Revista Brasileira de Herbicidas, v.14, n.2, p.155-163, abr./jun. 2015 (ISSN 2236-1065)
DOI: http://dx.doi.org/10.7824/rbh.v14i2.399 www.rbherbicidas.com.br

Carryover of herbicides applied in the pre-emergence of cotton on the corn grown in succession[1]

Carryover de herbicidas aplicados em pré-emergência do algodoeiro sobre o milho cultivado em sucessão

Eliezer Antonio Gheno[2]; Rubem Silvério de Oliveira Jr.[3]; Jamil Constantin[3]; Denis Fernando Biffe[3]; Carlos César Evangelista de Menezes[4]; Luiz Henrique Morais Franchini[2]; Jethro Barros Osipe[2]; Ricardo Travasso Raimondi[5]

Abstract - Herbicides that present long persistence in the soil can cause problems in crops sown in succession due to the soil's residual effect. That way, the objective of this paper was to evaluate the effects of herbicides applied in the pre-emergence of the cotton to the productivity of corn grown in succession. The experiment was installed in the municipality of Santa Helena de Goiás - GO. The application of herbicides treatments were carried out in a pre-emergence state of the cotton by using isolated clomazone or in mixtures of fomesafen, fomesafen + trifluralin, fomesafen + s-metolachlor, fomesafen + diuron and fomesafen + prometryn. In the condition in which the experiment was carried out, the results observed allowed us to see that the application of herbicides in the pre-emergence state of cotton crops did not have any significant effects in the insertion height of the cob, insertion height of the tassel, stem diameter and corn productivity, resulting in the absence of carryover on the hybrid corn RR® AG 7098 PRO 2, considering safe the sowing of corn 264 days after the application of herbicides.
Keywords: residual activity; phytointoxication; persistence

Resumo - Herbicidas que apresentam longa persistência no solo podem causar problemas em culturas semeadas em sucessão, devido ao efeito residual no solo. Desta forma, o objetivo deste trabalho foi de avaliar os efeitos de herbicidas aplicados em pré-emergência do algodoeiro sobre a produtividade da cultura do milho semeada em sucessão. O experimento foi instalado no município de Santa Helena de Goiás – GO. As aplicações dos tratamentos herbicidas foram realizadas em pré-emergência do algodoeiro, utilizando-se clomazone isolado ou em misturas com fomesafen, fomesafen + trifluralin, fomesafen + s-metolachlor, fomesafen + diuron e fomesafen + prometryne. Na condição que foi conduzido o experimento, os resultados observados permitiram constatar que a aplicação dos herbicidas aplicados em pré-emergência na cultura do algodoeiro não acarretaram em efeitos significativos na altura de inserção de espiga, altura de inserção do pendão, diâmetro do colmo e produtividade de milho, resultando em ausência de *carryover* sobre o híbrido de milho RR® AG 7098 PRO 2, sendo considerada segura a semeadura de milho realizada 264 dias após a

[1] Received for publication on 27/07/2015 and approved on 07/08/2015.
[2] Engº-Agrº., M.Sc., Aluno do Programa de Pós-Graduação em Agronomia, Universidade Estadual de Maringá - UEM, 87020-900, Maringá-PR, Brasil, <eliezer.gheno@gmail.com>.
[3] Prof. Dr., Dep. de Agronomia, DAG/UEM.
[4] Prof. Dr., Universidade de Rio Verde – UniRV.
[5] Acadêmico em Agronomia, Universidade Estadual de Maringá – UEM.

aplicação dos herbicidas.
Palavras-chaves: atividade residual; fitointoxicação; persistência

Introduction

Brazil is the fifth greatest producer of cotton in the world, with a production of 1,740 thousand tons of this fiber on the crop of 2013/2014 in 967.7 thousand hectares of crops (CONAB, 2014). In recent years, a new scenario in the production of cotton in Brazil has been noticed with the migration of cultivations of traditionally producer areas, after the decrease in domestic production in the 90s, to the Brazilian cerrado. In this region, the cultivation of cotton became an activity with a high level of technology, explored in great modules of production. Besides, its cultivation has been one of the main alternatives in the rotation with soy in the Midwest states of Brazil.

