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Article

Response of Three *Chloris elata* Populations to Herbicides Sprayed in Pre- and Post-Emergence

Resposta de Três Populações de ***Chloris elata*** *a Herbicidas Aplicados em Pré e Pós-Emergência*

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ABSTRACT - In agricultural areas of Brazil, where there is no establishment of cover crops in the off-season and in fruit orchards, an increase in *Chloris elata* infestations, syn. *Chloris polydactyla*, has been observed. With the purpose to evaluate the response of three populations (Itaberaí - GO, Matão - SP e Jaboticabal - SP) of *C. elata* to herbicides sprayed before and after emergence, four experiments were conducted. In the first one, the differential tolerance of three *C. elata* populations to the herbicide glyphosate (0, 0.18, 0.36, 0.72, 0.96, 1.44, 2.88, 5.76 and 11.52 kg a.e. ha^{-1}) was studied. In the other experiments, the control of the three populations by herbicides applied in pre-emergence (clomazone, diclosulam, flumioxazin, isoxaflutole, chlorimuron-ethyl, metribuzin, S-metolachlor, sulfentrazone and trifluralin) or in post-emergence (clethodim, fenoxaprop-p-ethyl, fluazifop-p-butyl, haloxyfop-methyl, quizalofop-p-tefuryl, mesotrione, nicosulfuron, tembotrione, glufosinate-ammonium, paraquat and glyphosate) was evaluated. The population from Jaboticabal was more susceptible to glyphosate than Itaberaí and Matão, at smaller doses. In pre-emergence, clomazone, isoxaflutole, metribuzin, S-metolachlor and trifluralin were effective in controlling the three populations. The same results were observed for clethodim, fenoxaprop, fluazifop, haloxyfop, quizalofop, paraquat and glyphosate, when sprayed on plants with 2-6 tillers. *C. elata* populations differed for the herbicides flumioxazin, chlorimuron-ethyl and nicosulfutron.

Keywords: biotype, tall windmill grass, chemical control, weed.

RESUMO - No Brasil, nas áreas agrícolas onde não há o estabelecimento de culturas de cobertura na entressafra e em pomares de frutíferas, tem-se observado aumento na infestação de Chloris elata, sinonímia Chloris polydactyla. Com o objetivo de avaliar a resposta de três populações (Itaberaí - GO, Matão - SP e Jaboticabal - SP) de C. elata a herbicidas pulverizados em pré ou pós-emergência, quatro experimentos foram desenvolvidos. No primeiro, foi estudada, por meio de curva de dose-resposta, a tolerância diferencial de três populações de C. elata ao herbicida glyphosate (0, 0,18, 0,36, 0,72, 0,96, 1,44, 2,88, 5,76; e 11,52 kg e.a. ha^{-1} de equivalente ácido). Nos outros experimentos, foi avaliado o controle das três populações por herbicidas aplicados em pré (clomazone, diclosulam, flumioxazin, isoxaflutole, chlorimuron-ethyl, metribuzin, S-metolachlor, sulfentrazone e trifluralin) ou pós-emergência (clethodim, fenoxaprop-p-ethyl, fluazifop-p-butyl, haloxyfop-methyl, quizalofop-p-tefuryl, mesotrione, nicosulfuron, tembotrione, amônio-glufosinato, paraquat e glyphosate). A população de Jaboticabal foi mais suscetível ao glyphosate do que a de Itaberaí e Matão, nas menores doses. Em pré-emergência, clomazone, isoxaflutole, metribuzin, S-metolachlor e trifluralin foram eficazes no controle das três populações. O mesmo resultado foi observado para clethodim, fenoxaprop, fluazifop, haloxyfop, quizalofop, paraquat e glyphosate,

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quando pulverizados em plantas com 2-6 perfilhos. As populações de C. elata diferiram entre si para os herbicidas flumioxazin, chlorimuron-ethyl e nicosulfuron.

Palavras-chave: biótipo, capim-branco, controle químico, planta daninha.

INTRODUCTION

The genus *Chloris* is large and has species distributed over tropical and subtropical regions in different continents. Many species occur in Brazil natively, while *C. gayana* was introduced as a forage species (Kissmann, 1997). In agricultural areas where there is no cover crops are established in the off-season, as well as in fruit orchards, there has been an increased infestation by *Chloris elata* Desv. synonymy *C. polydactyla* (L.) Sw. (tall windmill grass). This species is native to the American continent, occurring from the southern United States to Argentina, and is very common in Brazil, especially in the northern and central-western regions (Kissmann, 1997).

C. elata plants are perennial, not very caespitose, with glabrous and subcilindrical stems and 50 to 110 cm tall. It forms clumps from short rhizomes and reproduces by seeds (Lorenzi, 2008). It has slow initial development and growth, with high dry matter production at the end of the cycle and with a high seed production capacity, about 30,000 per plant (Carvalho et al., 2005); they are covered in hair and are spread by the wind at great distances.

