were transformed into a percentage in relation to control, considering that they are different species with different developmental characteristics. The results were subsequently submitted to analysis of variance using the SISVAR program (Ferreira, 2011), and the means were submitted to the Tukey test at 5% probability when significant.

Table 1. Chemical properties of Red-Yellow Latosol (RYL) soil and Quartzarenic sandy soil - QN.

Soil	pH	P	K	Ca	Mg	Al	H	BS	T	V	O.M
	H_2O	mg dm^{-3}			-------------- cmolc dm^{-3} --------------					%	g dm^{-3}
RYL	5.10	1.44	33.0	1.21	0.43	0.25	5.36	1.72	7.33	23.49	30.09
QN	4.40	1.02	14.0	0.13	0.07	0.60	3.53	0.24	4.37	5.51	16.56

BS: base sum; T: CTC potential; V%: base saturation and O.M: organic matter.

Table 2. Physical properties of Red-Yellow Latosol soils - RYL, and Quartzarenic sandy soil - QN.

Soil	Sand	Silt	Clay	Textural class
	--------------------g kg^{-1}----------------------			
RYL	404	142	454	Clay soil
QN	842	79	79	Sandy soil

3. RESULTS AND DISCUSSION

3.1. Assessment of phytoremediation potential of forest species

Atrazine and 2,4-D herbicides caused phytotoxicity symptoms in all species studied. However, the intensity of the symptoms varied for each species.

The eucalyptus hybrid was the most tolerant species to herbicidal action, since it presented the lowest phytotoxicity at the end of the experiment for both treatments, corresponding to 20.31% for 2,4-D and 23.44% for atrazine, respectively (Table 3).

The symptoms caused by 2,4-D were characterized by shrinkage, chlorosis, epinasty, necrosis and leaf fall, leading to the death of some plants; these symptoms are characteristic of auxinic herbicides. Oliveira (2011), states that the first obvious symptom of hormonal herbicide damage in broadleaf plants is epinasty of leaves and petioles.

The highest degree of phytotoxicity was more pronounced after the first evaluation in *Hymenaea coubaril* seedlings, with 70.31% damage at the end of the experiment (Table 3).

The high phytointoxication means in *Hymenaea coubaril* plants submitted to the 2,4-D resulted in the death of some seedlings in this treatment. The reason for the low tolerance to this herbicide may be related to this species belonging to a successional group of late secondary species to climax (Costa et al., 2011), as these are late-growth species which take longer to establish, and therefore are more susceptible. The same was observed by Fiore (2014) who evaluated the potential of forest species to remediate substrate contaminated with 2,4-D, finding that the species with the lowest tolerance to this herbicide belonged to the secondary group.

The symptoms caused by the atrazine herbicide were characterized by chlorosis followed by necrosis. Chlorosis started between the leaf ridges and the leaf edges, progressing towards the center and later into generalized necrosis; symptoms similar to those observed by Dias (2015). These phytointoxication symptoms were more evident in *Cecropia hololeuca* seedlings, as they caused the greatest damage (51.56%) in the species 14 days from the first application (Table 3). However, in *Hymenaea coubaril* plants, new leaves emerged as older ones necrosed, indicating a certain tolerance to this herbicide evidenced by the survival of all the seedlings at the end of the experiment.

Bicalho et al. (2007) claim that *Cecropia hololeuca* is a species with phytoremediation potential for atrazine, since it presents tolerance and biodegradation mechanisms for the herbicide, and can be used in revegetation projects in order to speed up the soil decontamination process through phytoremediation, thereby protecting surface and subsurface waters.

Table 3. Phytotoxicity means observed in *Embaúba (Cecropia hololeuca)*, Eucalyptus and *Jatobá (Hymenaea coubaril)* seedlings at 7, 14 and 21 days after each of the three applications of 2,4-D and atrazine herbicides.

	1st APPLICATION		2nd APPLICATION		3rd APPLICATION	
	2,4 – D	ATRAZINE	2,4 - D	ATRAZINE	2,4 - D	ATRAZINE
7 DAYS						
Embaúba	3.13 bA	6.25 aA	23.44 bB	37.50 aA	20.31 bB	50.00 aA
Eucalyptus	0.00 bA	0.00 aA	9.38 cA	6.25 cAB	17.19 bA	12.50 cA
Jatobá	20.31 aA	6.25 aB	45.31 aA	25.00 bB	65.63 aA	29.69 bB
14 DAYS						
Embaúba	6.25 bAB	12.50 aA	23.44 bB	45.31 aA	18.75 bB	46.875 aA
Eucalyptus	6.25 bA	4.69 aA	10.94 cA	7.81 cAB	20.31 bA	17.19 cA
Jatobá	37.50 aA	7.81 aB	56.25 aA	26.56 bB	70.31 aA	35.94 bB
21 DAYS						
Embaúba	7.81 bB	26.56 aA	21.88 bB	50.00 aA	23.44 bB	51.56 aA
Eucalyptus	7.81 bA	4.69 bA	10.94 cA	7.81 cAB	20.31 bA	23.44 cA
Jatobá	43.75 aA	7.81 bB	62.50 aA	29.69 bB	70.31 aA	39.06 bB