One of the problems faced by the farmers from its implantation to the harvest is related to weeds. Cotton is a plant with low initial growth, which makes it difficult for the canopy to cover the soil, and it provides conditions so that the weeds can emerge and establish themselves, characterizing an interference process (Freitas et al., 2002).

To ensure productivity and quality of the produced fiber, it is crucial to adopt strategies to control the infecting community, and currently the chemical method is the most used in Brazil with herbicides. The rational use of these products enable the efficient control of weeds, in addition to facilitating the execution, ensuring good yield for the producer. The different modalities of herbicides application in the cotton crops include the handling in the pre-sowing, pre-emergence, post-emergence and post-emergence in directed jet states (Troxlet et al., 2002).

The application of herbicides in the pre-emergence state of the crop and the weeds constitute a very important modality for the cultivation of cotton. This form of application ensures that the initial development of the crop is free of weeds interference, which is the moment of greater sensitivity in the culture (Raimondi et al., 2010). Usually, these herbicides present residual activity in the soil, providing control of the first flows of the emergence of weeds, until another control intervention is used.

From the standpoint of agricultural exploration, when the persistence of residual activity of a certain herbicide exceeds the crop cycle where it was used and it persists in enough intensity to cause damage to the species cultivated in succession, a phenomenon called carryover happens (Oliveira Jr., 2011). The potential of such phenomenon depends on the herbicide used, on the crop in succession and on the environmental conditions after the application of herbicides (Mancuso et al., 2011). However, there is a lack of results in the literature about carryover of herbicides used in cotton crops for the crops in succession.

Thus, the objective of this paper is to evaluate whether the treatments with herbicides applied in the pre-emergence stage of cotton cultivation can compromise the cultivation of corn grown in succession.

Material and Methods

The experiment was installed in the municipality of Santa Helena de Goiás, GO (17°50'19,40" latitude South, 50°35'98,60" longitude West and 553 meters altitude), in the period of February 2012 to April 2013, in an area with soil classified as Dystrophic Red Latosol, presenting 470 g kg^{-1} of clay, 50 g kg^{-1} of silt, 480 g kg^{-1} of sand, saturation of basis 51%, 1.68% of Organic Carbon and pH in water of 6.2.

The handling of weeds preceding the sowing of cotton was done through two applications of paraquat (600 g ha^{-1}), carried out at seven and one day before sowing. The sowing of cotton crop DP 555 BGRR® was carried out in a mechanized way on February 2, 2012. The seeds were treated with abamectin (0.150 L 100 kg seeds^{-1}) and thiamethoxam (0.210 L 100 kg seeds^{-1}). The spacing between the rows was of 0.76 m and the density of sowing was of 10 seeds per meter, resulting in 131500 plants ha^{-1}. Simultaneously, there was a basis fertilization with 400 kg ha^{-1} of the 02-20-18 formulate. The additional top dressing was carried out with 100 kg ha^{-1} of N at 35 days after emergence (DAE), in the form of urea, applied by fertilizer discs.

The herbicides were applied in pre-emergence on the same day of the sowing, with the following environmental conditions: average temperature of 29.1 ºC, average RH of 52%, wind speed of 3.7 km h^{-1} and humid soil. The applications were carried out with a backpack sprayer based on CO_2, equipped with XR 110.02 tips, kept at a pressure of 35 lb.pol^{-2}, resulting in a spray volume equivalent to 200 L ha^{-1}.

All treatments were weeded during the whole cotton cycle to eliminate possible interferences of weeds regarding the applied herbicides. The harvest of cotton was carried out on 07/17/2012.

The handling of weeds after the cotton harvest and before the sowing of cotton was carried out by two desiccations, the first being taking place 20 days before sowing, using the mixture in a glyphosate tank (1920 g ha^{-1}) and 2.4 D (806 g ha^{-1}), and the second happening one day before sowing, using paraquat (400 g ha^{-1}).