As forthe chemical control of *C. elata*, the first resistance case of this species to glyphosate was reported in 2014 in Brazil (Brunharo et al., 2016). Glyphosate inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP), which is responsible for one of the synthesis stages of aromatic amino acids (tryptophan, phenylalanine and tyrosine) (Kruse et al., 2000). The basis for the resistance of *C. elata* plants to glyphosate may be associated with the lower absorption and translocation of the herbicide, compared to the susceptible biotype (Brunharo et al., 2016). In a previous study, populations of *C. polydactyla* from Matão and Jaboticabal had similar levels of susceptibility to glyphosate and differed from the Palmital and Pallotina biotypes, which are considered susceptible and with intermediate susceptibility, respectively (Barroso et al., 2014).

Little information is available in literature about the management and possible differential tolerance among *C. elata* populations to the herbicides used in no-tillage and citrus fruit orchard areas. Therefore, the purpose of this study was to evaluate the response of three populations of *C. elata* to herbicides sprayed during pre- and post-emergence.

MATERIAL AND METHODS

Four experiments were carried out in a greenhouse, from 11/19/2015 to 04/11/2016, in the Setor de Matologia of Embrapa Hortaliças, Brasília - Distrito Federal, Brazil. The altitude of the site is 993 meters, the latitude is 15°56'02,10" S, and the longitude is 48°08'15,94" O.

Between September and October 2015, *C. elata* seeds were collected in Itaberaí - Goiás state (soybean and maize no-tillage area, altitude 752 meters, latitude 16°00'46.41"S and longitude 49°50'09,79" O), in Matão - São Paulo state (citrus fruit orchard, altitude 622 meters, latitude 21°40'20,76" S and longitude 48°21'45,59" O) and Jaboticabal - São Paulo state (area with no herbicide application history, altitude 617 meters, latitude 21°15'57,73" S and longitude 47°17'46,68" W).

In the four experiments, the experimental design was the completely randomized one with four replications. In the first one (3 x 9 factorial arrangement), the differential tolerance of three *C. elata* populations to glyphosate was studied using a dose-response curve. Plants were sprayed with the herbicide (0, 0.18, 0.36, 0.72, 0.96, 1.44, 2.88, 5.76, and 11.52 kg ha^{-1} of glyphosate acid equivalent) when they were in full vegetative growth, with seven to eight tillers and 12.7 to 17.1 cm height. In the other experiments, the control of the three populations per herbicide applied in pre- (second experiment) or post-emergence (third and fourth experiments) of the plants was evaluated.

In the pre-emergence experiment (3 x 9 + 3 factorial arrangement), the herbicides clomazone (800 g ha^{-1}), diclosulam (35 g ha^{-1}), flumioxazin (50 g ha^{-1}), isoxaflutole (37.5 g ha^{-1}), chlorimuron-ethyl (20 g ha^{-1}), metribuzin (480 g ha^{-1}), S-metolachlor (1,920 g ha^{-1}), sulfentrazone (400 g ha^{-1}) were applied one day after sowing 100 *C. elata* seeds into planters. In addition, three control treatments with no application were maintained, one for each population.

The post-emergence experiments (3 x 11 + 3 factorial arrangement) were defined according to the stage of development of the plants at the time of application. When plants had 2-3 tillers (third experiment) and 5-6 tillers (fourth experiment), the three *C. elata* populations were sprayed with clethodim (108 g ha^{-1} + mineral oil at 0.5%), fenoxaprop-p-ethyl (110 g ha^{-1}), fluazifop-p-butyl (250 g ha^{-1}), haloxyfop-methyl (60 g ha^{-1} + mineral oil at 0.5%), quizalofop-p-tefuryl (72 g ha^{-1} + mineral oil at 0.5%), mesotrione (192 g ha^{-1} + mineral oil at 0.5%), nicosulfuron (50 g ha^{-1}), tembotrione (100.8 g ha^{-1} + vegetal oil at 0.5%), ammonium-glufosinate (500 g ha^{-1} + vegetal oil at 0.5%), paraquat (300 g ha^{-1} + surfactant at 0.1%) and glyphosate (960 g e.a. ha^{-1}). In each experiment, three control treatments were maintained without application, one for each population.

For the dose-response curve (first) and post-emergence experiments (third and fourth), *C. elata* seeds were sown in styrofoam trays for seedling formation. Seventeen days after sowing, transplant to planters was completed, with subsequent thinning, maintaining three plants per planter.

Each experimental unit consisted of a plastic planter with a 5 dm^3 soil capacity. As a substrate, a soil, sand and vegetable compost mixture was used, in the proportion of 3:1:1, respectively, fertilized with 100 mg of nitrogen, 200 mg of phosphorus and 150 mg of potassium per kg of substrate. The substrate had clayey texture (404, 440 and 91 g kg^{-1} of sand, clay and silt, respectively), whose chemical analysis indicated pH in $CaCl_2$ of 5.6; CEC, sum of bases, H + Al, Ca, Mg and K of 84, 60, 24, 40, 14 and 5.7 $mmol_c$ dm^{-3}, respectively; 45 g dm^{-3} of organic matter; and 64 mg dm^{-3} of P. Each planter was placed on a plastic container of larger diameter and without holes, in order to maintain the water regime of the plots. Soil moisture was controlled daily, with water being replenished in the planters whenever necessary.

Herbicides were applied with a 2.8 kgf cm^{-2} constant pressure (maintained by CO_2) backpack sprayer, equipped with a bar having two flat jet TT110015 nozzles, spaced 0.5 m apart, with a mixture consumption equivalent to 200 L ha^{-1}.

