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Selectivity of the herbicide linuron sprayed in pre-emergence and post-early in carrot

Seletividade do herbicida linuron pulverizado em pré-emergência e pós-inicial para cenoura

Núbia Maria Correia[1*]; Agnaldo Donizete Ferreira de Carvalho[1]

Abstract

Herbicide application is a method for weed control in carrot crops. However, the choice of the chemical treatment (herbicide, association of products, dose, and time of application) should consider its selectivity to the crop. It is desired to analyze the selectivity of linuron for carrot plants, when sprayed on pre-emergence and post-early cultivated plants. Two experiments were carried out in the field in an area of the commercial production of carrots, one with the Verano cultivar and the other with BRS Planalto. Both experiments included an experimental design with randomized blocks in a factorial 2 x 4 + 1 with six and four replications for the experiments with Verano and BRS Planalto, respectively. The herbicide linuron (675 and 990 g a.i. ha^{-1}) was sprayed at four times, counting from the carrot sowing day: in the pre-emergence of the crop at 0, 3, and 6 days after sowing (DAS) and in the post-early emergence at 9 DAS, when the plants had 1 or 2 cotyledons. An untreated control was maintained as an additional treatment. Linuron was selective for the carrot plant cultivars Verano and BRS Planalto, in both doses tested, when sprayed in the pre-emergence, up to six days after sowing, and in the post-early (plants with 1 or 2 cotyledon leaves) at nine days after sowing
Key words: *Daucus carota* L. Phytointoxication. Tolerance.

Resumo

A aplicação de herbicidas é uma alternativa para o controle de plantas daninhas na cultura da cenoura. No entanto, a escolha do tratamento químico (herbicida, associações de produtos, dosagem e época de aplicação) deve considerar a sua seletividade para a cultura. Objetivou-se estudar a seletividade do herbicida linuron para plantas de cenoura, quando pulverizado em pré-emergência e pós-inicial das plantas cultivadas. Dois experimentos foram desenvolvidos a campo, em área de produção comercial de cenoura, um com a cultivar Verano e outro com a BRS Planalto. Nos dois experimentos, o delineamento experimental foi o de blocos ao acaso, em esquema fatorial 2 x 4 + 1, com seis e quatro repetições, no experimento com Verano e BRS Planalto, respetivamente. O herbicida linuron (675 e 990 g i.a. ha^{-1}) foi pulverizado em quatro épocas a partir do dia da semeadura da cenoura: em pré-emergência da cultura aos 0, 3, 6 dias após a semeadura (DAS) e em pós-emergência inicial aos 9 DAS, quando as plantas tinham 1 ou 2 folhas cotiledonares. Uma testemunha sem herbicida foi mantida como tratamento adicional. O linuron, nas duas dosagens testadas, foi seletivo para as plantas de cenoura cultivares Verano e BRS Planalto, quando pulverizado em pré-emergência, até seis dias após a semeadura, e pós-inicial (plantas com 1 ou 2 folhas cotiledonares), aos nove dias após a semeadura.
Palavras-chave: *Daucus carota* L. Fitointoxicação. Tolerância.

[1] Drs. Pesquisadores, Embrapa Hortaliças, Brasília, DF, Brasil. E-mail: nubia.correia@embrapa.br; agnaldo.carvalho@embrapa.br
[*] Author for correspondence

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Introduction

One of the biotic factors responsible for reducing the quantity and quality of carrot roots is the occurrence of weeds, which can result in up to 100% total loss (COELHO et al., 2009; FREITAS et al., 2009; SOARES et al., 2010; SWANTON et al., 2010). In addition to reducing the quantity and quality of the harvested product, weeds can serve as an alternative source of host pests, such as nematodes, and diseases (ALVAREZ; HUTCHINSON, 2005; BOYDSTON et al., 2008; KAWARAZAKI et al., 2009).

Herbicide application has been identified as a particularly effective method for weed control in carrot crop (QUEIROZ et al., 2016). However, despite its many advantages, chemical control requires careful tuning so that the expected result is achieved, such as the correct choice of product(s), dose, and application technology that are appropriate under the climate conditions and are suitably selective for the crop.