Means followed by the same upper case letter along the lines and the same lower case letters in the column do not differ by Tukey test at 5% significance.

In relation to the 2,4-D herbicide, *Cecropia hololeuca* had a higher tolerance, given that lower phytotoxification (23.44%) was observed in comparison to atrazine (51.56%), showing a stabilization in phytotoxication symptoms after the second application. *Cecropia hololeuca* and eucalyptus seedlings presented similar visual phytotoxicity symptoms after the third application.

All *Cecropia hololeuca* and eucalyptus seedlings survived the presence of atrazine and 2,4-D molecules. The fact that these species belong to the group of pioneers, are faster growing, have a more developed root system and greater nutrient absorption capacity than secondary plants (Poggiani & Schumacher, 2004) ensures these seedlings perform better in the first months, therefore explaining this result.

When comparing the species in each treatment, it was possible to verify that eucalyptus was the species that presented the best results for all analyzed growth and development variables for 2,4-D, followed by *Cecropia hololeuca*. For atrazine, *Hymenaea coubaril* was the species with the best performance, followed by eucalyptus (Table 4).

In general, the best results were observed for growth and development variables in eucalyptus seedlings, since no significant differences were found between the treatments, except for DRB (Table 4).

Table 4. Growth and development variables for *Cecropia hololeuca*, eucalyptus and *Hymenaea coubaril* submitted to an application of atrazine and 2,4-D compared to their respective controls (100%).

Treatments	*EMBAÚBA*	EUCALYPTUS	*JATOBÁ*
		SD (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	91.31 aAB	98.08 aA	78.58 bB
Atrazine	84.72 bB	98.73 aA	106.32 aA
		PH (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	88.07aB	101.54 aA	69.64 bC
Atrazine	96.44 aAB	93.88 aB	108.69 aA
		NL (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	80.03 abA	92.08 aA	43.06 bB
Atrazine	73.57 bB	82.65 aAB	104.38 aA
		Cl *a* (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	92.87 aA	98.87 aA	74.96 bB
Atrazine	81.90 bB	95.71 aA	96.29 aA
		Cl *b* (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	87.55 aA	93.80 aA	71.30 bB
Atrazine	64.22 bB	89.29 aA	91.09 aA
		WSB (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	78.96 aAB	98.21 aA	33.59 bB
Atrazine	66.54 aA	84.11 aA	98.25 aA
		DSB (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	70.31 aAB	98.01 aA	41.16 bB
Atrazine	53.65 aB	80.18 aA	99.83 aA
		DRB (%)	
Control	100.00 aA	100.00 aA	100.00 aA
2,4-D	91.05 abAB	98.70 aA	101.46 aA
Atrazine	58.22 bB	62.98 bB	107.49 aA

SD: Stem diameter; PH: plant height; NL: number of leaves; Cl *a*: chlorophyll *a* content; Cl *b*: chlorophyll *b* content; WSB: wet shoot biomass; DSB: dry shoot biomass; and DRB: dry root biomass. Means followed by the same uppercase letters in the line and the same lowercase letters in the column do not differ according to the Tukey test at 5% significance level.

Cecropia hololeuca seedlings were directly affected by the atrazine herbicide in terms of stem diameter (SD), number of leaves (NL), Chlorophyll *a* and *b* content and dry root biomass (DRB), and less strongly affected by 2,4-D herbicide in relation to NL and DRB (Table 4).

Bicalho et al. (2007) reported that *Cecropia hololeuca* plants were able to translocate and accumulate 29 ± 9% of the ^{14}C atrazine applied, mainly accumulating it in its leaves. *Hymenaea coubaril* presented standard behavior for all growth and development variables studied, except for DRB, with a reduction of these parameters in the presence of 2,4-D. According to Oliveira (2011), auxinic herbicides are translocated both via phloem and xylem, and can therefore control the growth of several perennial plants.