For the first, third and fourth experiments, 15 and 45 days after the application (DAA) of the herbicides, visual control evaluations were performed, using a grade scale from 0 to 100%, where zero represents the absence of visual injuries and 100 represents plant death. For the second experiment, in the same periods, the emerged plants were counted. For all of them, at 45 DAA, the whole green shoot of plants was collected, in order to determine the dry matter of the shoot. The material was dried in a forced air circulation and renovation oven at 50 °C, until reaching constant wheight, when it was evaluated. In the second experiment, results were estimated as reduction percentage of the number of emerged plants and reduction percentage of dry matter, in relation to the control treatments.

The obtained data were submitted to F test of the analysis of variance. The effects of the treatments, when significant, were compared by Scott-Knott test at a 5% probability. Interactions, when significant, were analyzed, and means were compared by Scott-Knott test at 5% probability, or analyzed using dose-response curves. In this case, data were fitted to the Boltzmann sigmoidal equation:

$$y = A_2 + (A_1 - A_2)/(1 + \exp((x - C_{50}(\text{ou } GR_{50}))/dx)),$$

in which the parameter A_2 represents the highest dose where there was no phytointoxication or dry matter reduction; A_1, the lowest dose causing absolute damage; dx, the declivity; and C_{50} or GR_{50}, the required glyphosate dose to cause 50% injury on plants (Seefeldt et al., 1995; Lamego and Vidal, 2008). C50 or GR50 are the herbicide doses that provide 50% control or dry matter reduction of the weed, respectively.

RESULTS AND DISCUSSION

Dose-response curve of three *Chloris elata* populations to glyphosate

The interaction populations vs glyphosate doses was significant for all the evaluated variables (Table 1). By proceeding to the unfolding of the interaction, control and dry matter data from each

Table 1 - Results of F test from the analysis of variance for control percentage of three *Chloris elata* populations, 15 and 45 days after the application (DAA) of glyphosate doses on plants with 7-8 tillers, as well as shoot dry matter at 45 DAA - Experiment 1. Brasília, Distrito Federal. 2015/2016

Variation source	Control		Dry matter 45 DAA
	15	45	
Populations	3.89*	4.09*	3.23*
Glyphosate	1529.43**	2042.04**	749.93**
Populations x glyphosate	3.78**	9.33**	6.93**
VC (%)	4.91	4.39	22.53

**. * Significant at 1% and 5% probability, respectively, by F test from the analysis of variance.

population were fitted to the Boltzmann sigmoidal curves. For all populations, the response curves to glyphosate doses indicated that the control level or dry matter reduction increased with sigmoidal behavior according to the increase in herbicide doses (Figure 1).

The required glyphosate dose (in kg a.e. ha^{-1}) to promote 50% control (C_{50}) of *C. elata* was 0.328 and 0.352 for the population from Itaberaí; 0.295 and 0.350 for Matão, 0.330 and 0.352 for Jaboticabal, respectively, at 15 and 45 DAA (Table 2). For the shoot dry matter, the required glyphosate dose for a 50% reduction (GR_{50}) of mass accumulation was 0.275, 0.311 and 0.228 for the populations from Itaberaí, Matão and Jaboticabal, respectively.