The fertilization of corn sowing consisted in the application of 400 kg ha^{-1} of the 08-20-18 formulate. The sowing was carried out on 10/23/2012, using the AG 7098 PRO 2 simple hybrid. The spacing adopted was of 0.45 m between the rows, with density of 2.7 seed m^{-1}. An additional top dressing was used with 100 kg ha^{-1} of N, in the form of urea, when the crop was in the V4 development stage.

The outline used was of randomized blocks, with four repetitions and double control, where for each parcel with a herbicide treatment tested there are two adjacent parcels without the application of herbicide, according to the methodology previously described by Fagliari et al. (2001) and Constantin et al. (2007). The herbicide treatments with their respective doses applied in the pre-emergence state of the cotton crop are described according to Table 1.

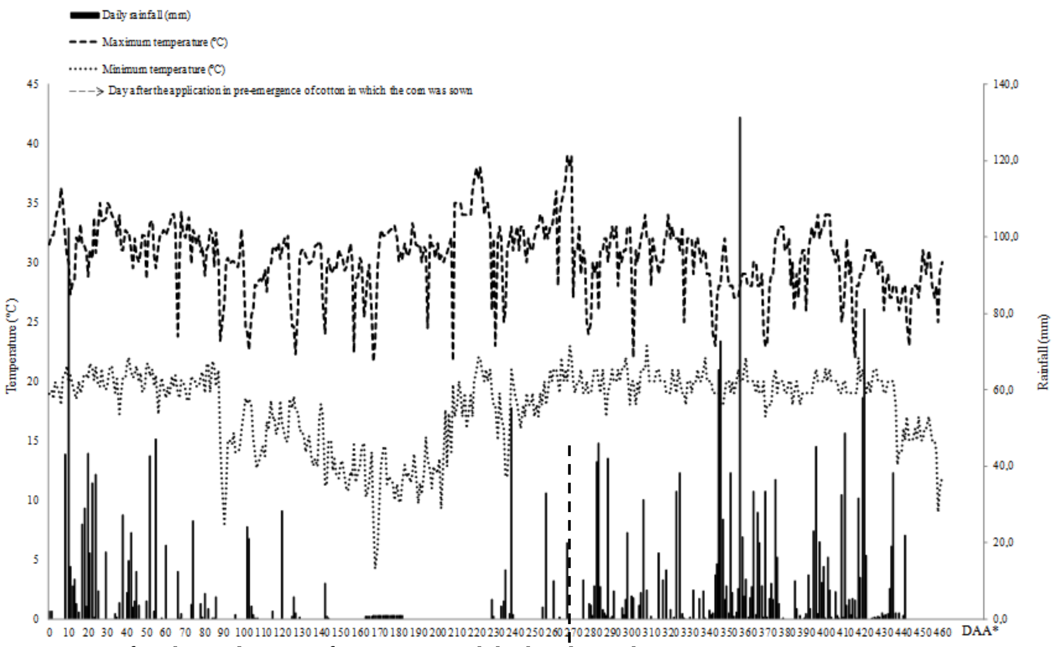
Table 1. Herbicides and their respective doses used in the cotton crop 264 days before corn sowing.

Application in pre-emergence	Dose (g ha^{-1})
T1 - clomazone	1000
T2 - clomazone + fomesafen	1000 + 450
T3 - clomazone + fomesafen	1000 + 625
T4 - clomazone + fomesafen + diuron	1000 + 450 + 1250
T5 - clomazone + fomesafen + prometryn	1000 + 450 + 1250
T6 - clomazone + fomesafen + trifluralin	1000 + 450 + 1818
T7 - clomazone + fomesafen + s-metolachlor	1000 + 450 + 768

Each experimental unit was composed of seven rows of corn with six meters in length. In the evaluations, 0.5 m of each end of the parcels were disregarded. The data regarding precipitation and maximum and minimum temperature during the period of the study is presented on Figure 1.

All treatments were weeded during the whole cycle of the corn to eliminate the weed competition effect on the productivity of the crop, leaving the plants exposed to the herbicide effect.