Further, according to Oliveira (2011), higher 2,4-D herbicide concentrations inhibit cell division and growth, usually in the meristematic regions, which accumulate both assimilates from photosynthesis and the herbicide carried by the phloem. This has mainly been observed in *Hymenaea coubaril*, followed by *Cecropia hololeuca*, being directly reflected in WSB and DSB. *Cecropia hololeuca* and eucalyptus both underwent DRB reduction when submitted to atrazine (Table 4).

Chlorophyll *a* and *b* content was lower in plants submitted to herbicide treatments, although the difference was only significant for *Cecropia hololeuca* and *Hymenaea coubaril* submitted to atrazine and 2,4-D, respectively (Table 4). This response demonstrated stress symptoms, which can be confirmed by the appearance of leaves with signs of chlorosis and necrosis resulting from chlorophyll loss.

Regarding the evaluated soils, overall the SD, PH, NL, WSB and Cl *b* of the three forest species were higher in RYL in all treatments (Figure 1).

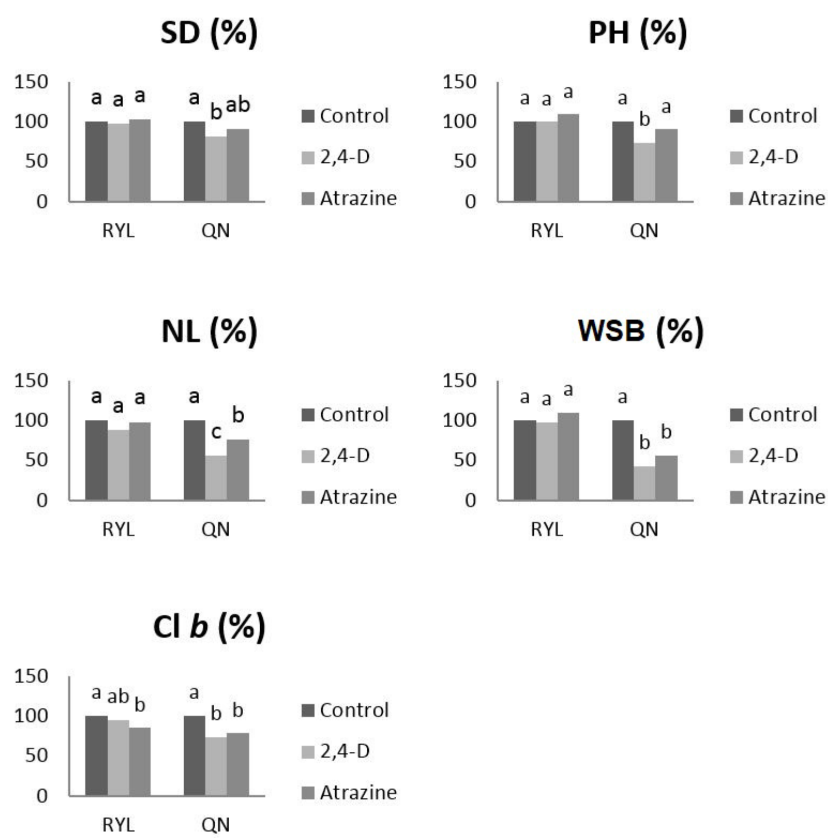

Figure 1. Growth and development variables stem diameter (SD), plant height (PH), number of leaves (NL), chlorophyll *b* content (CL *b*), Wet shoot biomass (WSB) of forest species in the Red-Yellow Latosol clay soil - RYL and Quartzarenic sandy soil - QN. Means followed by the same letter for each treatment did not differ from one another by Tukey test at 5% significance level.

The growth and development variables of the evaluated species did not change with herbicide application in the RYL soil, except for chlorophyll *b*. In the QN soil, 2,4-D reduced all evaluated variables, while atrazine reduced NL, WSB and CL *b* (Figure 1).

The difference in damage between the species in terms of soil type is possibly due to the lower clay (Table 2) and organic matter (Table 1) content in the QN soil, which implies a greater availability of herbicide in the soil solution. The literature has evidenced the close relationship between soil texture and organic matter content with the retention of 2,4-D (Vieira et al., 1999; Silva et al., 2011), as well as atrazine (Jenks et al., 1998; Vasconcelos, 2007).

Figure 2 shows higher *Hymenaea coubaril* and eucalyptus growth in the RYL soil, corroborating the previously presented results.

3.2. Evaluation of herbicide residues in the soils

The cucumber plants showed greater growth and development in the pots that previously contained *Hymenaea coubaril* cultures in comparison with the other species studied in both RYL and QN. This can be generally observed for all evaluated characteristics (Table 5).