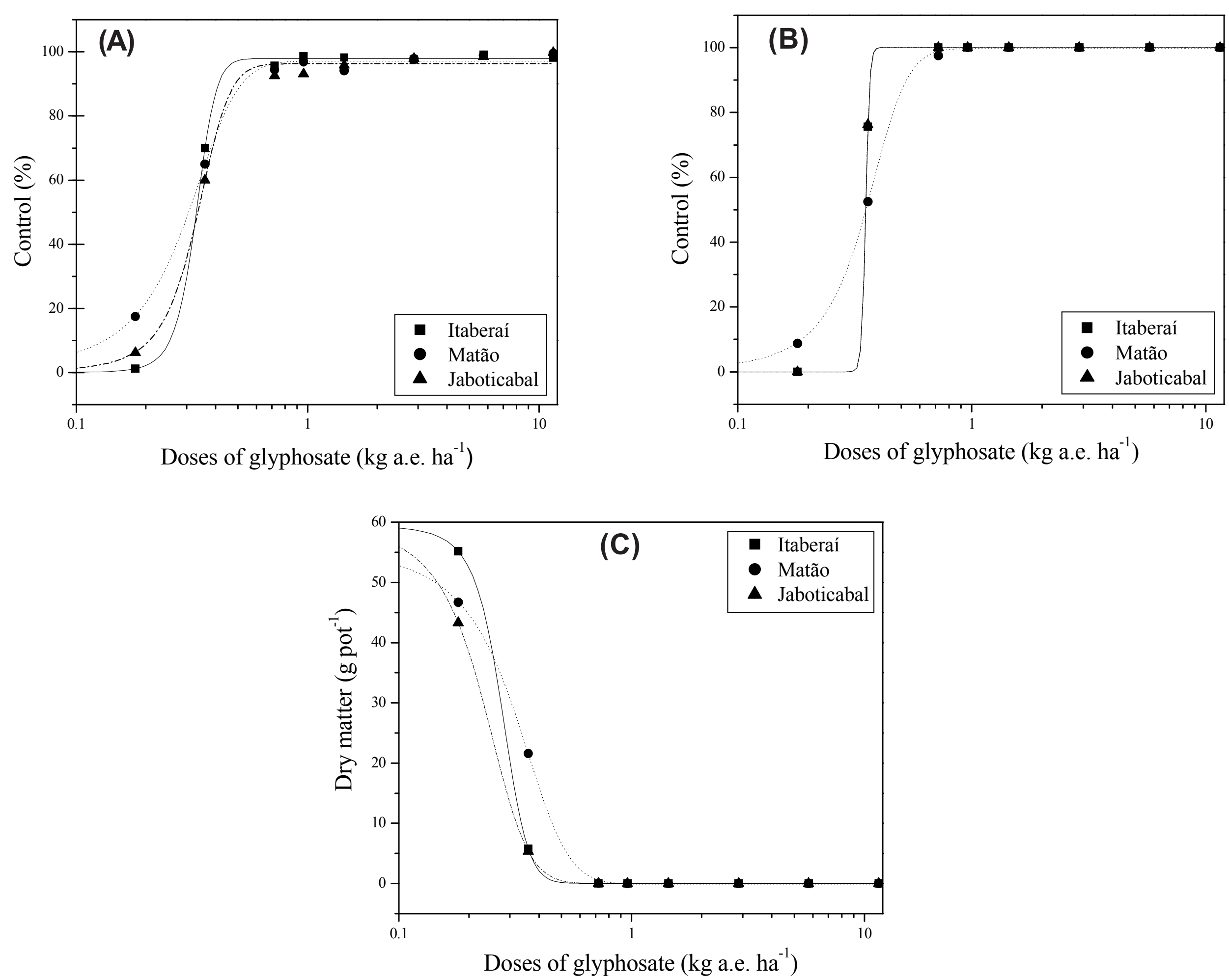

Figure 1 - Control (%) of three *Chloris elata* populations, 15 (A) and 45 (B) days after the application of different doses of glyphosate, as well as shoot dry matter (C) at 45 DAA - Experiment 1. Brasília. Distrito Federal. 2015/2016.

Table 2 - Parameters of the equations[1] that describe the control of three *Chloris elata* populations with different doses of glyphosate, as well as the doses obtaining 50% control (C_{50}) or dry matter reduction (GR_{50}) - Experiment 1. Brasília. Distrito Federal. 2015/2016

Variable	Population	Parameter			C_{50} or GR_{50}
		A_2	A_1	dx	
Control at 15 DAA	Itaberaí	97.902	-0.011	0.034	0.328
	Matão	97.093	-3.386	0.087	0.295
	Jaboticabal	96.298	-0.469	0.058	0.330
Control at 45 DAA	Itaberaí	100.000	-4.066	0.007	0.352
	Matão	99.753	-1.391	0.079	0.350
	Jaboticabal	100.000	-4.271	0.007	0.352
Dry matter at 45 DAA	Itaberaí	-7.704	59.621	0.038	0.275
	Matão	-0.108	58.281	0.093	0.311
	Jaboticabal	-0.002	61.699	0.056	0.228

[1] Equation: $y= A_2 + (A_1 - A_2)/(1 + \exp((x-C_{50}(\text{ou } GR_{50}))/dx))$.

These results indicated that the score variations in controlling the three *C. elata* populations through glyphosate were not very significant, although they were statistically significant. As for dry matter, the differences were more evident, mainly when comparing the populations from Jaboticabal and Matão, but without great practical relevance, since 100% control of the three populations was obtained starting from 0.72 kg ha^{-1} of glyphosate. The population from Jaboticabal was considered the most susceptible one in relation to the others, due to its GR_{50}.

Barroso et al. (2014), while evaluating the susceptibility difference of four *C. polydactyla* populations to glyphosate, found out that the GR_{50} values for the biotypes from Matão, Jaboticabal, Palotina and Palmital were 163.8 and 253.8; 146.2; and 107.9 and 63.8 g a.e. ha^{-1}, respectively. The GR_{50} of the Matão and Jaboticabal populations of the present study (0.311 and 0.228 kg a.e. ha^{-1}, respectively) was different from the values presented by Barroso et al. (2014) for individuals from the same regions (0.164 and 0.255, and 0.146 kg a.e. ha^{-1}, respectively). This fact may be justified by differences in plant size at the time of the application (4 leaves in the experiment by Barroso et al. (2014) and 7-8 tillers in this research) and in the seed collection sites, since the samples were collected in the same municipalities, but in different farms.

In another study, Brunharo et al. (2016) reported that the required glyphosate dose for a 50% reduction in the dry matter of plants from Matão and Piracicaba was 620 and 114 g a.e. ha^{-1}, respectively, resulting in a resistance factor of 5.4; that is, the resistant biotype (Matão) was 5.4 times less sensitive to the herbicide than the susceptible individual (Piracicaba). The basis for plant resistance to the herbicide may be associated with lower glyphosate absorption and translocation, compared to the susceptible biotype (Brunharo et al., 2016).

It is possible to conclude that the population from Jaboticabal was the most susceptible one to glyphosate, in relation to the others (Itaberaí and Matão). However, starting from 0.72 kg ha^{-1} of glyphosate, there was 100% control of the three populations.

