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Article

SELECTIVITY OF HERBICIDES TO CABBAGE (*Brassica oleracea* var. *capitata*)

Seletividade de Herbicidas à Cultura do Repolho (*Brassica oleracea* var. *capitata*)

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ABSTRACT - The presence of weeds in commercial fields of cabbage may interfere directly and indirectly on yield and on the quality of the commercial product. Therefore, the satisfactory production depends on a successful control of weeds. Because of the limited availability of herbicides registered in Brazil for cabbage crop in addition to the lack of information in the literature, the objective of this work was to evaluate the selectivity of herbicides to cabbage. The herbicides S-metolachlor (1,740 and 768 g ha^{-1}), oxyfluorfen (240 and 96 g ha^{-1}), flumioxazin (40 and 40 g ha^{-1}) clomazone (720 and 360 g ha^{-1}) and oxyfluorfen + flumioxazin (240 + 20 and 96 + 20 g ha^{-1}) were applied before and after transplant of seedlings, besides the S-metolachlor + flumioxazin (768 + 20 g ha^{-1}) mixture applied after transplant. The experiment was developed in the field, in a randomized block design with four replications. Weed control and cabbage crop injury were evaluated as well as the number of productive and suppressed cabbage plants, the average fresh mass of heads and yield. All herbicide treatments controlled weeds in the area satisfactorily; however, most of them caused high toxicity in plants with the exception of oxyfluorfen, applied before transplant, and flumioxazin and S-metolachlor, applied after transplant, which caused little leaf injury in plants. Oxyfluorfen applied before and after transplant and S-metolachlor, applied after transplant did not affect the number of productive and suppressed plants nor yield, being selective in cabbage.

Keywords: herbicides tolerance, weed management, yield.

RESUMO - A presença de plantas daninhas em áreas comerciais de repolho pode interferir direta e indiretamente na produtividade e na qualidade do produto comercial. Nesse sentido, a produção satisfatória depende do controle bem sucedido das infestantes. Diante da limitada disponibilidade de herbicidas registrados no Brasil para a cultura do repolho, aliada à escassez de informações na literatura, objetivou-se neste estudo avaliar a seletividade de herbicidas ao repolho. Os herbicidas S-metolachlor (1.740 e 768 g ha^{-1}), oxyfluorfen (240 e 96 g ha^{-1}), flumioxazin (40 e 40 g ha^{-1}), clomazone (720 e 360 g ha^{-1}) e oxyfluorfen + flumioxazin (240 + 20 e 96 + 20 g ha^{-1}) foram aplicados antes e após o transplante das mudas, respectivamente, e a mistura S-metolachlor + flumioxazin (768 + 20 g ha^{-1}), após o transplante. O experimento foi desenvolvido em campo, no delineamento em blocos casualizados com quatro repetições. O controle de plantas daninhas e a toxicidade da cultura do repolho foram avaliados, além do número de plantas produtivas e suprimidas de repolho, a massa fresca média de cabeça e a produtividade. Todos os tratamentos com herbicidas resultaram no controle satisfatório das plantas daninhas na área. Contudo, a maioria causou toxicidade elevada às plantas, com exceção de oxyfluorfen, aplicado antes do

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transplante, e flumioxazin e S-metolachlor, aplicados após o transplante, que provocaram poucos sintomas visuais nas plantas. Oxyfluorfen, aplicado antes e após o transplante, e S-metolachlor, aplicado após o transplante, não afetaram o número de plantas produtivas e suprimidas nem a produtividade, sendo seletivos ao repolho.

Palavras-chave: tolerância a herbicidas, manejo de plantas daninhas, produtividade.

INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata*) is a vegetable crop that stands out in the Brazilian scenario because of its economic importance due to the high volume produced and consumed in the country. In 2011, the cabbage production was 1.32 million tons, remaining stable in the years 2012 and 2013 (Anuário..., 2014) and excelling in relation the other broadleaf vegetable crops. According to the CONAB, in 2012, within the subgroup leaf, flower and stem, cabbage emerged as the most sold vegetable in Brazilian Supply Centers (Anuário..., 2013).

In cabbage production system, proper weed management is primordial for not compromising yield (Sonnenberg and Silva, 2005), crop management and harvesting, and especially the quality of the commercial product. In this regard, weeds popularly known in Brazil such as gallant soldier (*Galinsoga parviflora*) and hairy galinsoga (*Galinsoga quadriradiata*), of the Asteraceae family, whether present in cabbage areas, can reduce post-harvest product quality. This fact occurs because the drop of inflorescences of these weeds among cabbage leaves that overlap forming the head accelerates the deterioration process, reducing the shelf life of this vegetable (personal communication).