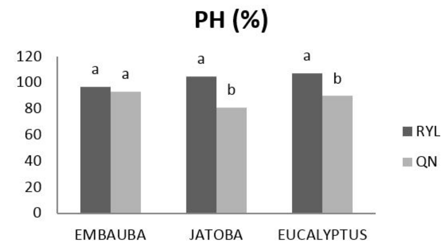

Figure 2. Plant height (PH %) in relation to the forest species. Means followed by the same letters for the soils (Red-Yellow Latosol soil - RYL and Quartzarenic sandy soil - QN), did not differ from one another by Tukey test at 5% significance level.

Table 5. Cucumber (*Cucumis sativus*) growth and development variables 30 days after planting, grown in soil with and without atrazine and 2,4-D application, previously cultivated with forest species.

Previous species:	RYL			QN		
	Control	2,4-D	ATRAZINE	Control	2,4-D	ATRAZINE
			SD			
Embaúba	0.42 c	0.47 b	0.47 b	0.44 c	0.40 c	0.36 c
Eucalyptus	0.58 b	0.49 b	0.58 a	0.56 b	0.55 b	0.49 b
Jatobá	0.85 a	0.65 a	0.68 a	0.68 a	0.70 a	0.66 a
			PH			
Embaúba	21.37 b	25.66 b	28.80 b	21.85 b	16.78 b	12.93 b
Eucalyptus	35.18 b	26.03 b	38.13 b	35.75 ab	29.14 b	35.50 ab
Jatobá	111.31 a	65.87 a	83.33 a	55.39 a	74.18 a	57.35 a
			NL			
Embaúba	7.50 b	7.00 b	8.50 b	7.50 a	6.25 b	6.25 b
Eucalyptus	9.00 b	7.75 b	9.00 b	9.00 a	7.75 b	7.00 b
Jatobá	15.50 a	11.00 a	13.00 a	9.50 a	11.75 a	9.50 a
			Cl *b*			
Embaúba	6.60 b	6.58 a	6.43 b	7.60 a	7.63 a	6.75 a
Eucalyptus	8.90 b	9.75 a	9.43 ab	7.75 a	6.18 a	6.75 a
Jatobá	13.10 a	10.00 a	10.73 a	5.60 a	7.90 a	6.93 a
			WSB			
Embaúba	8.45 b	9.23 b	11.62 b	5.90 b	4.72 b	3.55 b
Eucalyptus	14.95 b	10.68 b	20.22 b	7.70 b	12.63 b	8.27 b
Jatobá	66.00 a	30.33 a	44.59 a	25.35 a	36.02 a	26.63 a
			DSB			
Embaúba	1.05 b	1.21 b	1.42 b	0.72 b	0.63 b	0.52 b
Eucalyptus	1.75 b	1.23 b	2.30 b	0.77b	1.37 b	1.49 ab
Jatobá	6.15 a	3.08 a	4.37 a	2.50 a	4.13 a	2.67 a

SD: stem diameter; PH: plant height; NL: number of leaves; Cl *b*: Chlorophyll *b* content; WSB: wet shoot biomass; DSB: dry shoot biomass. Means followed by the same lowercase letter in the column do not differ according to the Tukey test at 5% significance level.

These results may be related to the ecological succession of *Hymenaea coubaril*, which due to being a secondary species, presents slow growth and a less developed root system, possibly using less soil nutrients in comparison with pioneer species (*Cecropia hololeuca* and eucalyptus), and providing better development of cucumber plants. Gonçalves et al. (1992) and Furtini et al. (2000), claim that the species corresponding to the initial successional stages (pioneers) have greater capacity for nutrient absorption than those of the following successional (secondary) stages, a trait closely related to growth potential, greater development and density of fine roots, as well as greater potential in biomass synthesis rate.

Regarding SD, PH, NL, Cl *b*, WSB and DSB, plants from pots previously cultivated with *Hymenaea coubaril* presented standard behavior in which the RYL control was superior with 2,4-D and atrazine treatments, indicating the presence of herbicide residues in these pots (Figure 3). However, with the exception of DSB, no significant differences were observed for the QN soil.

