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Original Article

Silviculture

Herbicide Selectivity In Eucalyptus Influenced By Spraying Nozzles

Luiz Eduardo Silva[1], Caio Montenegro[1], Renato Baboza Moura[1], Saymon Acchile[1], Hermeson Santos Vitorino[2], Lauricio Endres[1], Renan Cantalice de Souza[1]

[1]Centro de Ciências Agrárias, Universidade Federal de Alagoas – CECA/UFAL, Rio Largo/AL, Brasil
[2]Campus Professor Barros Araújo, Universidade Estadual do Piauí – UESPI, Picos/PI, Brasil

ABSTRACT

The objective of this study was to verify the influence of spraying nozzles on the selectivity of herbicides in eucalyptus seedlings. XR 110.02 and TTI 110.02 spraying nozzles were used for the application of the herbicides: control treatment; oxyfluorfen (150 g ha^{-1}) and saflufenacil (98 g ha^{-1}). The experimental arrangement was a 2 × 3 factorial one (two spraying nozzles × 3 herbicides), using a randomized complete block design with four replications. The application was performed 15 days after transplanting the seedlings. Plant height (PH), stem diameter (SD), number of leaves (NL), total dry matter (DM), leaf area (LA), visual phytotoxicity (P), quantum efficiency of photosystem II - Fv/Fm, electron transport rate (ETR) and SPAD (S) index were evaluated. The XR 110.02 and TTI 110.02 nozzles did not change the selectivity of oxyfluorfen and saflufenacil.

Keywords: application technology, phytotoxicity, chlorophyll a fluorescence.

1. INTRODUCTION

Eucalyptus can be used in the most diverse segments of the economy, from construction, energy production, cellulose, and furniture industry to cosmetics, among other purposes (Wilcken et al., 2008). Commercial planting for industrial purposes in Brazil totaled 7.74 million hectares in 2014, a 1.8% increase in relation to the previous year. This total corresponds to only 0.9% of the Brazilian territory. The Brazilian sector of planted trees accounts for 91% of all wood produced for industrial purposes in the country – the remaining 9% comes from legally managed native forests. Eucalyptus plantations occupy 5.56 million hectares of forest plantations in the country, representing 71.9% of the total, and are located mainly in the states of Minas Gerais (25.2%), São Paulo (17.6%) and Mato Grosso do Sul (14.5%). In the northeast region, the state of Bahia is in the fourth place in planted area, with 630,808 ha (IBA, 2015).

Similarly to other cultivated species, forest species are influenced by a variety of ecological factors that directly or indirectly affect the yield of trees. These factors can be biotic or abiotic, and within the biotic factors the interferences caused by weeds lead to productivity losses. To avoid losses caused by weeds in forest cultivations, it is necessary to adopt control methods with the use of herbicides for larger areas (Pitelli, 1987; Agostinetto et al., 2010).

Chemical control is characterized by advantages such as less labor dependence, control of vegetative propagation weeds, non-tillage of the soil, and they can be applied during weed pre- and post-emergence (Gelmini, 1998). However, it is worth highlighting that, due to the scarcity of products registered in relation to eucalyptus for the post-emergence selective control of weeds, the use of chemical control should be very cautious, avoiding injury and loss of productivity due to drifting (Tiburcio et al., 2012). Therefore, there is the need to use efficient pre-emergence products with long residual power and that are selective for weed control in eucalyptus.

Selectivity depends on the interaction of a number of factors such as herbicide formula, applied dose, application modality, cultivar, plant age, seed and seedling size, translocation rate, applied molecule metabolism and also application technology (Oliveira et al., 2011). The application technology of pesticides aims at reaching the target in the most efficient and economical way, by putting the right amount of active ingredient without affecting the environment (Matthews, 2002).

In the light of the aforementioned, this work aimed at evaluating the selectivity of herbicides applied in pre-emergence according to the chosen spraying nozzle.

2. MATERIAL AND METHODS

The experiment was conducted in a greenhouse located at the Centro de Ciências Agrárias of the Universidade Federal de Alagoas (CECA-UFAL) (latitude 09°28’ S, longitude 35°49’ W, altitude 127 m), in the municipality of Rio Largo, Alagoas, from November 2014 to July 2015.