Phytointoxication evaluations of corn plants were carried out at 7, 14 and 28 DAE through the phytointoxication visual scale (EWRC, 1964). Two evaluations were also carried out at 80 DAE, one of insertion height of the cob (measuring the height from the soil level up to the insertion of the cob in the stem, in ten random plants in the useful area of the parcel), and another of insertion height of the tassel (measuring the height from the soil level up to the insertion of the tassel at the top of the stem, in ten random plants in the useful area of the parcel). At 120 DAE, we evaluated the diameter of the stem right below the insertion of the cob, in ten random plants in the useful area of the parcel.



*Days after the application of treatments with herbicides in the pre-emergence state in cotton crops.

Figure 1. Maximum and minimum daily temperature and daily rainfall during the conduction of the experiments with different herbicide treatments used in the cotton crop. Santa Helena de Goiás (GO) 2012/2013.

To determine the corn productivity of each treatment, we proceeded to the harvest of all cobs from the useful area. The cobs collected were threshed with the help of a manual thresher of parcels, and the grains were later on separated from the impurities and heavy substances. Samples were taken to determine the humidity (portable humidity determiner model Mini GAC) of each parcel, and the productivity data was converted to 13% of humidity.

After collecting and tabling the data, they were subjected to a variance analysis, and the averages of these significant variables were compared by the F test ($p \leq 0,05$).

Results and Discussion

The long period between the application of herbicides and the sowing of corn (264 days) contributed to justify the results obtained, once none of the treatments with herbicides applied in the pre-emergence of the cotton caused visible injuries to the corn plants, in addition to not having affected the insertion height of the first cob, the insertion height of the tassel, the stem diameter and the crop productivity (Table 2 and 3). We should also consider that in this period the total rainfall was of 900 mm in the experimental area.

A number of factors are responsible for the residual activity of an herbicide in the soil. Among them, we can highlight the physical-chemical and microbiological characteristics of the soil, in addition to the soil and weather conditions of a certain region (Oliveira Jr. et al., 1999). The process of spreading herbicides in the environment is also related to the physical-chemical properties of the herbicide, with the handling applied, and with the crop system used (Niekamp and Johnson, 2001). In the present paper, most herbicides are sensitive to the degradation activity of microorganisms existent in the soil. In agricultural areas that use the tillage system, an increase in the superficial amount of organic matter and reduction of width variations of temperature and humidity is observed, which increases the diversity, the activity and the microbial biomass in the soil environment, emphasizing the degradation of herbicides (Weed et al., 1995; Mueller et al., 1999).

Table 2. Insertion height of the cob (cm), insertion height of the tassel (cm) in function of the application of herbicides in cotton crops.

Treatments	Insertion height of the cob (cm)			Insertion height of the tassel (cm)		
	Treat.[1/]	Contr.[2/]	Diff.[3/]	Treat.	Contr.	Diff.
T1 - clomazone	132.45	133.70	1.25	234.30	236.35	2.05
T2 - clomazone + fomesafen(450)	140.95	134.45	-6.50	245.95	237.47	-8.48
T3 - clomazone + fomesafen(625)	138.80	135.92	-2.88	240.90	236.92	-3.98
T4 - clomazone + fomesafen + diuron	127.95	131.35	3.40	233.85	231.82	-2.03
T5 - clomazone + fomesafen + prometryn	137.10	134.35	-2.75	243.65	240.15	-3.50
T6 - clomazone + fomesafen + trifluralin	135.20	134.07	-1.13	238.70	238.07	-0.63
T7 - clomazone + fomesafen + s-metolachlor	135.80	132.42	-3.38	239.60	241.10	1.50
CV (%)	3.94		-	3.38		-
F	2.16[ns]		-	1.39[ns]		-

[1/] Treatments with herbicide; [2/]Control without herbicide; [3/]Difference between control without herbicide and the treatment with herbicide; [ns] Non-significant by the F test (p≤0,05).

Table 3. Stem diameter (mm) and corn productivity (kg ha^{-1}) in function of the application of herbicides in cotton crops.