Control of three *Chloris elata* populations by herbicides sprayed in pre emergence

The isolated factors and their interaction had a significant influence on all the evaluated characteristics (Table 3); the unfolding of the interaction was chosen.

At 15 DAA, the herbicides clomazone, flumioxazin, isoxaflutole, metribuzin, S metolachlor, sulfentrazone and trifluralin resulted in better control of the populations from Itaberaí and Matão, unlike diclosulam, chlorimuron and the control treatment (Table 4). For the population from Jaboticabal, the most effective treatments were clomazone, isoxaflutole, metribuzin, S-metolachlor and trifluralin. When comparing populations within each herbicide treatment, there was a difference between them only with diclosulam and chlorimuron, since the population from Matão was more sensitive to these herbicides than to the others.

Table 3 - Results of the F test from the analysis of variance for plant number percentage, in relation to the herbicide-free control treatment, of three *Chloris elata* populations, 15 and 45 days after the application (AAD) of pre-emergence herbicides, as well as the percentage of shoot dry matter at 45 DAA - Experiment 2. Brasília, Distrito Federal. 2015/2016

Variation source	Number of plants		Dry matter 45 DAA
	15	45	
Populations	19.21**	5.93**	2.38**
Herbicides	64.99**	77.38**	92.76**
Populations x Herbicides	5.23**	3.30**	2.12*
VC (%)	13.94	13.27	11.91

**. * Significant at 1% and 5% probability, respectively, by the F test from the analysis of variance.

Table 4 - Reduction of plant number, in relation to the control treatment without herbicide, of three *Chloris elata* populations, 15 days after the application (AAD) of pre-emergence herbicides - Experiment 2. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose ($g\ ha^{-1}$)	Populations		
		Itaberaí	Matão	Jaboticabal
		Plant number reduction (%) - 15 DAA		
Clomazone	800	100.00 a A(1)	100.00 a A	100.00 a A
Diclosulam	35	22.41 b B	75.92 b A	34.18 c B
Flumioxazin	50	80.00 a A	97.99 a A	87.76 b A
Isoxaflutole	37.5	95.56 a A	99.08 a A	100.00 a A
Chlorimuron-ethyl	20	6.11 b B	66.96 b A	14.28 d B
Metribuzin	480	98.52 a A	98.61 a A	97.96 a A
S-metolachlor	1920	100.00 a A	100.00 a A	100.00 a A
Sulfentrazone	400	92.59 a A	96.91 a A	79.59 b A
Trifluralin	810	100.00 a A	100.00 a A	100.00 a A

(1) Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment.

In the subsequent evaluation (45 DAA), only treatments with diclosulam, for the population from Itaberaí; with diclosulam and sulfentrazone, for the population from Jaboticabal; and with hlorimuron, for the three populations, were ineffective and differed from the other herbicides (Table 5). In addition, the population from Matão was more sensitive to diclosulam than the ones from Itaberaí and Jaboticabal. However, as for the other herbicides, there was no response variability among them.

As for shoot dry matter, plants from Itaberaí treated with clomazone, isoxaflutole, metribuzin, S-metolachlor and trifluralin accumulated less matter, unlike the other herbicides (Table 6). The same was observed for the populations from Matão and Jaboticabal, including diclosulam and flumioxazin in the group of the most effective herbicides. As for flumioxazin and chlorimuron, populations differed among each other, with Matão and Jaboticabal being more sensitive to these herbicides than Itaberaí.

Although there was a considerable emergence of plants from the Itaberaí and Jaboticabal populations for the treatment with diclosulam, plants had their growth inhibited by this herbicide, with reflection in mass accumulation, obtaining an 80 and 87% reduction in the dry matter of the shoot, respectively for Itaberaí and Jaboticabal, compared to the control treatment with no application.

The herbicides clomazone, isoxaflutole, S-metolachlor and trifluralin have a broader spectrum of grass species control (Rodrigues and Almeida, 2011). Although none of them are registered for species from the genus *Chloris*, the excellent control of other grass species was confirmed in this study for *C. elata*. In another work, the herbicides S-metolachlor (1.44 $kg\ ha^{-1}$) and trifluralin

Table 5 - Plant number reduction, in relation to the control treatment without herbicide, of three *Chloris elata* populations, 45 days after the application (AAD) of pre-emergence herbicides - Experiment 2. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose (g ha^{-1})	Population		
		Itaberaí	Matão	Jaboticabal
		Plant number reduction (%) - 45 DAA		
Clomazone	800	100.00 a A[(1)]	100.00 a A	100.00 a A
Diclosulam	35	29.85 b C	86.77 a A	69.39 b B
Flumioxazin	50	80.59 a A	93.39 a A	87.76 a A
Isoxaflutole	37.5	96.27 a A	96.11 a A	100.00 a A
Chlorimuron-ethyl	20	8.58 c A	20.52 b A	18.36 c A
Metribuzin	480	98.51 a A	96.11 a A	97.96 a A
S-metolachlor	1920	100.00 a A	100.00 a A	100.00 a A
Sulfentrazone	400	89.55 a A	91.05 a A	79.59 b A
Trifluralin	810	99.25 a A	98.05 a A	100.00 a A

[(1)] Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment.