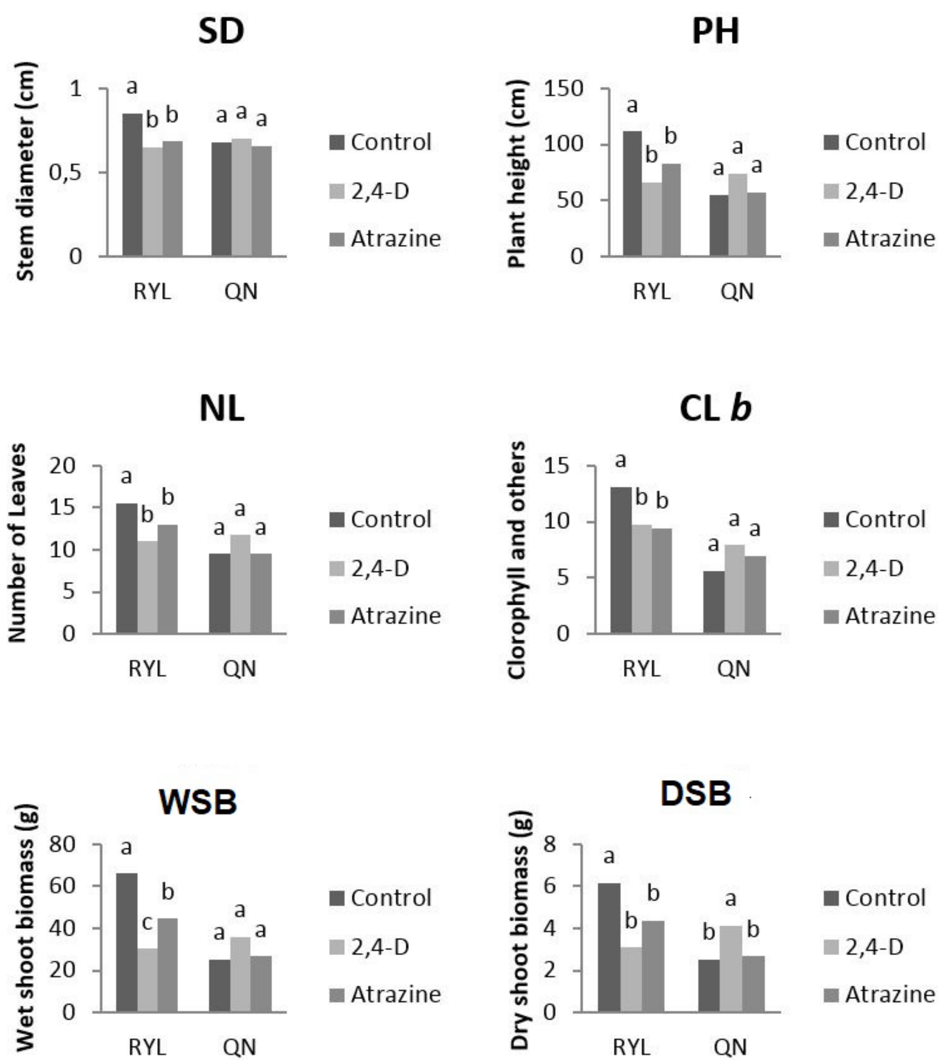

Figure 3. Stem diameter (SD), plant height (PH), number of leaves (NL), chlorophyll *b* content (CL *b*), Wet shoot biomass (WSB) and dry shoot biomass (DSB) of cucumber planted in pots previously cultivated with *Hymenaea coubaril*, in Red-Yellow Latosol soil - RYL and Quartzarenic sandy soil - QN. Means followed by the same letter for each treatment did not differ from each other by the Tukey test at 5% significance level.

This result may have been due to the fact that the herbicides were more available in the QN soil, resulting in higher absorption by the *Hymenaea coubaril* seedlings with less herbicides left in the pots, while the herbicides in RYL may have been more absorbed by soil colloids, thereby not being readily available for tree species to absorb.

Thus, we observed that previous cultivation of the tree species helped to reduce atrazine and 2,4-D residues in most treatments, since the phytotoxification of cucumber plants grown in soils where herbicide application had occurred did not significantly differ from the control, with the only exception being for the cucumber cultivated after *Hymenaea coubaril* in RYL soil.

4. CONCLUSION

- Eucalyptus species presented the best tolerance to atrazine and 2,4-D actions. This does not exclude the potential of the other species for use in phytoremediation programs, since all species tolerated the action of these products.
- The evaluated species have the potential for further study regarding the phytoremediation technique, especially *Cecropia hololeuca* and *Hymenaea coubaril* species in relation to areas contaminated with 2,4-D and atrazine, respectively, and eucalyptus for both herbicides;
- *Cecropia hololeuca* and eucalyptus presented phytoremediation capacity for atrazine and 2,4-D, both in Red-Yellow Latosol and in the Quartzarenic Neosol soils. *Hymenaea coubaril* presented the highest phytoremediation potential for both herbicides in the Quartzarenic Neosol soil.

SUBMISSION STATUS

Received: 15 aug., 2017
Accepted: 31 aug., 2017

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