Treatments	Stem diameter (mm)			Productivity (kg ha^{-1})		
	Treat.[1/]	Contr.[2/]	Diff.[3/]	Treat.	Contr.	Diff.
T1 - clomazone	16.94	16.63	-0.31	9186.90	8767.10	-419.80
T2 - clomazone + fomesafen(450)	16.42	16.45	0.03	9661.30	8573.00	-1088.30
T3 - clomazone + fomesafen(625)	16.52	16.76	0.24	9031.10	9820.80	789.60
T4 - clomazone + fomesafen + diuron	16.50	17.09	0.59	8814.50	7889.40	-925.10
T5 - clomazone + fomesafen + prometryn	16.69	17.32	0.63	9793.70	9444.20	-349.40
T6 - clomazone + fomesafen + trifluralin	17.18	17.57	0.39	8547.50	9179.70	632.20
T7 - clomazone + fomesafen + s-metolachlor	17.41	17.89	0.48	9610.10	9064.10	-546.00
CV (%)	7.28		-	13.12		-
F	0.47[ns]		-	0.99[ns]		-

[1/] Treatments with herbicide; [2/]Control without herbicide; [3/]Difference between control without herbicide and the treatment with herbicide; [ns] Non-significant by the F test (p≤0,05).

According to McBride (1994), many microorganisms have enzymes that immediately decompose the NO_2 radicals existent in the functional groups of the fomesafen molecule, showing the importance of this degradation pathway for this herbicide. Also for the trifluralin molecule, according to Tavares et al. (1996), the soil degradation is affected by aerobic and anaerobic conditions, which determine the predominance of oxidative or reductive degradation. Seasonal variations favor the degradation of both forms simultaneously. Such seasonal variations occur in agriculture regions of cerrado, mainly due to the greater rainfall during spring and summer and lower rainfall during autumn and winter.

Regarding the clomazone herbicide, the biological degradation is favored in conditions that stimulate an elevated bacterial activity, such as temperature, humidity and organic matter (GAMIT, 1999). Mervosh et al. (1995) analyzed the microbial activity, temperature and soil humidity in the presence of the clomazone herbicide. The results showed that the degradation depends on microorganisms, and 84 days after the application of the herbicide, 41% of the clomazone had been mineralized. Liu et al. (1996), on the other hand, studied the degradation pathway of clomazone and its metabolites in 41 microorganisms of different species capable of metabolizing this herbicide. The results obtained by the analysis of HPLC indicated that most of the microbial reactions involved the hydroxylation of the methylene carbon of the isoxazolidine ring and the hydroxylation of the methyl group of the oxazolidine ring, and some metabolic routes included dihydroxylation of clomazone in the aromatic ring, cleaving the connection of carbon-nitrogen (C-N) of the isoxazolidine ring or forming chlorobenzyl alcohol, reinforcing the importance of the microbial activity existent in the soil in the degradation of this compound.

Another factor that may have contributed to the absence of carryover is that, in the adoption of a direct cultivation system, the redistribution of herbicides in the soil can occur in a different way (Albuquerque et al., 2011). That can happen because the vegetable residues of the previous crop existent in the soil surface at the moment the herbicide is applied can prevent a direct contact with the soil. When they are retained in the straw, the herbicides may be absorbed by it, resulting in a low leaching for the soil, even after raining (Rodrigues et al., 2000).

The interactions among the physical-chemical properties of the herbicides with the environment allow us to understand the results obtained. Formesafen herbicide is considered a weak acid herbicide (pKa: 2.83) (Rodrigues and Almeida, 2011), being predominant in its neutral form when the medium pH is below its pKa and in the anionic form when the medium pH is higher than the pKa. The soil of the experimental area presented a 6.2 pH. Thus, due to the predominance of the anionic form of fomesafen, there must have been a low sorption to the soil, which enabled greater leaching (Oliveira et al., 2005), decreasing its concentration in the soil solution. Moreover, higher pH values may increase solubility and bioavailability of fomesafen (Weber, 1993).

