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Control of *Digitaria insularis* (L.) Fedde in eucalyptus forests: shading increases sensitivity to glyphosate applied alone and in a mixture with carfentrazone-ethyl

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Received: 12 September 2023 / Accepted: 23 January 2024
Published online: 05 February 2024

Abstract
Shading, the predominant condition in most of the eucalyptus cultivation cycle, causes changes in the morphological and physiological weed's characteristics, which can alter their responses to glyphosate and carfentrazone-ethyl, important herbicides for the crop. The objective was to evaluate the influence of light on the efficiency of glyphosate and carfentrazone-ethyl used alone and in a mixture in *Digitaria insularis* control, a priority pest in the crop. The experiment was carried out in a 3 × 6 factorial scheme. The first factor corresponded to 3 cultivation environments (full sunlight, 45 and 63% shading) and the second factor to doses of glyphosate and carfentrazone-ethyl applied isolated (1920 and 40 g ai ha^{-1}) and mixed (1536 + 8; 1152 + 16; 768 + 24 and 384 + 32 g ai ha^{-1}), respectively. Shading increased *D. insularis* sensitivity to glyphosate alone and in a mixture with carfentrazone-ethyl. In shading, the glyphosate application alone at a dose of 1920 g ha^{-1} and in a mixture with carfentrazone-ethyl at doses of 1536 + 8 and 1152 + 16 g ha^{-1} were efficient in *D. insularis* control. In the environment of 63% shading, the dose of 768 + 24 g ha^{-1} was also efficient in this species control. None of the doses were effective in controlling *D. insularis* in full sunlight. Isolated carfentrazone-ethyl was inefficient in controlling *D. insularis*, regardless of the growth environment. Shading increases the quantum yield of photosystem II and reduces the electron transport rate, photosynthetic rate, stomatal conductance, and transpiration rate of *D. insularis*. In shady environments, it is possible to control *D. insularis* with lower glyphosate doses, used alone and mixed with carfentrazone-ethyl.

Keywords Dose reduction · Herbicide mixture · Physiology · Planted forests · Sourgrass

1 Introduction

Eucalyptus sp. is considered the most planted forest species worldwide [1, 2]. In this scenario, Brazil stands out as one of the largest producers [3], obtaining high wood productivity per hectare/year in a shorter rotation period and growing crop expansion in the country [4, 5].

In areas of crop expansion or even the oldest stands, weed management is one of the most important practices in eucalyptus cultivation. Without control, weed interference can lead to losses of up to 40% in forest productivity [6, 7]. Of the five pests of economic importance and the greatest phytosanitary risk for eucalyptus, which are prioritized in the

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analysis of product registration processes and control technologies in Brazil, all are weeds [8]. Among them is *Digitaria insularis* [8], a perennial grass that is difficult to control, with biotypes resistant to glyphosate [9–11] and cross-resistance to acetyl-CoA carboxylase (ACCase) inhibiting herbicides [12]. Due to suitable climatic conditions and the constant use of the same mechanism of action, there is a risk of selecting glyphosate-resistant *D. insularis* biotypes in eucalyptus cultivation areas [13]. *Digitaria insularis* is also considered a weed in corn [14], soybean [15], cowpea [16], coffee [17], pastures [18], and in urban areas [10], which reinforces the species importance.

Glyphosate and carfentrazone-ethyl, herbicides that inhibit 5-enolpyruvylshikimate 3-phosphate synthase (EPSPS) and protoporphyrinogen oxidase (protox), respectively, are among the herbicides registered for eucalyptus in Brazil [19] and accepted by certifiers for use in the crop [20]. Both products have been used in eucalyptus plantations to control weeds between planting rows, even mixed in the tank as an alternative to increasing the control spectrum. In shaded environments, a condition commonly found under the canopies of eucalyptus planted forests [21], some weeds are more sensitive to glyphosate action, such as *Euphorbia heterophylla* [22] and *Merremia cissoides* [23] and protox-inhibiting herbicides, such as *Commelina benghalensis* [24], and can be controlled with lower doses of these products. The herbicides application in lower doses with high control efficiency, as may occur in shading conditions, helps to reduce the negative impacts of these pesticides on the environment, which is currently so questioned by society [25–31], in addition to reducing production costs.

