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Plant health

Carryover of ACCase inhibitors for corn[1]

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10.1590/0034-737X202370050019

ABSTRACT

Sequential crops may be affected by herbicide residuals in the soil. In corn crop there are reports of problems when the crop is sown soon after application of ACCase-inhibiting herbicides. The aim of this study was to evaluate safety intervals for the application of ACCase-inhibiting herbicides before sowing corn in different soils. Two experiments were conducted in a greenhouse, and in the field conditions. In both, the experimental design were completely randomized in factorial scheme 6x4+1 (6 periods of application x 4 herbicides + 1 control) with five replications. The treatments were: haloxyfop-P-methyl (124.7 g ha^{-1}), clethodim – formulation 1 (192 g ha^{-1}), quizalofop-P-ethyl (100 g ha^{-1}) and clethodim formulation 2 (192 g ha^{-1}) in applications at 15, 10, 5, 3, 1 and 0 days before sowing in sandy and clayey soil. In the greenhouse, formulations based on clethodim were more safety in both types of soils, and safety intervals for clethodim-based herbicides were 5 days and greater than 15 days for quizalofop-P-ethyl and haloxyfop. Haloxyfop should not be applied on day of sowing in clay soil. In the field none of the treatments compromised the development and yield of the crop, even when applied on the day of sowing.

Keywords: clethodim; haloxyfop-P-methyl; quizalofop-p-ethyl; *Zea mays*.

INTRODUCTION

Due to the serious damage that can directly or indirectly affect crops, weed management is pointed out as one of the most challenging tasks in agricultural production. The use of chemicals in agriculture worldwide has become the main and most widespread method in weed management (Oliveira Júnior, 2011). However, the repetitive application of herbicides with the same mechanism of action, can increase the frequency of resistant individuals in a population (Christoffoleti & Lópes-Overejo, 2003).

Acetyl-CoA Carboxylase (ACCase) inhibitors were introduced in the mid-1970s mainly for weed control in dicotyledonous crops (Kaudun, 2014). They are still recognized today for their effective control over species of the Poaceae family, including annual and perennial grass species (Oliveira Júnior, 2011; Lancaster *et al.,* 2018). On the other hand, these herbicides are recognized for being very selective for eudicotyledons, which makes them essential tools in several important cultures, such as soybeans, cotton and beans, among others.

ACCase inhibitors have gained more prominence in recent years due to their effectiveness in controlling grasses that have been selected for resistance to glyphosate, such as tall windmill grass (*Chloris elata*), goosegrass (*Eleusine indica*) perennial ryegrass (*Lolium perenn* sp. *multiflorum*) and sourgrass (*Digitaria insularis*) (Heap, 2023). ACCase-inhibiting herbicides play a key role in managing

Submmited on April 27th, 2022 and accepted on March 19th, 2023.
[1] The work was extracted from a dissertation of the graduate student Mateus Dalpubel Mattiuzzi and the funding source was CAPES.
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glyphosate-resistant (GR) grasses, one of the greatest weed management challenges facing South America (Lopez Ovejero *et al.*, 2017).

In infested fields with glyphosate resistant weeds, such as *D. insularis* and *E. indica*, normally more than one application is required in the pre-sowing burndown. Often, however, there is not enough time for such sequential applications to be made and the decision is made to perform only one application of burndown, which can occur very close to the date of sowing the crops. The longer delay in corn sowing, increase risks of yield loss due to adverse weather events that may occur during the crop cycle (Garcia *et al.*, 2018).

Due to the replacement of management systems with two burndown applications by systems with a single application, in many field situations the doses used of ACCase-inhibitors are higher than those prescribed, especially in late post-emergence stage for sourgrass and goosegrass. In these cases, application of up to twice the dose of the haloxyfop or clethodim, has been observed (Mendes *et al.*, 2020). Although ACCase-inhibitors are generally not applied in pre-emergence of weeds, it is known that they have limited residual activity in soil, especially if higher doses are used (Barber *et al.*, 2015; Mahoney *et al.*, 2016; Lancaster *et al.*, 2018).