Clomazone, an isoxazolidinone, is a non-ionic herbicide with solubility in water of 1,1 g L^{-1}, octanol-water partition coefficient (Kow) of 350, sorption coefficient (Koc) equal to 300 mL g^{-1} and steam pressure of 19.2 mPa at 25°C, being an extremely volatile compound (Senseman, 2007). This volatilization is accentuated both in the conditions where the soil presents humidity of 20% above its field capacity and in those with humidity 20% below (Halstead and Harvey, 1988). It is assumed that the mean contents of clay and organic matter present in the soil where this experiment was conducted must have contributed to the adsorption of clomazone, decreasing its concentration in the soil solution during the period until the sowing of corn.

Prometryn is a basic dissociation herbicide to which the retention of molecules is influenced mainly by the content of carbon and clay in the soil, and that presents a sorption index (Koc) between 400 and 500 mL g^{-1} of soil (Oliveira Jr., 2007). Cao et al. (2008) studied the mobility of prometryn in two different soils. The first soil presented 9.36 g kg^{-1} of M.O; 29.5 g kg^{-1} of clay and 7.65 pH in water. The second one presented 20.9 g kg^{-1} of M.O; 49.4 g kg^{-1} of clay and 4.92 pH in water. The authors found moderate mobility for the first soil, especially in function of the high pH, because the prometryn herbicide presents pKa of 4.09 (Rodrigues and Almeida, 2011). Therefore, its basic dissociation character caused the predominance of neutral loads, decreasing the sorption of this herbicide to soil colloids, having a higher occurrence of leaching when compared to the second soil, whose pH was closer to the pKa of prometryn, resulting in lower mobility.

Several studies indicate that the sorption behavior of diuron presents a positive correlation with the organic matter and CTC contents of the soil (Spurlock and Biggar, 1994; Rocha, 2003), especially by the organic fraction, being considered little leachable in clay soils (Liu et al., 1970; Luchini, 1987). On the other hand, in soils with low content of organic matter it presents a greater leaching potential.

The herbicides desorption is very important because it determines the release rate and the mobility potential of these compounds in the soils. The herbicides with a lower desorption rate can present higher risk to succession crops (Liu et al., 2010). In that sense, Rocha et al. (2013) found distinctive desorption rates among these soils by evaluating the sorption and desorption behavior in four latosols. Those authors saw that in extremely loamy soils (590 and 690 g kg^{-1}) and with elevated organic matter contents (43 e 37 g kg^{-1}), usually there was high sorption and low desorption, decreasing the availability of diuron in the soil solution. In contrast, soils with low contents of organic matter (8 g kg^{-1}) and clay (270 g kg^{-1}), present high desorption percentage, which can benefit a greater movement of the herbicide in the soil profile.

Due to the average levels of clay (47 g kg^{-1}) and organic matter (28,9 g kg^{-1}), it is assumed that diuron, at a first moment, may have been absorbed by the soil and, as the desorption process occurred along the great period between its application and the sowing of corn, the molecule was exposed to the degrading action of the microorganisms, photolysis and leaching.

That hypothesis corroborates the results found by Inoue et al. (2006), who determined the importance of microbiological degradation for this herbicide in samples of two contrasting soils by studying the effect of different methods to reduce the microbial activity in diuron degradation with or without the presence of light. Those authors saw that, in the presence of light, there was an increase in diuron degradation capacity, mainly in function of the herbicide's photolysis. Dehalogenation is the most common photochemical reaction to herbicides such as diuron. In this type of reaction, due to the elevated energy involved, the ultraviolet irradiation can perform direct dehalogenation even on more stable halogens connected to aromatic rings (Vulliet et al., 2002).

Conclusions

In the conditions in which the experiment was carried out, the use of herbicides in the pre-emergence stage of cotton crop did not cause carryover on the corn hybrid RR® AG 7098 PRO 2, sown 264 days after the application of products.

Acknowledgments

The authors thank Fundação Goiás for the support during the execution of the experiment.

References

Albuquerque, M.A.; Schaefer, C.E.G.R.; Foloni, J.M.; Ker, J.C.; Fontes, L.E.F. Mineralização e sorção de atrazine em Latossolo Roxo sob cultivo convencional e direto. **Revista Brasileira de Ciência do Solo**, v.25, n.1, p.179-188, 2001.