The meteorological variables collected during the experimental period were registered in an automatic station, located in the CECA/UFAL. The maximum and minimum air temperature averages were approximately 35.1 °C and 20.7 °C, respectively; the mean air relative humidity was 77.4%.

The experiment was conducted in a randomized complete block design in a 2 × 3 factorial arrangement, where the factors were, respectively, spraying nozzles (XR 110.02 and TTI 110.02) × herbicides (oxyfluorfen at 150.0 g ha^{-1}, saflufenacil at 98.0 g ha^{-1} and one control treatment, with no application) with four replications. The experimental units were pots with five liters of capacity, filled with substrate (sieved soil). The chemical characteristics of the substrate used in the experiments are presented in Table 1.

VC865 eucalyptus clones from the crossing between *Eucalyptus urophylla* and *Eucalyptus grandis* were used in the study. The seedlings acquired for the experiment were standardized, presenting 4 to 5 pairs of leaves, measuring approximately 20 cm in height, aged three months.

Pots were weighed and standardized to have a constant weight. Periodic irrigations were performed so that the pots remained with approximately 80% of their field capacity during the entire experimental period.

The application of the herbicides was carried out 15 days after transplanting the seedlings, using a CO_2 pressurized backpack sprayer equipped with a two-nozzle

Table 1. Chemical analysis of the substrate used in the experiment about herbicide selectivity to eucalyptus seedlings according to the spraying nozzles.

Soil chemical analysis	
pH (in water)	6.20
Na (mg dm^{-3})	46.00
P (mg dm^{-3})	80.00
K (mg dm^{-3})	147.00
Ca + Mg (cmol$_c$ dm^{-3})	6.00
Ca (cmol$_c$ dm^{-3})	4.50
Mg (cmol$_c$ dm^{-3})	1.50
Al (cmol$_c$ dm^{-3})	0.03
H + Al (cmol$_c$ dm^{-3})	3.58
S (Base sum)	6.61
Effective C.C.E.	6.60
C.C.E. (pH 7.0)	10.18
% V	64.60
% M	0.50
% Na (PST)	2.00
Sat. in K (%)	3.80
Total Org. Mat. (%)	3.31
Iron (mg dm^{-3})	181.70
Copper (mg dm^{-3})	0.90
Zinc (mg dm^{-3})	5.50
Manganese (mg dm^{-3})	17.70

bar, spaced 0.5 m apart, operating at 220 Kpa, adjusted to a spraying volume equivalent to 220 L ha^{-1}.

Applications were performed between 06:00 and 08:00 a.m., when the conditions of temperature and humidity (20 °C and 80%, respectively) and wind speed were ideal for a good application result (Silva & Silva, 2007). After the application, seedlings remained protected from the rain in a greenhouse for 12 hours, to avoid the removal of the herbicides from the leaves.

The phytotoxicity of the herbicides was determined through visual evaluations of the eucalyptus clone seedlings, with intervals of 3, 7, 15, 30 days after application (DAA), using a scale developed by EWRC (1964), with grades varying from 1 to 9, where 1 implies the absence of any injury and 9 the death of the seedlings.

Chlorophyll fluorescence measurements were performed at intervals of 1, 2, 3, 7, 15, 30, 45 DAA with the aid of a PAM-2500 portable fluorometer with modulated amplitude (Walz, Effeltrich, Germany) and the WinControl® program. Readings were standardized on the second expanded leaf from the apex in all plots. In order to determine the maximum quantum yield of FSII (Fv/Fm), there was a 30-minute wait for the adaptation of the leaves to the dark.

In addition to this, a light curve was also generated by the fluorometer to determine the maximum electron transport rate (Etrmax). It was constructed with the following light intensities: 0, 11, 26, 56, 97, 169, 283, 443, 651, 971 and 1,531 μmol m^{-2} s^{-1}. Each lighting period lasted 10 seconds (Kalaji et al., 2014).

The intensity of the green color was determined with the SPAD index (Soil Plant Analysis Development), at intervals of 1, 2, 3, 7, 15, 30, 45 DAA, performed with a portable Konica Minolta SPAD-502 chlorophyll meter) at six points on the same leaf used to determine the chlorophyll fluorescence variables.