There have been reports of problems in corn when the crop is sown soon after the application of ACCase-inhibiting herbicides. One of the major problems observed in different crops has been the carryover effect of herbicides, given the residual activity that can compromise the yield of crops in succession or rotation (Mancuso *et al.*, 2011). Several factors are responsible for the length, and extent of activity of residual herbicides in soils. When in the environment contact, herbicides are subject to retention, transport, and degradation processes. The retention of herbicides in the soil is a process influenced by the physicochemical properties of the herbicide, and the soil, such as texture, pH, cation exchange capacity (CEC), and organic carbon content (OC) (Takeshita *et al.*, 2019). Among them, OC and soil texture are the main important factors associated the herbicides sorption and desorption in soils (Huang *et al.*, 2015). Especially the sorption and desorption processes between soil and herbicide which influence its availability for weeds and mobility in soils (Polati *et al.*, 2006).

In this context, considering the potential damage that ACCase-inhibiting herbicides can cause in corn, the hypothesis of this study was about smaller plant back intervals between herbicides application and corn sowing can result in damage to corn. Thus, this work aimed to define the safety intervals between herbicide applications of this mechanism of action and the sowing of corn.

MATERIAL AND METHODS

Greenhouse experiments

Initially, two experiments were carried out in a greenhouse with contrasting textural soils (sandy loam and clay texture) at the Irrigation Training Center of the State University of Maringá (23°23’44.70” S and 51°57’3.23” O, at 510m altitude), in Maringá - PR. The soils were collected in the 0-20 cm layer of agricultural areas, homogenized, sieved and placed in plastic pots with a capacity of 4 dm^3.

The soils used in the experiments had the following physical-chemical characteristics: sandy soil: sand = 84%; clay = 14%; silt = 2%; pH ($CaCl_2$) = 4.9 and M.O = 15.77 g dm^{-3}, clayey soil: sand = 37%; clay = 57%; silt = 6%; pH ($CaCl_2$) = 5.4 and M.O = 24.24 g dm^{-3}.

The experiments were conducted in a completely randomized design, in a factorial scheme (6x4) +1 with five replications. The levels of the first factor consisted of time intervals of 15, 10, 5, 3, 1 and 0 days between the application of the herbicides, and the sowing of corn (referred to hereinafter as 15, 10, 5, 3 and 0 days before sowing - DBS). The levels of the second factor were constituted by the herbicides haloxyfop-P-methyl (124.7 g ai ha^{-1}, Verdict® R, 124.7 g a.i L^{-1}, CTVA Crop Protection Ltda, 267 Tamboré Avenue, Barueri-SP, Brazil, 0646-000), clethodim (192 g ai ha^{-1}, Select 240 EC, 240 g a.i L^{-1}, UPL from Brazil, Maeda Avenue, Ituverava-SP, Brazil, 14500-000 – formulation 1), quizalofop-P-ethyl (100 g ai ha^{-1}, Targa Max, 50 g a.i L^{-1}, Iharabras S.A, 1701 Liberdade Avenue, Sorocaba-SP, Brazil, 18087-170) and clethodim (192 g ai ha^{-1}, Select One Pack, 120 g a.i L^{-1}, UPL from Brazil, Maeda Avenue, Ituverava-SP, Brazil, 14500-000 - formulation 2). The additional treatment consisted in untreated control. The formulations of clethodim will be called formulation 1, and formulation 2 along the manuscript.

Seeds of the hybrid corn P3380HR were used. Moments before sowing, the seeds were treated with the insecticide imidacloprid (Gaucho FS) at a dose of 4.0 mL kg^{-1}. Five seeds were sown per pot at a depth of 3.5 cm. The first irrigation was carried out four hours after the application of the herbicides and throughout the experiment it was maintained daily. The sowing of all treatments was done on the same date.