Maintaining the viability of glyphosate and carfentrazone-ethyl is essential for successful weed management in eucalyptus crops. Mixing herbicides with different mechanisms of action increases the weed control spectrum, reduces selection pressure, delays the resistance emergence [32–34], and can also be used to control already resistant biotypes [35–38].

The mixture of glyphosate with protox-inhibiting herbicides has an additive and synergistic effect on the control of several species of broadleaf and grass weeds [39–41]. However, shading can interfere with the herbicide mixture's efficiency since the morphological and physiological plants characteristics [42–46] and herbicides efficiency when applied alone are altered under low light intensity [22–24].

The mixture of glyphosate and carfentrazone-ethyl can be a promising strategy to delay the emergence of resistant biotypes. However, the weed growth environment promoted by eucalyptus plantations must be considered when evaluating these herbicides' efficiency, which has been neglected. The objective of this study was to evaluate the effect of shading on the efficiency of glyphosate and carfentrazone-ethyl applied alone and in a mixture in the *D. insularis* control, a priority weed in the eucalyptus crop in Brazil.

2 Materials and methods

2.1 Site and plant material description

The experiment was carried out at the Instituto de Ciências Agrárias of the Universidade Federal de Minas Gerais, Brazil (16°40′58.1"S, 43°50′19.3"W). Köppen classifies the region's climate as Aw—tropical with a dry season in winter [47].

Digitaria insularis seedlings were produced from tillers collected from plants in areas with frequent glyphosate applications. The seedlings were transplanted into 10 dm^3 pots containing a substrate of sandy soil and bovine manure in a 3:1 ratio (volume:volume). In each pot, two *D. insularis* plants were grown and taken to the cultivation environments after transplanting. The soil used had the following characteristics: pH (water) = 5.3; organic matter = 1.66%; sand = 72%; silt = 16%; and clay = 12%. The substrate was fertilized with NPK 4-30-10 fertilizer, as recommended for pots fertilization [48], and irrigated once a day to maintain humidity between 80 and 100% of field capacity.

2.2 Experimental design and treatments

The design adopted was randomized blocks with four replications. The treatments were established in a 3 × 6 factorial scheme, where the first factor consisted of plants in full sunlight and two shading levels (45 and 63%), and the second factor, by doses of glyphosate and carfentrazone-ethyl, applied isolated and in a mixture (Table 1).

Shading was obtained with a black polypropylene shade screen, installed on structures built with wooden posts and wire 2 m high, closing the sides. The shading levels adopted in the study are similar to those previously reported for eucalyptus planted forests [49, 50]. The incidence of photosynthetically active radiation (PAR) in the growth environments was determined in 20 days during the experiment execution, at 8:00, 12:00, and 16:00 h, with the fluorometer device Y (II) meter (OPTI- SCIENCES, Hudson, USA) (Fig. 1).

Table 1 Glyphosate and carfentrazone-ethyl applied alone and in a mixture to control *Digitaria insularis*

Herbicides common name	Herbicides commercial name	Doses (g ai ha^{-1})
Glyphosate	Roundup Original DI®	1920
Carfentrazone-ethyl	Aurora®	40
Glyphosate + carfentrazone-ethyl	Roundup Original DI® + Aurora®	1536 + 8
Glyphosate + carfentrazone-ethyl	Roundup Original DI® + Aurora®	1152 + 16
Glyphosate + carfentrazone-ethyl	Roundup Original DI® + Aurora®	768 + 24
Glyphosate + carfentrazone-ethyl	Roundup Original DI® + Aurora®	384 + 32

ai = active ingredient

The plants remained in the cultivation environments for 52 days. A standardization cut was performed during this period at 37 cultivation days, at 5 cm height. At 15 days after plant cutting, the herbicides were applied. The application was carried out with a backpack sprayer pressurized with CO_2 with a TTI 11002 nozzle model (Teejet, Wheaton, Illinois, USA) and a pressure regulating valve (Comam, Belo Horizonte, Brazil) constant at 300 kPa, calibrated to apply 116 L ha^{-1} of spray volume.