Selectivity is the basis for successful chemical weed control in agricultural production, and it can be considered as a distinctive response measurement of several plant species to a particular herbicide. The greater the difference in tolerance between the crop and weed, the safer the application (OLIVEIRA JUNIOR.; INOUE, 2011). The soil, climate, and use of adjuvants may also alter the degree of selectivity, and in some cases, the sensitivity varies depending on the genetic material (ALTERMAN; JONES, 2003).

According to horticulturists, linuron is the most commonly used herbicide among those registered for the cultivation of carrots in Brazil. There are some reports in the literature on its selectivity for carrot plants (LUCCHESI et al., 1975; BELLINDER et al., 1997; JENSEN et al., 2004; GRUSZECKI et al., 2015; MAIN et al., 2013; PACANOSKI et al., 2014; WILLIAMS II; BOYDSTON, 2005), but only one, the first cited, was tested under Brazilian conditions.

Linuron inhibits electron transport in Photosystem II in the photochemical step in photosynthesis. It belongs to the chemical group of substituted ureas, has the chemical name 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea and is registered for the control of pre- or post-emergence eudicotyledon weeds in carrot crops, at doses of 720-990 g a.i. ha^{-1} (RODRIGUES; ALMEIDA, 2011). In areas of the commercial production of the carrot, it is common to work with smaller doses (approximately 225 g a.i. ha^{-1}) sprayed in post-emergence two to three times until the closing of the crop. In these doses, linuron has a short residual effect in the soil, acting basically in post-emergence and not inhibiting the new emergence flow of weeds. It is done that way because technicians are concerned that higher herbicide doses will impair the quantity or quality of the carrot roots.

This present work has been conducted taking into account the hypothesis that linuron, in the doses recorded for the crop, is selective for carrot plants, regardless of the genetic material and time of application in relation to the day of sowing. Thus, it aimed at assessing the selectivity of linuron herbicide for Verano and BRS Planalto carrot plants when sprayed in pre-emergence and post-early.

Materials and Methods

Two experiments were carried out in the field, in the area of commercial carrot production in the municipality of Cristalina, in the state of Goiás in Brazil, one with the cultivar Verano (Jan. 9th to Apr. 27th/2015) and the other with BRS Planalto (Jul. 6th to Oct. 20th/2015).

The local altitudes are 970 and 991 meters, the latitudes 16°05'43.1"S and 16°13'18.4"S, and the longitudes 47°27'44.5"W and 47°28'06.4"W for the experiments with the Verano and BRS Planalto cultivars, respectively. According to the Köppen classification, the climate is Aw – tropical humid, with a dry reverse (CARDOSO et al., 2014). The experimental area's soil is representative of this region, classified as red latosol: clayey (in the

experiment with Verano), with a soil texture, in g kg^{-1}, of 590 clay, 368 silt, and 42 sand; a pH (in water) of 6.7 and an organic matter content of 2.8 dag kg^{-1}; and extremely clayey (in the experiment with BRS Planalto), with a soil texture, in g kg^{-1}, of 690 clay, 268 silt, and 42 sand; a pH (in water) of 6.5, and an organic matter content of 2.7 dag kg^{-1}.

Both experiments included an experimental design with randomized blocks in factorial 2 x 4 + 1, with six and four replications in the experiments with Verano and BRS Planalto, respectively. Linuron herbicide in doses of 675 and 990 g i.a. ha^{-1} was sprayed at four moments counting from the carrot sowing day: in the pre-emergence of the crop at 0, 3, and 6 days after sowing (DAS) and in the post-emergence at 9 DAS, when the plants had 1 or 2 cotyledons. An untreated control was kept as an additional treatment.

The carrot cultivars were selected according to the possible genetic differences between them. Verano is a popular summer hybrid, and BRS Planalto is an open pollinated cultivar directly derived from the cultivar Brasília that has been a model cultivar in the summer production of carrots in Brazil.

All the plots were maintained without weeds until the carrot harvest, with the manual elimination of eventual "escapes" from the chemical control and the manual removal of all the weeds in the treatment without herbicide (zero dose).