Because of the issues arising from the presence of weeds in the production area, a successful weed control becomes essential. The chemical method on large cropped areas is more economically viable and due to its larger practicality, it has been used by farmers for a long time. However, only two products are registered for cabbage crop in Brazil: glufosinate ammonium, which should be applied in directed spray, with limited use in large areas in addition of risks when achieving the crop, causing injuries, and trifluralin, especially recommended for grasses control applied in pre-planting with incorporation to soil (Brasil, 2016). Thus, it is highlighted the importance of selecting molecules that are effective in controlling weeds and selective for cabbage crop.

Selectivity is the basis for achieving effectiveness in the control with safety for crop. This is influenced by factors related to plants (retention, uptake, translocation, herbicide differential metabolism, cultivar and growth stage), to the herbicide (dose, formulation and mode of application) and environmental conditions (Oliveira Jr. and Inoue, 2011). In the Brazilian literature, there are quite few studies on selectivity of herbicides for cabbage crop. The information related to this subject is limited to works carried out in Canada and the United States. (Sikkema et al., 2006; 2007a,b; Harrison Jr. and Farnham, 2013; Harrison Jr. et al., 2015).

Cabbage tolerance to herbicides registered for other broadleaf vegetable crops, combined with the effective control, would extend the use of those products, enabling weed chemical control in the crop. Therefore, the objective of this study was to evaluate selectivity of different herbicides to cabbage crop.

MATERIAL AND METHODS

The experiment was developed in the field at the Instituto de Pesquisa Agrícola do Cerrado – IPACER, in the period from 06/26/2014 to 09/26/2014. The soil in the area is classified as Oxisol, clay texture (Embrapa, 2013), and it was prepared with plowing, two disking operations and the use of rotary hoe. The soil had the following chemical characteristics: pH (H_2O) 5.8; organic matter 4.8 dag dm^{-3}; P-rem 6.1 mg L^{-1}; P 9.9 mg dm^{-3}; K 118 mg dm^{-3}; Ca^{2+} 3.8 $cmol_c$ dm^{-3}; Mg^{2+} 0.8 $cmol_c$ dm^{-3}; Al^{3+} 0.0 $cmol_c$ dm^{-3}; H+Al 2.8 $cmol_c$ dm^{-3}; sum of bases 4.33 e cation exchange capacity 7.13 $cmol_c$ dm^{-3}.

The planting fertilization consisted of 70, 400 and 100 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. The source used for N was the monoammonium phosphate (MAP - 11% N and 52% P_2O_5), MAP and superphosphate (18% P_2O_5) sources was used for P and KCl (60% K_2O) for K. It was applied in coverage 60, 100 and 2 kg ha^{-1} N, K_2O and B, respectively, 15 day after transplant (DAT) of the seedlings. On 30 and 50 DAT, over 60 and 100 kg ha^{-1} of N and K_2O, respectively, was applied. The source of N used was urea (44% N), KCl for K and boric acid (17% B) for B.

Seedlings of Astro cultivar, more planted in areas of commercial production of cabbage in the Alto Paranaíba region, were grown in trays with 200 cells with a mixture of soil and animal manure in a greenhouse. After 21 days of sowing, the seedlings, standardized with two true leaves were manually transplanted into the field, in a spacing of 0.4 m between rows and 0.3 between seedlings. The final cabbage population was 62,000 plants per hectare.

Cultural practices commonly employed in commercial crops were carried out according to the requirement of the cabbage crop. The area was irrigated by a center pivot sprinkling system.

The experimental plots consisted of five rows with 10,0 m in length, spaced by 40,0 cm from each other, totaling 20,0 m^2. It was considered as useful area for evaluations, the three central rows, disregarding 2.5 m on each side, totaling 6 m^2.

The experiment was installed in a complete randomized block design with four replications. Application in the treatments (Table 1) was carried out before transplant (one day before), and after transplant of cabbage seedlings (two days after). A CO_2 pressurized coastal sprayer, fitted with a bar with four flat jet range tips, spaced 0.5 cm, pressure of 200 kPa and flow rate of 200 L ha^{-1} was used.