Cao, J.; Guo, H.; Zhu, H.M.; Jiang, L.; Yang, H. Effects of SOM, surfactant and pH on the sorption-desorption and mobility of prometryne in soils. **Chemosphere**, v.1, p.2127-2134, 2008.

CONAB. Companhia Nacional de Abastecimento. **Séries históricas**. Disponível em: <http://www.conab.gov.br>. Acesso em: 01/10/2014.

Constantin, J.; Oliveira JR., R.S.; Cavalieri, S.D.; Arantes, J.G.Z.; Alonso, D.G.; Roso, A.C. Estimativa do período que antecede a interferência de plantas daninhas na cultura da soja, Var. Coodetec 202, por meio de testemunhas duplas. **Planta Daninha,** v.25, n.2, p.231-237, 2007.

EUROPEAN WEED RESEARCH COUNCIL – EWRC. Report of 3rd and 4rd meetings of EWRC. Committee of methods in weed research. **Weed Research**, v.4, n.1, p.88, 1964.

Fagliari, J.R.; Oliveira JR., R.S.; Constantin, J. Métodos de avaliação da seletividade de herbicidas para a cultura da cana–de–açúcar. **Acta Scientiarum**, v.23, n.5, p.1229–1234, 2001.

Freitas, R.S.; Berger, R,P.G.; Ferreira, L.R.; Cardoso, A.A.; Freitas, T.A.S.; Pereira, C.J. Interferência de plantas daninhas na cultura do algodão em sistema de plantio direto. **Planta Daninha**, v.20, n.2, p.197-205, 2002.

Gamit. Arroz irrigado. Campinas, **Boletim Técnico**, FMC, p.12, 1999.

Halstead, S.J; Harvey, R.G. Effect of rate and carrier on clomazone dissipation in two Montana soils. **Weed Technology**, v.2, p.179-182, 1988.

Inoue, M.H.; Oliveira JR., R.S.; Regitano, J.B.; Tormena, C.A.; Constantin, J.; Tornisielo, V.L. Sorption-desorption of atrazine and diuron in soils from southern Brazil. **Journal Environmental Science and Health - Part B: Pesticicides, Food Contaminants, and Agricultural Wastes**, v.41, n.5, p.605-621, 2006.

Liu, L.C.; Cibes-ViadÉ, H.; Koo, F.K.S. Adsorption of ametryne and diuron by soils. **Weed Science**, v.18, p.470-474, 1970.

Liu, S.Y.; Shocken, M.; Rosazza, J.P.N. Microbial transformations of clomazone. **Journal of Agricultural and Food Chemistry**, v.44, p.313-319, 1996.

Liu, Y.; Xu, Z.; Wu, X.; Gui, W.; Zhu, G. Adsorption and desorption behavior of herbicide diuron on various Chinese cultivated soils. **Journal of Hazardous Materials**, v.178, n.1, p.462-468, 2010.

Luchini, L.C. **Adsorção-dessorção dos herbicidas paraquat, diuron e 2,4-D em seis solos brasileiros**. 1987. 91f. Dissertação (Mestrado) Escola Superior de Agricultura Luiz de Queiroz, Piracicaba. 1987.

Mancuso, M.A.C.; Negrisoli, E.; Perim, L. Efeito residual de herbicidas no solo ("*Carryover*"). **Revista Brasileira de Herbicidas**, v.10, n.2, p.151-164, 2011.

MC Bride, M.B. **Environmental Chemistry of Soils**. New York: Oxford University Press. p.406, 1994.

Mervosh, T.L.; Simms, G.K.; Stoller, E.W. Clomazone fate as affected by microbial activity, temperature, and soil moisture. **Journal Environmental Science and Health**, v.43, p.537-543, 1995.

Mueller, T.C.; Shau, D.R.; Witt, W.W. Relative dissipation of acetochlor, alachlor, metolachlor and SAN 582 from three surface soils. **Weed Technology**, v.13, n.1, p.341-346, 1999.