Biometric evaluations of plant height (PH), stem diameter (SD) and number of leaves (NL) were performed in the following periods: 1, 7, 15, 30, 45 DAA. In order to determine the number of leaves, they were counted when fully expanded. Plant height was measured in centimeters with the aid of a ruler, based on a permanent mark made on the stem at one centimeter from the ground level until the insertion of the youngest leaf. The stem diameter (SD) was measured with the aid of a Digimess digital caliper.

The leaf area of each plant was quantified in square centimeters (cm^2) using a bench leaf area meter, model LI 3100, LI-COR, inc. Lincoln, Nebraska, USA, at 45 DAA of herbicides.

Then, each plant was oven dried at 60 °C for 72 hours until reaching constant weight, in order to determine the total dry matter per plant by weighing on a precision scale.

The obtained data were submitted to analysis of variance to detect possible effects of the treatments on the analyzed variables, using the software SISVAR (Ferreira, 1998) version 5.3, and right after, the Tukey's Test was applied ($P < 0.05$). The values of the scores attributed for visual phytotoxicity were transformed through their square root. Light curve data were reported as means ± standard error.

3. RESULTS AND DISCUSSION

When observing the visual effects of herbicide application with different spraying nozzles, it was noticed that there was a greater intensity of visual phytotoxicity in the seedlings at 3 DAA, and that these events ended at 30 DAA. The effects were more accentuated with saflufenacil and the TTI 110.02 spraying nozzle (Table 2).

The results obtained in this study with clone VC865 in relation to saflufenacil resemble those of Pereira et al. (2011), who evaluated the intoxication of *Eucalyptus urograndis* in relation to saflufenacil

Table 2. Visual phytotoxicity, SPAD, Fv/Fm, and ETRmax of eucalyptus seedlings after application of herbicides with different spraying nozzles.

Spraying nozzles	CONTROL TR.		OXIFLUORFEN		SAFLUFENACIL	
			Phytotoxicity* 3 DAA			
XR 110.02	1.00	A a	1.25	A a	3.00	A a
TTI 110.02	1.00	A a	1.75	A a	4.50	A b
CV%			**17.68**			
			Phytotoxicity* 7 DAA			
XR 110.02	1.00	A a	1.00	A a	2.50	A a
TTI 110.02	1.00	A a	1.25	A a	3.75	B b
VC%			**9.82**			
			Phytotoxicity* 15 DAA			
XR 110.02	1.00	A a	1.00	A a	1.50	A a
TTI 110.02	1.00	A a	1.25	A a	2.50	B b
VC%			**7.73**			
			Phytotoxicity* 30 DAA			
XR 110.02	1.00	A a	1.00	A a	1.00	A a
TTI 110.02	1.00	A a	1.00	A a	1.00	A a
VC%			**0.01**			
			SPAD 1 DAA			
XR 110.02	39.08	A a	42.90	A a	40.50	A a
TTI 110.02	42.83	A a	40.90	A a	40.95	A a
VC%			**10.52**			
			SPAD 2 DAA			
XR 110.02	36.75	A a	39.55	A a	43.55	A a
TTI 110.02	38.00	A a	37.78	A a	42.60	A a
VC%			**10.39**			
			SPAD 3 DAA			
XR 110.02	35.40	A a	40.58	A a	45.10	A a
TTI 110.02	39.40	A a	36.05	A a	42.00	A a
VC%			**13.68**			
			SPAD 7 DAA			
XR 110.02	34.83	A a	32.80	A a	40.23	A a
TTI 110.02	39.35	A a	36.30	A a	44.45	A a
VC%			**15.69**			
			SPAD 15 DAA			
XR 110.02	30.45	A a	27.55	A a	27.18	A a
TTI 110.02	31.98	A a	29.93	A a	32.43	A a
VC%			**14.73**			
			SPAD 30 DAA			
XR 110.02	27.15	A a	27.50	A a	26.15	A a
TTI 110.02	29.08	A a	28.70	A a	27.85	A a
VC%			**14.31**			

Averages followed by the same uppercase letter in the rows and lowercase in the columns do not differ statistically by Tukey's test ($p \geq 0.05$); * phytotoxicity data were transformed using $\sqrt{X}$.