Table 6 - Shoot dry matter reduction, in relation to the control treatment without herbicide, of three *Chloris elata* populations, 45 days after the application (DAA) of pre-emergence herbicides - Experiment 2. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose (g ha^{-1})	Populations		
		Itaberaí	Matão	Jaboticabal
		Dry matter reduction (%) - 45 DAA		
Clomazone	800	100.00 a A[(1)]	100.00 a A	100.00 a A
Diclosulam	35	80.25 b A	94.22 a A	87.48 a A
Flumioxazin	50	65.45 c B	88.23 a A	90.05 a A
Isoxaflutole	37.5	98.08 a A	92.58 a A	100.00 a A
Chlorimuron-ethyl	20	0.00 d B	23.11 c A	16.05 c A
Metribuzin	480	94.34 a A	88.68 a A	97.67 a A
S-metolachlor	1920	100.00 a A	100.00 a A	100.00 a A
Sulfentrazone	400	86.15 b A	79.61 b A	70.32 b A
Trifluralin	810	99.85 a A	99.50 a A	100.00 a A

[(1)] Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment.

(1.8 kg ha^{-1}), sprayed in pre-emergence, were also effective in controlling *C. polydactyla* (Brighent et al., 2007).

Metribuzin, flumioxazin and sulfentrazone have a greater control spectrum of eudicot species, but with actions on some grasses (Rodrigues and Almeida, 2011). Chlorimuron has a suppressive effect of grasses when sprayed in pre-emergence (Sharma et al., 2014), and it is mainly used to control eudicot species in post-emergence. The inclusion of these non-specific herbicides to control grasses is justified by their importance in agricultural crops, either in the pre-sowing management ("desiccation") of soybean (flumioxazin and chlorimuron), maize and cotton (flumioxazin) in no-tillage systems, or in sugarcane (metribuzin and sulfentrazone), soybean (sulfentrazone) crops or for potato and tomato (metribuzin) (Corrigan et al., 2000; Jaremtchuk et al., 2008; Cahoon et al., 2014; Perez-Moreno et al., 2014; Dittmar et al., 2015; Correia, 2016).

It is possible to conclude that, in pre-emergence, there was a differential response from the populations to flumioxazin and chlorimuron-ethyl. The herbicides clomazone, isoxaflutole, metribuzin, S-metolachlor and trifluralin were effective in controlling the three populations of *C. elata*.

Control of three *Chloris elata* populations by herbicides sprayed in post-emergence

When herbicides were sprayed on *C. elata* plants with 2-3 tillers, there was a significant difference between the populations only for the control percentage at 15 DAA (Table 7). Treatments with herbicides, as well as the interaction of the factors (populations x herbicides) affected significantly all the evaluated characteristics. In plants with 5-6 tillers, *C. elata* populations differed as for control percentage at 45 DAA and shoot dry matter. Treatments with herbicides influenced significantly all the evaluated characteristics. The interaction between populations and herbicides was significant only for the control percentage at 45 DAA. When the isolated factor and its interaction were significant for the same variable, the unfolding of the interaction was chosen.

In plants with 2-3 tillers, at 15 DAA, mesotrione was ineffective to control the three *C. elata* populations, while tembotrione, ammonium-glufosinate and nicosulfuron provided partial control (Table 8). The herbicide mesotrione controls eudicot species, but it acts on some grasses (species from the Poaceae family), unlike nicosulfuron and tembotrione, which control some eudicots, but their main target are grasses (Rodrigues and Almeida, 2011). The unsatisfactory control of *C. elata* by these herbicides can be explained by the plant size at the time of the application, since they are effective to control grasses before tillering (Zhang et al., 2013, De Cauwer et al., 2014) . On the other hand, *C. distichophylla* control by mesotrione was ineffective (75%) even in plants with four leaves (Nunes et al., 2007).

Table 7 - Results of the F test from the analysis of variance for the control percentage of three Chloris elata populations, 15 and 45 days after the application (DAA) of herbicides on plants with 2-3 or 5-6 tillers, as well as the shoot dry matter at 45 DAA - Experiments 3 and 4. Brasília, Distrito Federal. 2015/2016

Variation source	Plants with 2-3 tillers			Plants with 5-6 tillers		
	Control - DAA		DM 45 DAA	Control - DAA		DM 45 DAA
	15	45		15	45	
Populations	4.77*	2.11^{ns}	3.04^{ns}	0.66^{ns}	3.33*	6.51*
Herbicides	162.43**	232.29**	176.24**	292.07**	1056.45**	430.17**
Pop. x Herb.	2.39**	2.12**	1.66*	0.78^{ns}	1.74*	1.18^{ns}
VC (%)	14.91	15.66	33.96	13.12	8.42	21.21

**. * Significant at 1% adnd 5% respectively, by the F test from the analysis of variance. ns Non significant by F test from the analysis of variance.