Prior to the application of the herbicides, a survey of weeds present in the field was carried out by using the square inventory method (0.25 x 0.25 m), randomly released four times in each plot. The density of weeds in the area was 556 plants m^{-2}, with greater frequency and abundance of the species *Amaranthus* sp. and *G. parviflora*.

On days 15 and 30 after herbicide application (DAA), visual assessment of weed control and injury in the cabbage crop was carried out (SBCPD, 1995). The injury visual symptoms was evaluated using scale of 0 to 100%, where 0% represents no symptoms and 100% represents death of the plant, according to method described by SBCPD (1995).

At harvest, held 90 days after seedling transplant, was counted the number of productive and suppressed cabbage plants; productive plants in the useful area were collected for determination of head average fresh mass, and yield was estimated. The suppressed plants were considered those which not formed head or formed very small head, which is not harvested in production areas because not reached the commercial standard.

Data were submitted to analyses of variance and when they were significant, the means were clustered by the Skott-Knott ($P<0.05$) criterion.

Table 1 - Description of treatments evaluated in the experiment

Herbicides	Dose (g ha^{-1})	Application time (in relation to the transplant)
Untreated control (manual weeding)	-	-
Clomazone	720	Before
Flumioxazin	40	Before
Oxyfluorfen	240	Before
Oxyfluorfen + Flumioxazin	240 + 20	Before
S-metolachlor	1440	Before
Clomazone	360	After
Flumioxazin	40	After
Oxyfluorfen	96	After
Oxyfluorfen + Flumioxazin	96 + 20	After
S-metolachlor + Flumioxazin	768 + 20	After
S-metolachlor	768	After

RESULTS AND DISCUSSION

All herbicides were effective in weed control (≥80%) (SBCPD, 1995) after 15 and 30 DAA (Table 2). However, some caused severe injuries in cabbage plants. At 15 DAA, cabbage plants showed injury above 50% caused by the application before transplant of S-metolachlor, flumioxazin, clomazone and oxyfluorfen + flumioxazin, and by oxyfluorfen + flumioxazin, clomazone and S-metolachlor + flumioxazin after transplant. At 30 DAA with this herbicides applied before transplant and S-metolachlor + flumioxazin mixture after transplant, the plants still presented visual symptoms of high injury (>70%) (Table 2).

For flumioxazin and S-metolachlor herbicides, in both evaluation times, the injuries caused in cabbage plants were much smaller when sprayed after transplant compared to the application before transplant (Table 2). Such behavior was also evidenced by Giordani et al. (2000) in a study on herbicide selectivity on lettuce and it may be related to lower absorption and translocation in the product when applied on the plants, providing greater tolerance.

Table 2 - Weed control and injury of cabbage plants to 15 and 30 days after application (DAA) of the herbicides

Herbicides	Application time (in relation to the transplant)	Weed control (%)		Cabbage injury (%)	
		15 DAA	30 DAA	15 DAA	30 DAA
Untreated Control (manual weeding)	-	100.0 a	100.0 a	0.0 h	0.0 g
Clomazone	Before	100.0 a	95.0 a	76.3 b	78.3 b
Flumioxazin	Before	91.3 a	87.5 c	86.3 a	95.0 a
Oxyfluorfen	Before	100.0 a	100.0 a	16.3 f	21.7 e
Oxyfluorfen + Flumioxazin	Before	95.0 a	90.0 c	50.0 c	72.5 b
S-metolachlor	Before	100.0 a	93.8 b	77.0 b	80.0 b
Clomazone	After	100.0 a	92.5 b	51.3 c	47.5 c
Flumioxazin	After	100.0 a	96.0 a	26.3 e	25.0 e
Oxyfluorfen + Flumioxazin	After	98.8 a	97.0 a	51.3 c	45.0 c
Oxyfluorfen	After	93.3 a	89.8 c	41.5 d	35.0 d
S-metolachlor	After	80.0 b	97.5 a	11.3 g	12.5 f
S-metolachlor + Flumioxazin	After	100.0 a	98.8 a	86.3 a	80.0 b
Overall average		96.5	94.8	47.8	49.4
$F_{treatment}$		3.2 **	8.8 **	109.5 **	151.7 **
VC (%)		7.0	3.0	11.9	10.3

Means followed by the same letter in the columns do not differ from each other by the Scott-Knott criterion (p>0.05). ** Significant at 1% probability by the F test analysis of variance.