Niekamp, J.W.; Johnson, W.G. Weed management with sulfentrazone and flumioxazin in no-tillage soybean (*Glycine max*). **Crop Protect**, n.20, p.215-220, 2001.

Oliveira JR., R.S.; Koskine, W.C.; Ferreira, F.A.; Khakural, B.R.; Mulla, D.J.; Robert, P.J. Spatial variability of imazethapyr sorption in soil. **Weed Science**, v.47, p.243-248, 1999.

Oliveira JR., R.S. Introdução ao controle químico. In: Oliveira JR., R.S.; ConstantiN, J.; Inoue, M.H. (Eds.). **Biologia e Manejo de Plantas Daninhas**. Editora Omnipax, 2011. p.125-140.

Oliveira JR., R.S. **Comportamento dos herbicidas residuais no solo:** relação entre parâmetros físico-químicos e atributos do solo. Maringá: EDUEM, 2007.

Oliveira, M.F.; Prates, H.T.; Sans, L.M.A. Sorção e hidrólise do herbicida flazasulfuron. **Planta Daninha**, v.23, n.1, p.101-113, 2005.

Raimondi, M.A. et al. Otimização de herbicidas utilizados em pré-emergência para o controle de *Portulaca oleracea*. **. Revista Brasileira de Herbicidas**, v.9, n.2, p.42-53, 2010.

Rocha, P.R.R. Faria, A.T.; Borges, L.G.F.C.; Silva, L.O.C.; Silva, A.A.; Ferreira, E.A. Sorção e dessorção do diuron em quatro latossolos brasileiros. **Planta Daninha**, v.31, n.1, p.231-238, 2013.

Rocha, W.S.D. **Sorção de 2,4-D e diuron nos agregados organominerais de Latossolos em função dos conteúdos de matéria orgânica e de água**. 2003. 75f. Tese (Doutorado em Solos e Nutrição de Plantas) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, 2003.

Rodrigues, B.N.; Almeida, F.S. **Guia de herbicidas**. Londrina: IAPAR, 2011. 697p.

Rodrigues, B.N.; Lima, J.; Iada, I.F.U. Retenção pela palhada de herbicidas aplicados em pré-emergência na cultura do milho, em plantio direto. **Revista Brasileira de Herbicidas**, v.1, n.2, p.67-72, 2000.

Senseman, S. **Herbicide handbook**. 9. ed. Lawrence: Weed Science Society of America, 2007. 458p.

Spurlock, F.; Biggar, J.W. Thermodynamics of organic chemical partition in soils. II: Nonlinear partition of substituted phenylureas from aqueous solution. **Environmental Science and Technology**, v.28, n.4, p.996-1002, 1994.

Tavares, M.C.H.; Landgraf, M.D.; Vieira, E.M.; Rezende, M.O. Estudo da adsorção-dessorção da trifluralina em solo e em ácido húmico. **Química Nova**, v.19, n.6, p.605-608, 1996.

Troxler, S.C.; Askew, S.D.; Wilcut, J.W.; Smith, D.; Paulsgrove, M.D. Clomazone, fomesafen, and bromoxynil systems for bromoxynil-resistant cotton (*Gossypium hirsutum*). **Weed Technology**, v.16, n.4, p.838-844, 2002.

Vulliet, E.; Emmelin C.; Grenier-Loustallot, M.F.; Paise, O.; Chovelon, J.M. Simulated sunlight-induced photodegradations of triasulfuron and cinosulfuron in aqueous solutions. **Journal Environmental Science and Health**, v.50, n.4, p.1081-1088, 2002.

Weber, J.B. Ionization and sorption of fomesafen and atrazine by soils and soil constituents. **Pesticide Science**, v.38, p.31-38, 1993.

Weed, D.A.J.; Kanwar, R.S.; Stoltenberg, D.E.; Pfeiffer, R.L. Dissipation and distribution of herbicides in the soil profile. **Journal of Environmental Quality**, v.24, n.1, p.68-79, 1995.