Table 2. Continued...

Spraying nozzles	CONTROL TR.		OXIFLUORFEN		SAFLUFENACIL	
			SPAD 45 DAA			
XR 110.02	22.20	A a	23.50	A a	20.80	A a
TTI 110.02	23.18	A a	23.98	A a	21.05	A a
VC%			**9.56**			
			Fv/Fm 1 DAA			
XR 110.02	0.790	A a	0.795	A a	0.761	A a
TTI 110.02	0.784	A a	0.799	A a	0.785	A a
VC%			**4.7**			
			Fv/Fm 2 DAA			
XR 110.02	0.795	A a	0.812	A a	0.773	A a
TTI 110.02	0.810	A a	0.806	A a	0.769	A a
VC%	4.70					
			Fv/Fm 3 DAA			
XR 110.02	0.810	A a	0.810	A a	0.706	A a
TTI 110.02	0.807	A a	0.811	A a	0.784	A a
VC%			**9.99**			
			Fv/Fm 7 DAA			
XR 110.02	0.814	A a	0.808	A a	0.816	A a
TTI 110.02	0.808	A a	0.814	A a	0.814	A a
VC%			**0.91**			
			Fv/Fm 15 DAA			
XR 110.02	0.804	A a	0.806	A a	0.803	A a
TTI 110.02	0.805	A a	0.807	A a	0.808	A a
VC%			**1.03**			
			Fv/Fm 30 DAA			
XR 110.02	0.794	A a	0.791	A a	0.757	A a
TTI 110.02	0.789	A a	0.792	A a	0.793	A a
VC%			**2.76**			
			Fv/Fm 45 DAA			
XR 110.02	0.759	A a	0.756	A a	0.750	A a
TTI 110.02	0.733	A a	0.744	A a	0.750	A a
VC%			**4.14**			
			ETRmax 1 DAA			
XR 110.02	157.88	A a	181.30	A a	154.08	A a
TTI 110.02	145.45	A a	198.60	A a	153.23	A a
VC%			**30.85**			
			ETRmax 2 DAA			
XR 110.02	153.68	A a	139.25	A a	120.68	A a
TTI 110.02	134.13	A a	129.50	A a	125.65	A a
VC%			**20.12**			
			ETRmax 3 DAA			
XR 110.02	127.43	A a	120.55	A a	92.43	A a
TTI 110.02	138.43	A a	120.53	A a	118.00	A a
VC%			**25.38**			
			ETRmax 7 DAA			
XR 110.02	123.78	A a	107.93	A a	142.00	A a
TTI 110.02	135.75	A a	118.85	A a	137.00	A a
VC%			**22.80**			

Averages followed by the same uppercase letter in the rows and lowercase in the columns do not differ statistically by Tukey's test ($p \geq 0.05$); * phytotoxicity data were transformed using $\sqrt{X}$.

Table 2. Continued...

Spraying nozzles	CONTROL TR.		OXIFLUORFEN		SAFLUFENACIL	
			ETRmax 15 DAA			
XR 110.02	98.00	A a	89.45	A a	95.83	A a
TTI 110.02	96.30	A a	77.95	A a	74.78	A a
VC%	17.16					
			ETRmax 30 DAA			
XR 110.02	72.75	A a	78.73	A a	60.85	A a
TTI 110.02	95.83	A a	92.20	A a	76.08	A a
VC%			**24.77**			
			ETRmax 45 DAA			
XR 110.02	62.90	A a	75.63	A a	54.88	A a
TTI 110.02	61.28	A a	68.60	A a	67.60	A a
VC%			**21.19**			

Averages followed by the same uppercase letter in the rows and lowercase in the columns do not differ statistically by Tukey's test ($p \geq 0.05$); * phytotoxicity data were transformed using $\sqrt{X}$.

applications with and without adjuvant. The authors verified a marked visual effect up to 21 DAA, with total recovery at 56 DAA. In relation to oxyfluorfen application, this study resembles the results of Ribeiro & Oliveira (1987) with the soil application for *Eucalyptus camaldulensis*, where these species were highly tolerant and did not present phytotoxicity.