Table 8 - Control percentage of three *Chloris elata* populations, 15 days after the application (DAA) of herbicides on plants with 2-3 tillers, as well as the control treatment without herbicide - Experiment 3. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose ($g\ ha^{-1}$)	Populations		
		Itaberaí	Matão	Jaboticabal
		Control (%) - 15 DAA		
Clethodim	108	83.75 a A[(1)]	88.75 a A	78.75 b A
Fenoxaprop-p-ethyl	110	88.75 a A	92.25 a A	81.25 b A
Fluazifop-p-butyl	250	81.25 a A	75.00 b A	81.25 b A
Haloxyfop-methyl	60	82.50 a A	73.75 b A	78.75 b A
Quizalofop-p-tefuryl	72	83.75 a A	82.50 b A	90.62 a A
Mesotrione	192	2.50 d A	6.25 d A	8.75 d A
Nicosulfuron	50	53.75 b B	73.75 b A	48.75 c B
Tembotrione	100.8	12.50 d B	46.25 c A	35.00 c A
Ammonium-glufosinate	500	38.75 c A	48.75 c A	38.75 c A
Paraquat	300	97.50 a A	99.75 a A	97.50 a A
Glyphosate	960[(2)]	80.00 a A	86.25 a A	90.00 a A
Control treatment	-	0.00 d A	0.00 d A	0.00 d A

(1) Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment. (2) Dose of the acid equivalent.

When comparing populations within each herbicide/control treatment, there was a significant difference between them only for nicosulfuron and tembotrione. When spraying nicosulfuron, there was a higher control percentage (74%) for the population from Matão, compared to the others. As for tembotrione, the population from Itaberaí was more tolerant to this herbicide than the ones from Matão and Jaboticabal; however, the control scores of all three populations were unsatisfactory (<46%).

Changes related to absorption, translocation, site of action, metabolization or even compartmentalization of nicosulfuron and tembotrione by plants justify the response variability of the *C. elata* populations to the action of the products. The genetic diversity of weed populations, which is affected by numerous evolutionary factors such as production system, interaction between crops and weeds (gene flow through the dispersion of pollen and seeds), geographic distribution and natural selection, should also be considered (Huangfu et al., 2009).

At 45 DAA, the herbicides clethodim, fenoxaprop, fluazifop, haloxyfop, quizalofop, paraquat and glyphosate provided the best control on the three weed populations, with a reflection on the shoot dry matter (Tables 9 and 10). The correlation coefficient between control scores and dry matter was 98.7% (data not shown). Among the herbicides, the populations differed only for nicosulfuron, with higher control percentage and lower mass accumulation by plants from Matão. As for the control treatment, plants from Itaberaí had greater dry matter than the other populations.

The herbicides clethodim, fenoxaprop, fluazifop, haloxyfop and quizalofop control only grasses (Poaceae family species) in post-emergence, and are selective for several crops; however, none of them is registered to control species from the *Chloris* genus (Rodrigues and Almeida, 2011). Paraquat and glyphosate have a broad control spectrum and may be applied before or after the establishment of crops, depending on the cultivated species (and on possible genetic modification /transgeny) and on the registration recommendation (Rodrigues and Almeida, 2011). The herbicide glyphosate is registered for some species from the genus *Chloris*, depending on the commercial product, but it has no registration for *C. elata*.

In the second experiment (plants with 5-6 tillers), at 15 DAA, paraquat resulted in the best control of *C. elata*, unlike other herbicides (Table 11). However, at 45 DAA, the herbicides clethodim, fenoxaprop, fluazifop, haloxyfop, quizalofop and glyphosate were also effective in controlling the three populations; on the population from Itaberaí, paraquat differed from the most effective treatments (Table 12). The populations differed only for the herbicide nicosulfuron; Matão was more sensitive to the herbicide than the others. However, this response difference

Table 9 - Control percentage of three *Chloris elata* populations, 45 days after the application (DAA) of herbicides on plants with 2-3 tillers, as well as the control treatment without herbicide - Experiment 3. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose (g ha^{-1})	Populations		
		Itaberaí	Matão	Jaboticabal
		Control (%) - 45 DAA		
Clethodim	108	96.25 a A[(1)]	98.12 a A	94.38 a A
Fenoxaprop-p-ethyl	110	100.00 a A	100.00 a A	98.75 a A
Fluazifop-p-butyl	250	95.00 a A	91.25 a A	94.38 a A
Haloxyfop-methyl	60	99.12 a A	88.75 a A	90.62 a A
Quizalofop-p-tefuryl	72	98.75 a A	95.00 a A	98.12 a A
Mesotrione	192	0.00 c A	0.00 d A	0.00 c A
Nicosulfuron	50	35.00 b B	66.25 b A	27.50 b B
Tembotrione	100.8	2.50 c A	10.00 d A	10.00 c A
Ammonium-glufosinate	500	32.50 b A	32.50 c A	15.00 b B
Paraquat	300	95.00 a A	100.00 a A	93.75 a A
Glyphosate	960[(2)]	93.75 a A	88.75 a A	99.38 a A
Control treatment	-	0.00 c A	0.00 d A	0.00 c A

[(1)] Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment. [(2)] Dose of the acid equivalent.