The carrots were sown in beds with 1.4 m at the top and 0.4 m of distance between them. The sowing was mechanical (Stanhay Star seeder), with the seed distribution in three triple lines (one central and lateral double), 0.1 m wide each, spaced at 0.4 m. Base fertilization was performed by applying 2000 kg ha^{-1} of a 03-35-06 formulation. At 35, 45, 60 and 75 days after sowing, cover fertilization was performed using 57 kg ha^{-1} K_2O each time in the form of potassium chloride.

In the experiment with Verano, the plots were 1.4 m wide (three triple lines) and 4.0 m long, with a central triple line, and 2.0 m long as usable area, for a total of 1.0 m^2. For BRS Planalto, the plots were 1.4 m wide (three triple lines) and 2.0 m long, with three central triple lines x 1.0 m long (1.4 m^2) as useful area.

Herbicide was applied with the aid of a backpack sprayer with a constant pressure (maintained by compressed CO_2) of 2.8 kgf cm^{-2}, equipped with three flat spray nozzles (TTI 110015) in the bar, spaced at 0.5 m, with a spray consumption equivalent to 200 L ha^{-1}. Table 1 shows the day and soil and climatic conditions at the time of application.

Table 1. Date, climatic and soil conditions at the time of the application of the herbicides. Cristalina, GO. 2015.

Exp.	Time (DAS)	Date	Temperature (°C)		Relative humidity (%)	Wind speed (km h^{-1})	Soil moisture
			Air	Soil			
Verano	0	01/09	30.7	31.1	53	3.8-4.2	[1]Wet 5 to 10 cm
	3	01/12	23.4	23.5	69	6.2-7.4	Wet
	6	01/15	23.7	21.5	63	4.5-5.6	Wet
	9[2]	18/01	22.7	22.5	84	6.0-7.4	Wet
BRS Planalto	0	07/06	26.5	21.5	55	5.2-2.7	Wet
	3	07/09	22.1	17.5	61	3.5-5.8	Wet 5 to 10 cm
	6	07/12	24.5	18.5	58	8.7-9.5	Wet
	9[3]	07/15	27.3	24.5	43	6.2-4.3	Wet 5 to 10 cm

DAS – days after sowing. [1] Soil dry on the surface (0 to 5 cm). [2] 5 to 10% of emerged plants with cotyledon leaves. [3] Approximately 50% of the emerged plants with 1 to 2 cotyledons.

Possible visual damage in carrot plants were evaluated at 15, 30, 45 and 60 days after the application (DAA) of the herbicide, using a scale from 0 to 100%, where zero represents the absence of visual damage and 100 represents plant death (SBCPD, 1995).

Harvesting was performed by hand by removing all roots from the plot area. These were separated into commercial and discard sets and counted and weighed to determine the number and fresh matter of roots per plot. The values were estimated for t ha^{-1} and a thousand uni. ha^{-1}, respectively, for the yield and number of commercial roots, discard and total (commercial + discard). The discard roots were those with a diameter less than 2.5 cm, length less than 12 cm, presence of deformation, green shoulder, cracks or insect attack.

Based on the data of the yield and number of commercial roots and discards per plot, the root fresh matter of commercial or discard quality per plant was determined. The foliage fresh matter of 10 plants (kg) and length and diameter of ten roots (cm and mm $root^{-1}$, respectively) were also evaluated.

The results were submitted to the F test of the analysis of variance. The effects of doses of linuron, when significant, were compared by the Tukey test at 5% probability and sowing dates by a polynomial fit of the data. Interactions, when significant, were deployed and the means were compared by the Tukey test at 5% probability for linuron doses and a polynomial data set for application times. To evaluate the behavior of the control without product in relation to the dosage and application time, the degrees of freedom of the treatments were deployed as a course of orthogonal contrasts of interest. The control without product was compared to the appropriate treatments. The F test was applied to each contrast to accept or reject the hypothesis H_0 (Y = 0).