Despite the appearance of visual effects following the applications, these were generally considered as small alterations, according to the EWRC scale (EWRC, 1964); this was probably the cause of not having significant difference in the SPAD variable, which expresses the intensity of the green color (Table 2).

It was possible to observe the same for the physiological variables with Fv/FM and Etrmax, where there were no significant differences between spraying nozzles and herbicides (Table 2). The use of physiological variables has been a very useful tool to detect changes even before the appearance of visual events. Among these, the use of chlorophyll fluorescence to quantify stresses of various origins stands out (Baker, 2008). The Fv/FM values for C3 plants under optimum conditions are around 0.83, but conditions that cause stress in plants can lead to a decline of this variable values (Kalaji et al., 2014).

The light curves for both spraying nozzles reinforce what was observed for phytotoxicity grades with saflufenacil, promoting a significant reduction of the ETR in the first hours of application in relation to the control treatment, and with later recovery in larger intervals after application (Figures 1 and 2).

Oxyflourfen and saflufenacil are herbicides that act by inhibiting the activity of the protoporphyrinogen oxidase IX (PROTOX) enzyme, which catalyzes the conversion of protoprophyrinogen to protoprophyrin, an important step in the synthesis of chlorophyll, hemes and cytochromes in chloroplasts; they are protein components involved in the uptake of light, energy transduction, signal transduction and detoxification (Geoffroy et al., 2002; Grossmann et al., 2010). Thus, these herbicides can directly affect the photosystem II by the deficiency in the formation of components, and indirectly by the degradation of membrane lipids (Grossmann et al., 2010). These facts may have led to the ETR decrease by saflufenacil observed at 1 DAA with the rapid reversal of these effects. Studies conducted by Belapart et al. (2013), verifying the effects of several herbicides on the ETR of *Brachiaria decumbens* plants showed that treatments with no recovery of ETR levels resulted in higher mortality of the grass species. Thus, the recovery of ETR after application of herbicides seems to be an essential step for the survival of plants after the exposure of molecules that alter the functioning of photosystem II.

The confirmation that oxyfluorfen and saflufenacil were selective to the VC865 clone regardless of the spraying nozzle was observed due to the fact that there was no significant difference in the biometric variables, the leaf area and the dry matter of eucalyptus seedlings in relation to the control treatment (Table 3).

Similarly to this work, Pereira et al. (2011), studying different doses of saflufenacil applied separately on

Eucalyptus urograndis seedlings, found no differences in their biometric variables (stem diameter and height), showing that the molecule is selective for soil and plant application.

The tolerance of the VC865A clone to the saflufenacil molecule can be related to the fact that this herbicide is slightly absorbed by the plant shoot and roots, and thus, in its full vegetative growth, when absorbed it is