2.3 Assessments

At 3 and 6 days after application (DAA), photosynthetic rate (P_N, µmol CO_2 m^{-2} s^{-1}), stomatal conductance (g_s, mol H_2O m^{-2} s^{-1}), and transpiration rate (E, µmol H_2O m^{-2} s^{-1}) of the plants were analyzed using an infrared gas analyzer (IRGA, model LCpro-SD Portable, Hoddesdon, England) and the quantum yield of photosystem II (ΦPSII) and electron transport rate (ETR) with the fluorometer device Y (II) meter (OPTI-SCIENCES, Hudson, USA).

Visual control assessments were carried out at 28 and 60 DAA, adopting a scale from 0 to 100%, where 0 is the absence of herbicide injuries, and 100 is the plant death. Extra plants without herbicide application were maintained in each growth environment as a comparison parameter for treatment control scores. Three evaluators assigned control scores. The values per plot were determined by the arithmetic mean of the three scores. At 60 DAA, the plant biomass remaining in the pots was collected and weighed to determine the fresh biomass. For *D. insularis*, fresh biomass has the same behavior as dry biomass [51] and therefore was used as a parameter.

2.4 Statistical analysis

Data were submitted to analysis of variance (ANOVA), and when significant, means were grouped using the Scott-Knott test ($p \leq 0.05$). ANOVA and the Scott-Knott mean clustering test were performed using the R Studio statistical program [52] and the ExpDes.pt package [53].

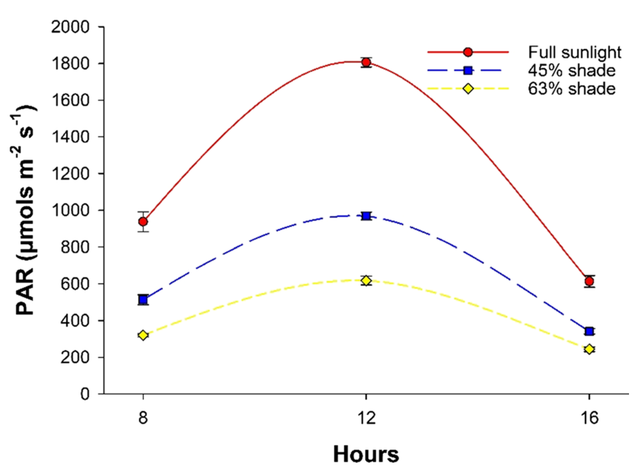

Fig. 1 Availability of photosynthetically active radiation (PAR) in growing environments at different times. Bars = mean standard error

Table 2 Photosynthetic rate (P_N), stomatal conductance (g_s), and transpiration rate (E) of *Digitaria insularis* in different environments at 3 and 6 days after application (DAA) of glyphosate and carfentrazone-ethyl alone or in a mixture

Growth environments	Variables					
	3 DAA			6 DAA		
	P_N	g_s	E	P_N	g_s	E
Full sunlight	9.18 a	0.0945 a	2.85 a	9.01 a	0.1333 a	2.89 a
45% shading	7.99 a	0.0629 b	2.28 b	6.74 b	0.0616 b	1.88 b
63% shading	7.18 a	0.0516 b	1.87 b	4.91 b	0.0433 b	1.24 c
CV (%)	42.63	40.23	30.77	46.53	51.16	35.44

Means followed by the same letter in the column do not differ by the Scott-Knott mean clustering test ($p \leq 0.05$)

CV = coefficient of variation

Table 3 Photosynthetic rate (P_N), stomatal conductance (g_s), and transpiration rate (E) of *Digitaria insularis* at 3 and 6 days after application (DAA) of glyphosate (Gly) and carfentrazone-ethyl (Car) alone or in a mixture