The presence of herbicides in soil from applications before transplant and application on the aerial parts of cabbage plants may cause deleterious effects and their suppression. Among the evaluated treatments, only oxyfluorfen applied before and after transplant and S-metolachlor applied after transplant did not affect the number of productive and suppressed plants. Clomazone, followed by flumioxazin and S-metolachlor applied before transplant and S-metolachlor + flumioxazin applied after transplant were responsible for eliminating 54 to 84% of the population of cabbage plants (Table 3).

Flumioxazin and clomazone applied before transplant were the most harmful treatments to the cabbage, reducing by 70% and 85% the yield, respectively (Table 3). The clomazone herbicide is registered for cabbage crop in the USA, at doses of 280 to 560 g ha ^{1}, however, studies have shown differential tolerance among cultivars of cabbage and broccoli to the herbicide applied before transplant at doses of 280 to 1,120 g ha^{-1} (Harrison Jr. and Farnham, 2013; Harrison Jr. et al., 2015). The cabbage cultivar tested in this work in tropical conditions was highly sensitive to clomazone. Selectivity of herbicides to crops can be influenced by cultivar, plant growth stage and climatic conditions (Oliveira Jr. and Inoue, 2011).

Table 3 - Number of productive and suppressed cabbage plants, head average fresh mass and yield of cabbage sprayed with herbicides before and after transplant of seedlings

Herbicides	Application time (in relation to the transplant)	Productive plants	Suppressed plants	Head average fresh mass (kg)	Yield (t ha^{-1})
		(thousand plants ha^{-1})			
Untreated Control (manual weeding)	-	58.95 a	3.05 g	2.39 a	141.23 a
Clomazone	Before	9.71 g	52.29 a	2.17 a	21.34 f
Flumioxazin	Before	21.44 f	40.56 b	1.98 a	42.37 e
Oxyfluorfen	Before	60.05 a	1.95 g	2.34 a	140.78 a
Oxyfluorfen + Flumioxazin	Before	34.88 d	27.12 d	2.37 a	82.85 c
S-metolachlor	Before	28.36 e	33.64 c	2.29 a	65.06 d
Clomazone	After	54.73 b	7.27 f	2.33 a	127.79 b
Flumioxazin	After	54.84 b	7.16 f	2.31 a	126.83 b
Oxyfluorfen	After	57.36 a	4.64 g	2.46 a	141.26 a
Oxyfluorfen + Flumioxazin	After	50.50 c	11.50 e	2.29 a	115.79 b
S-metolachlor	After	58.84 a	3.62 g	2.31 a	135.18 a
S-metolachlor + Flumioxazin	After	31.12 e	30.88 c	2.74 a	85.74 c
Overall average		43.36	18.64	2.33	102.18
$F_{treatment}$		194.40 **	194.40 **	3.85**	81.46 **
VC (%)		5.7	13.3	7.7	9.1

Means followed by the same letter in the columns do not differ from each other by the Scott-Knott criterion (p>0.05). ** Significant at 1% probability by the F test analysis of variance.

The application of oxyfluorfen before and after transplant as well as S-metolachlor after transplant not affected the yield of the cabbage in compared to treatment with no herbicide (Table 3), evidencing their selectivity of the two herbicides to cabbage crop. The results corroborate with studies conducted in other countries, which did not evidence reduction in cabbage yield when those herbicides were applied (Sikkema et al., 2007a,b).

Experiments realized in Ontario tested the tolerance of cabbage to S-metolachlor applied before transplant and incorporated in the soil and before and after transplant at doses of 800, 1,600 and 2,400 g ha^{-1}. The results indicate the potential use of the S-metolachlor in cabbage crop because the dosages and times of application do not cause any injury in plants and did not affect the number and weight of commercial heads and the yield (Sikkema et al., 2007a). In this Canadian province, S-metolachlor is registered only in pre-emergence application of weeds (Sikkema et al., 2006). Oxyfluorfen was tested before transplant of cabbage, broccoli and cauliflower and showed acceptable level of safety for use in these crops (Sikkema et al., 2007b).

Currently, chemical control of weeds in cabbage crop in Brazil is very restricted due to the low number of registered products. In addition, works carried out under tropical conditions on the selectivity of herbicides to cabbage and other leafy vegetable crops are scarce in the literature. Thus, the study of selective molecules and the possibility of extending the use for this crop are fundamental to the viability of chemical control of weeds in commercial production fields of cabbage.

The oxyfluorfen herbicides applied before and after transplant, and s-metalochlor applied after transplant were selective to cabbage crop.

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