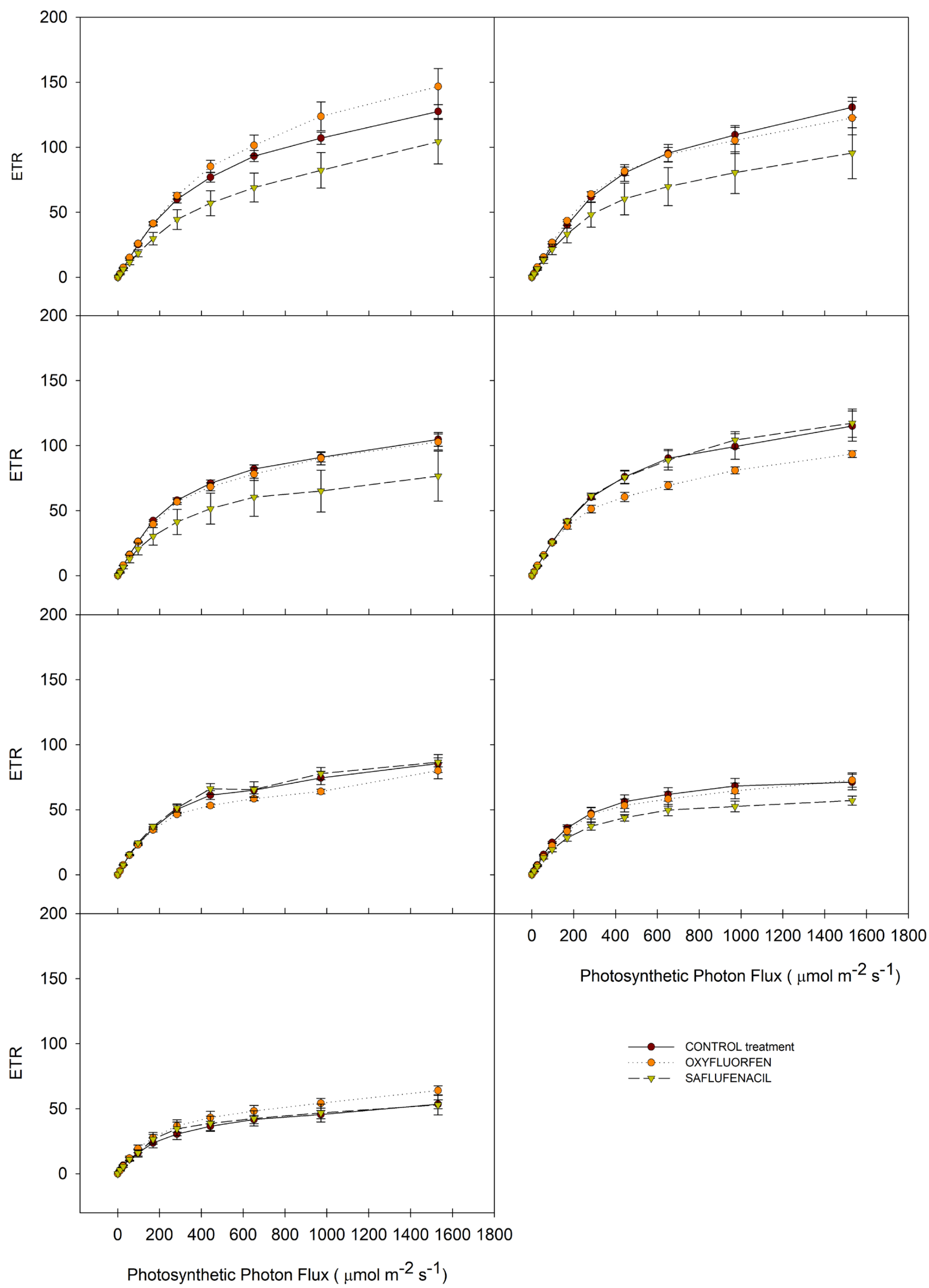

Figure 1. Electron transport rate (ETR) versus photosynthetic photon flux of eucalyptus seedlings under different treatments: control treatment, oxyfluorfen and saflufenacil, applied with a XR 110.02 spraying nozzle. Averages ± standard error.

quickly translocated via xylem, with little movement in the phloem, so its selectivity is due to the physical barrier of the vascular system and the faster metabolism of the product by tolerant species (Grossmann et al., 2011). For oxyfluorfen, the tolerance of the VC865A clone is related to absorption and translocation as