Herbicides	Doses (g ai ha^{-1})	Variables					
		3 DAA			6 DAA		
		P_N	g_s	E	P_N	g_s	E
Gly	1920	4.62 c	0.050 c	1.77 c	2.84 c	0.039 b	1.19 c
Car	40	17.33 a	0.139 a	4.04 a	17.21 a	0.160 a	3.52 a
Gly + Car	1536 + 8	4.67 c	0.045 c	1.66 c	3.43 c	0.054 b	1.55 c
Gly + Car	1152 + 16	4.46 c	0.038 c	1.52 c	4.26 c	0.064 b	1.77 b
Gly + Car	768 + 24	6.03 c	0.055 c	1.97 c	6.37 b	0.084 b	2.12 b
Gly + Car	384 + 32	11.59 b	0.089 b	3.04 b	7.24 b	0.074 b	1.87 b
CV (%)		42.63	40.23	30.77	46.53	51.16	35.44

Means followed by the same letter in the column do not differ by the Scott-Knott mean clustering test ($p \leq 0.05$)

ai = active ingredient; CV = coefficient of variation

3 Results

3.1 Photosynthetic rate (*PN*), stomatal conductance (g_s), and transpiration rate (*E*)

At 3 DAA, there was no difference between the growth environments in the plant's P_N (Table 2). However, at 6 DAA, plants in shading showed lower P_N. At 3 and 6 DAA, shading reduced the g_s and E of *D. insularis* (Table 2).

At 3 DAA, the herbicide doses that most reduced P_N, g_s, and E were glyphosate applied alone at a dose of 1920 g ha^{-1} and mixed with carfentrazone-ethyl at doses 1536 + 8, 1152 + 16 and 768 + 24 g ha^{-1} (Table 3). At 6 DAA, the doses that most reduced these variables were glyphosate applied alone at a dose of 1920 g ha^{-1} and mixed with carfentrazone-ethyl at doses 1536 + 8 and 1152 + 16 g ha^{-1} (Table 3). Carfentrazone-ethyl applied alone was the treatment with the least impact on P_N, g_s, and E of *D. insularis* (Table 3).

3.2 Quantum yield of photosystem II (Φ_{PSII}) and electron transport rate (ETR)

Shading increased Φ_{PSII} and reduced the ETR of *D. insularis* at 3 and 6 DAA (Table 4). Between shading levels, there was no difference in ETR, however, the 63% shading environment showed higher Φ_{PSII}.

The glyphosate application alone at a dose of 1920 g ha^{-1} and mixed with carfentrazone-ethyl at doses 1536 + 8 and 1152 + 16 g ha^{-1} caused the most significant reductions in Φ_{PSII} and ETR of *D. insularis* at 3 and 6 DAA (Table 5). Carfentrazone-ethyl applied alone and in a mixture with glyphosate at doses of 768 + 24 and 384 + 32 g ha^{-1} caused the smallest impacts on these variables.

Table 4 Quantum yield of photosystem II (Φ_{PSII}) and electron transport rate (ETR) of *Digitaria insularis* in different environments, at 3 and 6 days after application (DAA) of glyphosate and carfentrazone-ethyl alone or in a mixture

Growth environments	Variables			
	3 DAA		6 DAA	
	Φ_{PSII}	ETR	Φ_{PSII}	ETR
Full sunlight	0.2093 c	134.46 a	0.1255 c	91.98 a
45% shading	0.2780 b	92.95 b	0.2031 b	58.94 b
63% shading	0.3566 a	78.82 b	0.3473 a	50.50 b
CV (%)	33.66	35.13	48.70	63.98

Means followed by the same letter in the column do not differ by the Scott-Knott mean clustering test ($p \leq 0.05$)

CV = coefficient of variation

Table 5 Quantum yield of photosystem II (Φ_{PSII}) and electron transport rate (ETR) of *Digitaria insularis* at 3 and 6 days after application (DAA) of glyphosate (Gly) and carfentrazone-ethyl (Car) alone or in a mixture