Results and Discussion

The linuron herbicide, regardless of the dose (675 and 990 g a.i. ha^{-1}) and the time of application in relation to the sowing day, did not cause visual damage to the carrot plants of cultivars Verano and BRS Planalto. The same was observed by Bellinder et al. (1997) when applying 140 and 280 g a.i. ha^{-1} of linuron once or twice to carrot plants cv. Sativa 'Mark I', depending on the number of leaves. Linuron (1,100 g a.i. $ha^{-1)}$ sprayed in post-emergence also caused no herbicide symptoms to carrot cv. Cosmos (WILLIAMS II; BOYDSTON, 2005). In pre-emergence, this herbicide isolated (1,250 g a.i. ha^{-1}) or in combination with s-metolachlor (800 + 1,248 g a.i. ha^{-1}) did not induce visible damage in carrot plants cv. Nantes grown in a sandy-texture fluvisol (PACANOSKI et al., 2014).

Isolated treatments or those in interaction did not significantly influence the characteristics evaluated (Tables 2, 3, 4 and 5). Linuron herbicide was non-phytotoxic to carrots, even at nine days after sowing, when 5 to 10% of the Verano and approximately 50% of the BRS Planalto had already emerged in the field and had grown 1 or 2 cotyledons. This flexibility to the time of application of the herbicide is very important for the horticulturist, since it widens the range of use of the product in the crop. Thus, under the evaluated soil and climatic conditions, especially the textural class of the soil (clay and heavy clay) and organic matter content (2.8 and 2.7 dag kg^{-1}), linuron was very safe for the carrot. This result can be justified by the selectivity mechanism of the crops to linuron, which occurs through the metabolism of the product by the tolerant plants. This occurs through demethoxylation and demethylation reactions of the molecule, inactivating it into a non-toxic form (PASCAL-LORBER et al., 2010; RODRIGUES; ALMEIDA, 2011).

Table 2. Results of the F test of the analysis of variance for the yield and number of commercial roots, discard and total (commercial + discard) of carrot cv. Verano due to the application of the herbicide linuron and the control without product. Cristalina, GO. 2015.

Source of variation	Carrot yield			Number of roots		
	Commercial	Discard	Total	Commercial	Discard	Total
Treatments	0.56 ns	0.48 ns	0.36 ns	0.59 ns	0.19 ns	0.08 ns
Dose	0.97 ns	0.91 ns	0.40 ns	1.05 ns	0.26 ns	0.11 ns
Time	0.26 ns	0.08 ns	0.51 ns	0.06 ns	0.01 ns	0.05 ns
Dose x time	0.28 ns	0.28 ns	0.33 ns	0.34 ns	0.08 ns	0.06 ns
Factorial(1) x control	0.45 ns	0.23 ns	0.16 ns	0.51 ns	0.54 ns	0.09 ns
CV (%)	17.66	20.26	10.91	17.31	23.73	14.82
Average factorial	(t ha-1)			(thousand uni. ha-1)		
	33.29	13.68	46.97	331.99	338.37	670.36
Average control	31.60	14.25	45.85	314.16	363.89	678.05

(1) Doses of linuron (675 and 990 g ha-1) associated with times of application (0, 3, 6 and 9 days after sowing).
ns not significant by F test analysis of variance.

Table 3. Results of the F test of the analysis of variance for root fresh matter, commercial and discard per plant, diameter and length of carrot root cv. Verano and foliage fresh matter of ten plants due to the application of the herbicide linuron and the control without product. Cristalina, GO. 2015.

Source of variation	Root fresh matter per plant		Root diameter	Root length	Foliage fresh matter
	Commercial	Discard			
Treatments	0.30 ns	1.15 ns	0.31 ns	0.49 ns	0.88 ns
Dose	0.35 ns	1.90 ns	0.34 ns	0.30 ns	0.80 ns
Time	0.22 ns	0.02 ns	0.00 ns	0.13 ns	0.05 ns
Dose x time	0.37 ns	0.89 ns	0.47 ns	0.97 ns	1.22 ns
Factorial(1) x control	0.01 ns	0.77 ns	0.09 ns	0.83 ns	0.97 ns
CV (%)	10.38	11.48	8.48	9.02	25.18
Average factorial	(g)		(mm)	(cm)	(kg)
	100.86	41.07	25.77	17.12	0.32
Average control	101.34	39.27	26.05	16.51	0.28

(1) Doses of linuron (675 and 990 g ha-1) associated with times of application (0, 3, 6 and 9 days after sowing).
ns not significant by F test analysis of variance.