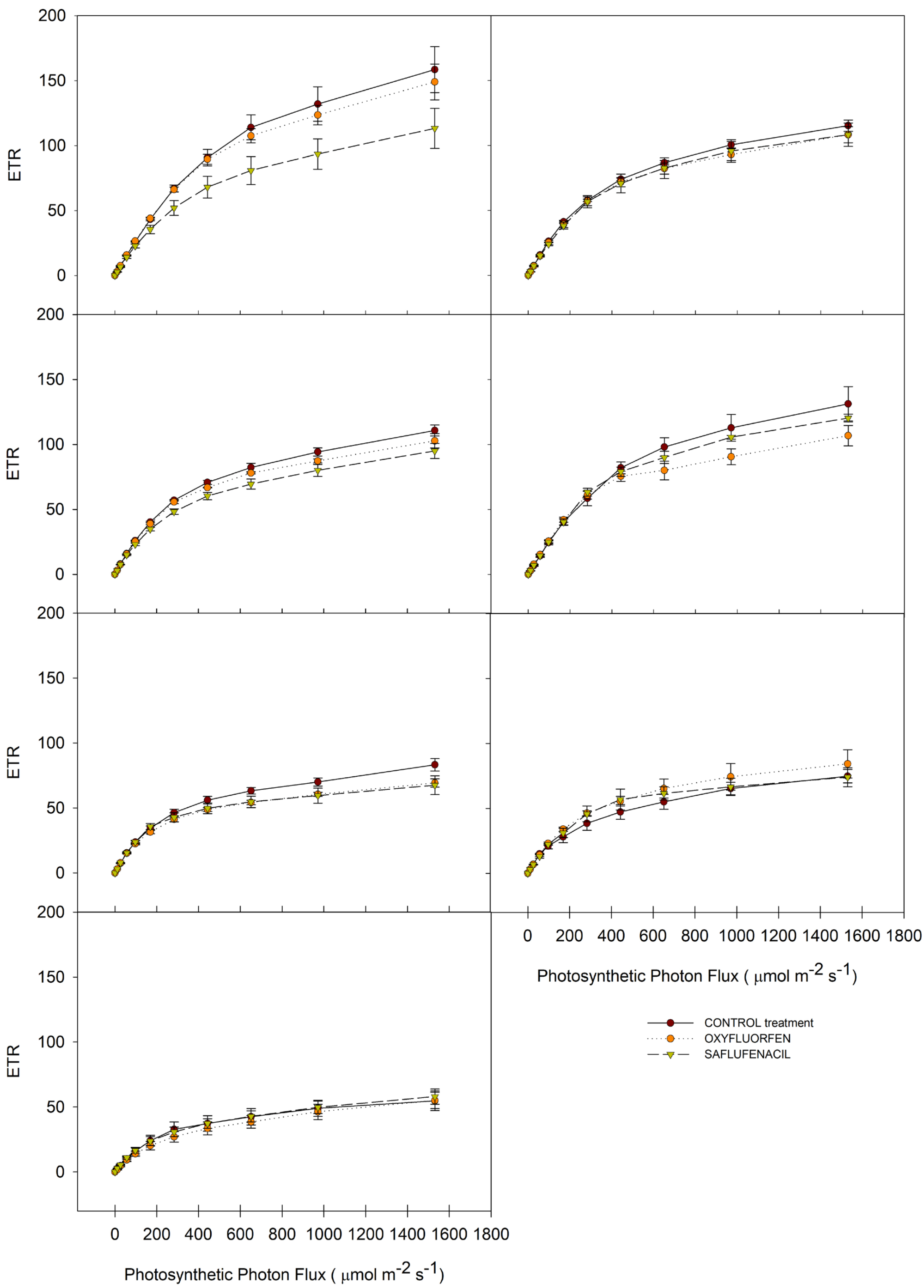

Figure 2. Electron transport rate (ETR) versus photosynthetic photon flux of eucalyptus seedlings under different treatments: control treatment, oxyfluorfen and saflufenacil, applied with a TTI 110.02 spraying nozzle. Averages ± standard error.

Table 3. Biometry, leaf area and dry matter of eucalyptus seedlings after the application of herbicides with different spraying nozzles.