Herbicides	Doses (g ai ha^{-1})	Variables			
		3 DAA		6 DAA	
		Φ_{PSII}	ETR	Φ_{PSII}	ETR
Gly	1920	0.1716 b	62.87 c	0.0672 c	25.43 c
Car	40	0.3975 a	152.10 a	0.4064 a	117.15 a
Gly + Car	1536 + 8	0.2201 b	69.55 c	0.1712 b	49.74 c
Gly + Car	1152 + 16	0.2504 b	95.58 c	0.2115 b	57.36 c
Gly + Car	768 + 24	0.3006 a	111.56 b	0.2360 b	78.81 b
Gly + Car	384 + 32	0.3475 a	120.80 b	0.2596 b	74.35 b
CV (%)		33.66	35.13	48.70	63.98

Means followed by the same letter in the column do not differ by the Scott-Knott mean clustering test ($p \leq 0.05$)

ai = active ingredient; CV = coefficient of variation

3.3 Control and fresh biomass of *D. insularis*

Shading increased the *D. insularis* sensitivity to glyphosate applied alone and in a mixture with carfentrazone-ethyl (Tables 6 and 7). At 28 and 60 DAA, in environments with 45 and 63% shading, the isolated glyphosate application at a dose of 1920 g ha^{-1} and in a mixture with carfentrazone-ethyl at doses 1536 + 8 and 1152 + 16 g ha^{-1} were efficient in *D. insularis* management. In the environment of 63% shading, the application of 768 + 24 g ha^{-1} was also efficient in controlling this species (Table 6). These treatments means were not statistically different, with control levels above 80%. These doses totally reduced the plant's fresh biomass at 60 DAA (Table 7). For this variable, there was also no statistical difference between treatments. Although at 28 DAA, the doses 768 + 24 and 384 + 32 g ha^{-1} were efficient in environments with 45 and 63% shading, respectively, at 60 DAA, the control means for these treatments were statistically lower. The plants recovered from the herbicide injuries and the control was less than 80%, considered unsatisfactory (Table 6). In full sunlight, none of the applied doses effectively controlled *D. insularis* (Tables 6 and 7). In this environment, the plants recovered from the herbicide injuries, with drastic control reductions at 60 DAA compared to 28 DAA (Table 6). At 60 DAA in full sunlight, *D. insularis* control levels were less than 18% at all applied doses. Carfentrazone-ethyl applied alone is inefficient in controlling *D. insularis*, regardless of the growth environment (Tables 6 and 7).

4 Discussion

Shading increased *D. insularis* sensitivity to glyphosate applied alone and in a mixture with carfentrazone-ethyl. The increased *D. insularis* sensitivity to glyphosate applied alone and in a mixture with carfentrazone-ethyl in shading may be associated with lower ETR and P_N of plants in these environments. These variables are related to carbon

Table 6 Visual control (%) of *Digitaria insularis* plants at 28 and 60 days after application (DAA) of glyphosate (Gly) and carfentrazone-ethyl (Car) alone or in a mixture in environments with different light intensities

Herbicides	Doses (g ai ha^{-1})	Growth environments		
		Full sunlight	45% shading	63% shading
28 days after application				
Gly	1920	75.41 Ab	100.00 Aa	100.00 Aa
Car	40	7.50 Ca	5.00 Ca	3.33 Ba
Gly + Car	1536 + 8	70.83 Ab	100.00 Aa	100.00 Aa
Gly + Car	1152 + 16	54.58 Bb	87.91 Aa	100.00 Aa
Gly + Car	768 + 24	45.83 Bb	91.25 Aa	96.25 Aa
Gly + Car	384 + 32	15.83 Cc	38.54 Bb	87.91 Aa
CV (%) = 14.2				
60 days after application				
Gly	1920	17.91 Ab	100.00 Aa	100.00 Aa
Car	40	5.00 Aa	5.00 Da	5.00 Ca
Gly + Car	1536 + 8	13.75 Ab	100.00 Aa	100.00 Aa
Gly + Car	1152 + 16	17.08 Ac	85.00 Bb	100.00 Aa
Gly + Car	768 + 24	13.33 Ac	34.33 Cb	100.00 Aa
Gly + Car	384 + 32	10.41 Ab	14.58 Db	57.91 Ba
CV (%) = 17.43				