Table 10 - Shoot dry matter of three *Chloris elata* populations, 45 days after the application (DAA) of the herbicides on plants with 2-3 tillers, as well as the control treatment without herbicide - Experiment 3. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose ($g\ ha^{-1}$)	Population		
		Itaberaí	Matão	Jaboticabal
		Plant dry matter (g per planter)		
Clethodim	108	0.16 a A	0.08 a A	0.34 a A
Fenoxaprop-p-ethyl	110	0.00 a A	0.00 a A	0.08 a A
Fluazifop-p-butyl	250	0.21 a A	0.49 a A	0.34 a A
Haloxyfop-methyl	60	0.28 a A	0.56 a A	0.50 a A
Quizalofop-p-tefuryl	72	0.06 a A	0.18 a A	0.05 a A
Mesotrione	192	35.83 e A	34.23 e A	33.42 c A
Nicosulfuron	50	15.28 b B	9.10 b A	17.37 b B
Tembotrione	100.8	26.62 d A	24.92 d A	21.93 b A
Ammonium-glufosinate	500	19.33 c A	16.64 c A	20.15 b A
Paraquat	300	2.26 a A	0.00 a A	2.07 a A
Glyphosate	960[2]	0.42 a A	2.73 a A	0.02 a A
Control treatment	-	45.17 f B	34.74 e A	33.18 c A

[1] Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment. [2] Dose of the acid equivalent.

Table 11 - Control percentage of *Chloris elata*, 15 days after the application (DAA) of herbicides on plants with 5-6 tillers, as well as shoot dry matter at 45 DAA - Experiment 4. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose ($g\ ha^{-1}$)	Control (%) 15 DAA	DM (g per planter) 45 DAA
Clethodim	108	62.92 c	0.01 a
Fenoxaprop-p-ethyl	110	60.42 c	0.00 a
Fluazifop-p-butyl	250	61.25 c	0.01 a
Haloxyfop-methyl	60	60.42 c	0.00 a
Quizalofop-p-tefuryl	72	61.25 c	0.11 a
Mesotrione	192	34.58 d	41.09 d
Nicosulfuron	50	0.83 f	33.56 c
Tembotrione	100.8	61.25 c	21.36 b
Ammonium-glufosinate	500	7.50 e	41.09 d
Paraquat	300	96.96 a	2.04 a
Glyphosate	960[2]	87.29 b	0.00 a
Control treatment	-	0.00 f	46.62 e

[1] Based on the Scott-Knott test at 5% probability, means followed by lowercase letters, in the columns, compare herbicide/control treatments within each evaluated characteristic. [2] Dose of acid equivalent.

did not reflect in higher herbicide effectiveness, since, even for plants from Matão, control was under 30%.

As for the shoot dry matter, the interaction between populations and herbicides was not significant. In this case, clethodim, fenoxaprop, fluazifop, haloxyfop, quizalofop, paraquat and glyphosate promoted less mass accumulation by plants (Table 11). In addition, plants from the Itaberaí control treatment had higher dry matter than the other populations (data not shown).

In another study, clethodim (120 $g\ ha^{-1}$), fluazifop-p-butyl (187.5 $g\ ha^{-1}$), haloxyfop-methyl (60 $g\ ha^{-1}$) and quizalofop-p-tefuryl (120 $g\ ha^{-1}$) were also effective in controlling *C. polydactyla* in plants with six leaves (Brighenti et al., 2007). The same result was observed for *C. verticillata*, in plants with 5 to 10 tillers, with glyphosate (1.121 kg a.e. ha^{-1}), clethodim (210 $g\ ha^{-1}$) and quizalofop (70 $g\ ha^{-1}$) (Hennigh et al., 2005).

Table 12 - Control percentage of three *Chloris elata* populations, 45 days after the application (DAA) of herbicides on plants with 5-6 tillers, as well as the control treatment without herbicide - Experiment 4. Brasília, Distrito Federal. 2015/2016

Herbicide/ Control treatment	Dose (g ha^{-1})	Population		
		Itaberaí	Matão	Jaboticabal
		Control (%) - 45 DAA		
Clethodim	108	100.00 a A[1]	100.00 a A	99.38 a A
Fenoxaprop-p-ethyl	110	100.00 a A	100.00 a A	100.00 a A
Fluazifop-p-butyl	250	100.00 a A	99.38 a A	100.00 a A
Haloxyfop-methyl	60	100.00 a A	100.00 a A	100.00 a A
Quizalofop-p-tefuryl	72	100.00 a A	100.00 a A	97.50 a A
Mesotrione	192	0.00 d A	2.50 c A	0.00 d A
Nicosulfuron	50	10.00 c B	27.50 b A	7.50 c B
Tembotrione	100.8	16.25 c A	21.25 b A	16.25 b A
Ammonium-glufosinate	500	0.00 d A	0.00 c A	0.00 d A
Paraquat	300	88.75 b A	93.12 a A	96.25 a A
Glyphosate	960[2]	100.00 a A	100.00 a A	100.00 a A
Control treatment	-	0.00 d A	0.00 c A	0.00 d A

[1] Based on the Scott-Knott test at 5% probability, averages followed by lower case letters in the columns compare the herbicide/control treatments within each population, and those followed by uppercase letters on the lines, compare populations within each herbicide/control treatment. [2] Dose of the acid equivalent.

It is possible to infer that, for herbicides sprayed in post-emergence, there was a response variability among *C. elata* populations only for nicosulfuron. Treatments with clethodim, fenoxaprop, fluazifop, haloxyfop, quizalofop, paraquat and glyphosate were effective in controlling plants with 2-6 tillers from the three populations.

The results obtained in this study provided new and potentially useful information on the chemical control of *C. elata*, an increasingly problematic species in Brazil, especially within citrus fruit orchards in the State of São Paulo.

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