Spraying nozzles	CONTROL TREATMENT		OXIFLUORFEN		SAFLUFENACIL	
			Height (cm) 1 DAA			
XR 110.02	31.00	A a	32.75	A a	31.50	A a
TTI 110.02	31.13	A a	32.25	A a	32.00	A a
VC%			**6.00**			
			Height (cm) 7 DAA			
XR 110.02	34.88	A a	38.25	A a	34.50	A a
TTI 110.02	33.75	A a	37.00	A a	34.25	A a
VC%			**8.12**			
			Height (cm) 15 DAA			
XR 110.02	37.00	A a	43.50	A a	38.75	A a
TTI 110.02	37.25	A a	43.25	A a	37.50	A a
VC%			**11.07**			
			Height (cm) 30 DAA			
XR 110.02	53.00	A a	51.25	A a	52.25	A a
TTI 110.02	48.25	A a	54.50	A a	51.25	A a
VC%			**8.25**			
			Height (cm) 45 DAA			
XR 110.02	59.00	A a	56.00	A a	59.25	A a
TTI 110.02	55.00	A a	61.25	A a	60.50	A a
VC%			**10.75**			
			Diameter (mm) 1 DAA			
XR 110.02	3.24	A a	3.21	A a	3.15	A a
TTI 110.02	3.03	A a	3.04	A a	3.20	A a
VC% 10.99						
			Diameter (mm) 7 DAA			
XR 110.02	3.38	A a	3.45	A a	3.37	A a
TTI 110.02	3.35	A a	3.43	A a	3.46	A a
VC%			**7.27**			
			Diameter (mm) 15 DAA			
XR 110.02	3.52	A a	3.58	A a	3.40	A a
TTI 110.02	3.54	A a	3.39	A a	3.34	A a
VC%			**11.71**			
			Diameter (mm) 30 DAA			
XR 110.02	4.51	A a	4.48	A a	4.76	A a
TTI 110.02	4.49	A a	4.72	A a	4.64	A a
VC%			**8.97**			
			Diameter (mm) 45 DAA			
XR 110.02	5.18	A a	5.22	A a	5.41	A a
TTI 110.02	5.21	A a	5.36	A a	5.56	A a
VC%			**9.71**			
			Number of leaves 1 DAA			
XR 110.02	16.00	A a	15.50	A a	15.25	A a
TTI 110.02	15.50	A a	15.25	A a	14.25	A a
VC%			**11.09**			
			Number of leaves 7 DAA			
XR 110.02	19.25	A ab	23.50	A b	17.00	A a

Means followed by the same uppercase letter in the rows and lowercase in the columns do not differ statistically by the Tukey's test ($p \geq 0.05$).

Table 3. Continued...

Spraying nozzles	CONTROL TREATMENT		OXIFLUORFEN		SAFLUFENACIL	
TTI 110.02	17.25	A a	19.00	A a	14.00	A a
VC%			**17.07**			
		Number of leaves 15 DAA				
XR 110.02	50.50	A a	54.25	A a	46.50	A a
TTI 110.02	47.00	A a	57.25	A a	54.75	A a
VC%			**19.64**			
		Number of leaves 30 DAA				
XR 110.02	55.75	A a	60.25	A a	51.50	A a
TTI 110.02	52.50	A a	62.75	A a	60.25	A a
VC%			**18.11**			
		Number of leaves 45 DAA				
XR 110.02	82.50	A a	87.50	A a	89.25	A a
TTI 110.02	81.00	A a	80.00	A a	89.00	A a
VC%			**16.45**			
		Leaf area (cm) 45 DAA				
XR 110.02	1,381.06	A a	1,489.96	A a	1,765.23	A a
TTI 110.02	1,323.96	A a	1,341.78	A a	1,462.56	A a
VC%			**16.4**			
		Shoot dry matter (g) 45 DAA				
XR 110.02	9.97	A a	10.32	A a	11.62	A a
TTI 110.02	8.83	A a	9.90	A a	9.96	A a
VC%			**14.07**			

Means followed by the same uppercase letter in the rows and lowercase in the columns do not differ statistically by the Tukey's test ($p \geq 0.05$).

well, since it was applied in post-emergence, and in this application mode, its action is more localized (Vidal, 1997).

4. CONCLUSION

The herbicides saflufenacil and oxyflourfem are selective to the seedlings of the VC865 Eucalyptus clone (*Eucalyptus urophylla* × *Eucalyptus grandis*), regardless of whether the application occurs with XR 110.02 or TTI 110.02 spraying nozzles.

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CORRESPONDENCE TO

Renan Cantalice de Souza
Centro de Ciências Agrárias, Universidade Federal de Alagoas – CECA/UFAL, BR 104, Km 85, s/n, CEP 57072-970, Rio Largo, AL, Brasil
e-mail: renanibp@hotmail.com

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Erratum

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Due to a desktop publishing error in the article "Herbicide Selectivity In Eucaplyptus Influenced By Spraying Nozzles", DOI number: https://doi.org/10.1590/2179-8087.065117, published in the journal Floresta e Ambiente, volume 26, issue 2, e20170651, in the title and in the pages header,

where it reads:

Eucaplyptus

it should read:

Eucalyptus