Means followed by the same letter, uppercase in the column and lowercase in the row, do not differ by the Scott-Knott mean clustering test ($p \leq 0.05$)

ai = active ingredient; CV = coefficient of variation

Table 7 Fresh biomass (g/pot) of *Digitaria insularis* plants at 60 days after application (DAA) of glyphosate (Gly) and carfentrazone-ethyl (Car) alone or in a mixture in environments with different light intensities

Herbicides	Doses (g ai ha^{-1})	Growth environments		
		Full sunlight	45% shading	63% shading
Gly	1920	150.20 Ba	0.00 Bb	0.00 Cb
Car	40	168.42 Bb	243.18 Aa	269.20 Aa
Gly + Car	1536 + 8	146.32 Ba	0.00 Bb	0.00 Cb
Gly + Car	1152 + 16	142.25 Ba	0.00 Bb	0.00 Cb
Gly + Car	768 + 24	222.46 Aa	211.89 Aa	0.00 Cb
Gly + Car	384 + 32	202.53 Aa	221.54 Aa	101.89 Bb
CV (%) = 35.51				

Means followed by the same letter, uppercase in the column and lowercase in the row, do not differ by the Scott-Knott mean clustering test ($p \leq 0.05$)

ai = active ingredient; CV = coefficient of variation

fixation and plant energy availability [54]. Plants with lower energy reserves are less likely to recover from the herbicides' injuries and may become more sensitive to these products' actions [55, 56]. The doses considered efficient in controlling *D. insularis* (1920 g ha^{-1} of glyphosate alone and mixed with carfentrazone-ethyl at doses 1536 + 8 and 1152 + 16 g ha^{-1}) presented, for the physiological variables analyzed, means that were statistically lower than those treatments that did not control *D. insularis*. The shikimate metabolic pathway, inhibited by glyphosate, has an indirect role in plastoquinone production and ribulose-1,5-bisphosphate regeneration in the Calvin-Benson cycle [57], important proteins in electron transport rate and carbon fixation. The influence of glyphosate in plastoquinone production and ribulose-1,5-bisphosphate regeneration may explain the reductions in ETR and P_N of plants. Similar results were observed in *Euphorbia heterophylla* [22] and *Salix miyabeana* [58] after glyphosate application.

In addition to the energy deficit, changes in *D. insularis* growth caused by shading may be associated with greater herbicide sensitivity. *Digitaria insularis* has rhizomes, reserve organs that, when present, make it difficult to control [59]. *Digitaria insularis* begin to produce rhizomes 45 days after emergence [60]. In the present study, the herbicides were applied at 52 cultivation days, after the formation beginning of these structures in full sunlight. However, shading alters the dry matter partition of some grasses, investing more resources in shoot development as a function of root growth [61, 62], which, combined with lower ETR and P_N, may have delayed or compromised rhizome development and increased *D. insularis* sensitivity. Shading can also reduce wax deposition on the leaf surface [56]. The smaller wax amount in the shade can increase herbicide penetration and efficiency [56].

Digitaria insularis is a C4 metabolism grass. C4 metabolism plants have a high light and temperature saturation point [63]. The reductions in ETR, P_N, g_s, and *E* in *D. insularis* grown in shading are due to the lower light incidence in these environments. These results align with those found in other grasses grown in the shade [64–67].

Increased sensitivity in shading to glyphosate applied alone was also observed in *Euphorbia heterophylla* [22] and *Merremia cissoides* [23], and the mixture of glyphosate and carfentrazone-ethyl in *Macroptilium atropurpureum* [68]. Unlike what was observed in the present study, where no increase in the efficiency of carfentrazone-ethyl isolated under shading was found, Santos Júnior [24] found an increase in saflufenacil efficiency, another protox-inhibiting herbicide, in controlling *Commelina benghalensis*.