Table 4. Results of the F test of the analysis of variance for the yield and number of commercial roots, discard and total (commercial + discard) of carrot cv. BRS Planalto due to the application of the herbicide linuron and the control without product. Cristalina, GO. 2015.

Source of variation	Carrot yield			Number of roots		
	Commercial	Discard	Total	Commercial	Discard	Total
Treatments	0.68 ns	1.04 ns	1.78 ns	0.58 ns	0.85 ns	1.01 ns
Dose	0.76 ns	0.84 ns	0.85 ns	0.92 ns	0.24 ns	0.39 ns
Time	1.38 ns	0.00 ns	0.49 ns	0.03 ns	0.00 ns	0.01 ns
Dose x time	0.82 ns	1.41 ns	2.31 ns	0.79 ns	1.74 ns	2.11 ns
Factorial(1) x control	0.00 ns	0.53 ns	0.39 ns	0.01 ns	0.82 ns	0.56 ns
CV (%)	14.11	19.13	8.92	15.51	19.16	13.03
Average factorial	(t ha-1)			(thousand uni. ha-1)		
	29.32	16.46	45.78	246.88	356.42	603.30
Average control	29.31	15.25	44.56	248.61	323.61	572.22

(1) Doses of linuron (675 and 990 g ha-1) associated with times of application (0, 3, 6 and 9 days after sowing).
ns not significant by F test analysis of variance.

The assumption that the linuron herbicide, in the doses tested for the crop, affects the development of carrot plants was not supported by this work, which proved that the linuron was selective for the cultivars Verano and BRS Planalto in doses of 675 and 990 g ha^{-1}, sprayed nine days after sowing. Other studies have also demonstrated the selectivity of linuron for the carrot crop, such as Main et al. (2013), in which 1,186 g a.i. ha^{-1} of linuron, applied post-emergence, did not affect the productivity of carrot cv. Neptune. When sprayed in pre-emergence, this herbicide also did not affect the carrot yield of cultivars Dominator and Caro-Choice (1,000 g a.i. ha^{-1}) (JENSEN et al., 2004), Flakkese (675 g a.i. ha^{-1}) (GRUSZECKI et al., 2015) or Nantes (1,250 g a.i. ha^{-1}) (PACANOSKI et al., 2014).

Table 5. Results of the F test of the analysis of variance for root fresh matter, commercial and discard per plant, diameter and length of carrot root cv. BRS Planalto and foliage fresh matter of ten plants due to the application of the herbicide linuron and the control without product. Cristalina, GO. 2015.

Source of variation	Root fresh matter per plant		Root diameter	Root length	Foliage fresh matter
	Commercial	Discard			
Treatments	0.98 ^{ns}	1.67 ^{ns}	1.23 ^{ns}	0.75 ^{ns}	0.24 ^{ns}
Dose	0.28 ^{ns}	3.61 ^{ns}	1.82 ^{ns}	0.40 ^{ns}	0.15 ^{ns}
Time	5.31 ^{ns}	0.11 ^{ns}	0.16 ^{ns}	3.21 ^{ns}	0.93 ^{ns}
Dose x time	0.55 ^{ns}	0.80 ^{ns}	1.35 ^{ns}	0.52 ^{ns}	0.16 ^{ns}
Factorial$^{(1)}$ x control	1.11 ^{ns}	0.05 ^{ns}	0.23 ^{ns}	0.03 ^{ns}	0.02 ^{ns}
CV (%)	9.20	13.85	8.60	9.22	29.88
	(g)		(mm)	(cm)	(kg)
Average factorial	119.26	47.09	27.26	15.57	0.46
Average control	118.49	47.91	27.86	15.71	0.47

$^{(1)}$ Doses of linuron (675 and 990 g ha^{-1}) associated with times of application (0, 3, 6 and 9 days after sowing).
^{ns} not significant by F test analysis of variance.

Based on the results, it was concluded that linuron at 675 and 990 g a.i. ha^{-1} was selective for the carrot plant cultivars Verano and BRS Planalto when sprayed in pre-emergence, up to six days after sowing, and post-early (plants with 1 or 2 cotyledons), at nine days after sowing.

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