Although *D. insularis* sensitivity to herbicides increased under shade, control after the doses application of 40 g ha^{-1} of carfentrazone-ethyl and 384 + 32 g ha^{-1} of glyphosate + carfentrazone-ethyl were inefficient in this environment. Caron [50] did not identify the need for weed control in eucalyptus planted forests when the shading level was greater than 60% due to low plant growth. However, the study does not report the radiation level corresponding to the shading levels studied, a factor that depends on the time and region where the study was conducted and that directly impacts weed growth and the decision to manage them. In addition, the weed community in the study was mainly composed of the species *Sida rhombifolia*, *Stellaria media*, *Sonchus oleraceus*, and *Echium plantagineum*, different species from the present study, and which have an unknown ability to adapt to shading. Therefore, the decision to manage or not to manage weeds depends more on the incident radiation level and the species' ability to grow in the shade than just the shade level imposed by the forest canopy. Even after the application of isolated carfentrazone-ethyl, which promoted control levels equal in full sunlight and shade, *D. insularis* accumulated more fresh biomass in shade, which reinforces the need for attention to the species in forest areas.

The low control obtained by isolated carfentrazone-ethyl, regardless of the growth environment, is due to the advanced plant stage at the application time. Carfentrazone-ethyl is a contact herbicide that acts by inhibiting chlorophyll synthesis [69, 70] but has no action on already-formed chlorophylls. As it does not act on already-formed chlorophylls and does not translocate in the plant, it is only efficient in controlling plants in the early development stages [71]. The low control obtained by the mixture of glyphosate and carfentrazone-ethyl at the dose of 384 + 32 g ha^{-1}, regardless of the growth environment, is associated with the low glyphosate dose used in the mixture. Carfentrazone-ethyl applied alone at a dose of 40 g ha^{-1} and mixed with glyphosate at a dose of 384 + 32 g ha^{-1} were the doses that had the least impact on *D. insularis* physiology.

Although isolated carfentrazone-ethyl has low control efficiency against *D. insularis*, it has good efficiency against other glyphosate-resistant weeds, such as *Commelina* ssp. [39]. Moreover, its use in a mixture with glyphosate can benefit *D. insularis* control in shading, as in the present study, and against other important weeds, like the glyphosate-tolerant species [39, 72]. Additionally, the constant glyphosate application, the most widely used herbicide in the world, led to the selection of resistant biotypes over time [73–75]. The use of two or more herbicides with different mechanisms of action has been an interesting agronomic practice because, in addition to improving the management efficiency of tolerant weeds [76–78], it decreases selection pressure for resistant weeds [32].

The application of glyphosate alone and in a mixture with carfentrazone-ethyl showed different behavior depending on the light intensity in the growth environments, indicating the need to consider this factor when defining weed control doses in eucalyptus areas. Considering the light availability in growing environments in the definition of herbicide doses for weed control creates a new possibility for efficient dose reduction and, consequently, gains in economy and sustainability. Weeds in shading conditions are widely found in crops of other forest species, orchards, and integration systems, adding up to millions of hectares where this new management approach could be applied. Studies on the absorption and translocation of glyphosate and carfentrazone-ethyl, starch accumulation and wax deposition in the leaves of *D. insularis* cultivated in environments with different light intensities are necessary to elucidate the mechanisms involved in the species susceptibility or tolerance when grown in shade or full sunlight, respectively.

5 Conclusions

The shading of 45 and 63% of the photosynthetically active radiation increases *D. insularis* sensitivity to glyphosate applied alone and mixed with carfentrazone-ethyl, requiring lower doses for its control in the understory of eucalyptus plantations. In full sunlight, *D. insularis* was not controlled. To manage this species in shade, glyphosate application alone at a dose of 1920 g ha^{-1} and in a mixture with carfentrazone-ethyl at doses of 1536 + 8 and 1152 + 16 g ha^{-1} were efficient. In the environment of 63% shading, the dose of 768 + 24 g ha^{-1} was also efficient. The light intensity in the growing environments must be considered when defining glyphosate doses, applied alone or mixed with carfentrazone-ethyl.

Acknowledgements The author's thanks Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) (Process PPM-00027-17) for funding the studies and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for providing scholarships to the first, second, and third authors (Finance Code 001).

Plant guidelines The study followed the national/institutional guidelines during the study.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by GAde PF, LMSD, WGM, LMR and LDTS. The first draft of the manuscript was written by GAdPF and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) (Process PPM-00027-17).

Data availability The data used in this research is available upon request.

Code availability Not applicable.

Declarations

Competing interests The authors declare no competing interests.

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