The variables analyzed during the crop development were: Seedling phytointoxication: visual assessment performed at 3 and 21 days after emergence (DAE) based on a percentage scale ranging from 0 to 100, in which 0 represents absence of injuries and 100 represents the plant death (Gazziero, 1995); Stand: determined by counting the number of plants per pot at 21 DAE; and Dry mass of the aerial part: evaluations were made at the end of the experiment (21 DAE), when the plants were cut close to the ground, stored in a paper bag and placed for drying in an oven with forced air circulation at 60 ºC, until constant weight. Subsequently, they were weighed and the result was expressed in mass per plant and in mass per pot. All response variables were expressed as a percentage the control:

Then, the data were subjected to analysis of variance, by the F test at 5% probability and, when the effects were significant, the means were compared with the additional treatment by the Dunnett test ($p \leq 0.05$). Additionally, the data were submitted to regression analysis in order to investigate the effect that each herbicide had on the crop as the applications approached the sowing. The statistical tests were conducted using Assistat Software (Silva & Azevedo, 2002) and the figures generated with the aid of the SigmaPlot program.

The regression models used, were the following: Decreasing exponential of three parameters:

$$y = y0 + a * \exp(-b * x) \quad (1)$$

Where "y" is the dependent variable, "y0" is the minimum sample value, "a" is the difference between the minimum sample value, and the maximum value and "b" is the quantity that decreases as a function of days, since the variables are in function of days after sowing the corn crop and "x" are the days before sowing - DBS; Three parameter sigmoidal:

$$y = \frac{a}{\left(1 + \exp\left(\frac{-(x - x0)}{b}\right)\right)} \quad (2)$$

Where "y" is the dependent variable, "a" is the maximum value of the sample, "b" is related to the average growth rate of the curve, "x0" related to the number of days to result in 50% of the value of "a", and "x" are the days before sowing; Gompertz of three parameters:

$$y = a * \left(-\exp\left(\frac{-(x - x0)}{b}\right)\right) \quad (3)$$

Where "a" is the maximum value expected of the sample, "b" is related to the average growth rate of the curve, "x0" is related to the number of days after corn emergence, "y" is the dependent variable, and "x" is the days before sowing; Linear, expressed by the equation:

$$y = y0 + a * x \quad (4)$$

Where "y" is the dependent variable, "a" is the difference between maximum, and minimum, "y0" is the minimum value of the sample, and "x" is the days before the sowing of the corn.

Field experiment

Two field experiments were conducted in different soils conditions (sandy clay loam and sandy clay). The experiment on a sandy clay loam soil was installed on the Experimental Farm Iguatemi, (23°20'88''S, 52°04'25''W and altitude of 550 m), located in the district of Iguatemi, in Maringá. The experiment on a sandy clay soil was carried out at the Experimental Station CONPEA - Sítio São Pedro II (23°13›39››S, 52° 01'06''W and altitude of 458 m), located in the district of Pulinópolis, Mandaguaçu.

The soils where the experiment was located had the following physical-chemical characteristics: sandy loam texture soil: sand = 74.70%; clay = 20%; silt = 5.30%; pH ($CaCl_2$) = 5.50 and M.O = 2.20 g dm^{-3}. Sandy clay texture soil: sand = 53%; clay = 45%; silt = 2%; pH ($CaCl_2$) = 4.40 and M.O = 23.72 g dm^{-3}.

The climatic data related to the period of conduction of the experiments were collected in the agrometeorological station of the National Institute of Meteorology - Main Campus UEM - Maringá - PR, and are presented in the Figure 1.

The experiments were conducted in a randomized complete block design, in a factorial scheme (4x4) +1, consisting of four herbicides and four application dates, in addition to an additional control without herbicide application, with five replications. The herbicides haloxyfop-P-methyl (124.7 g ha^{-1}), clethodim (192 g ha^{-1} - formulation 1), quizalofop-P-ethyl (100 g ha^{-1}) and clethodim (192 g ha^{-1} - formulation 2) were applied at 15, 7, 2 and 0 DBS. The trade name of the products is the same as in the greenhouse experiment and the clethodim formulations will be called formulation 1 and formulation 2 in the course of the work.

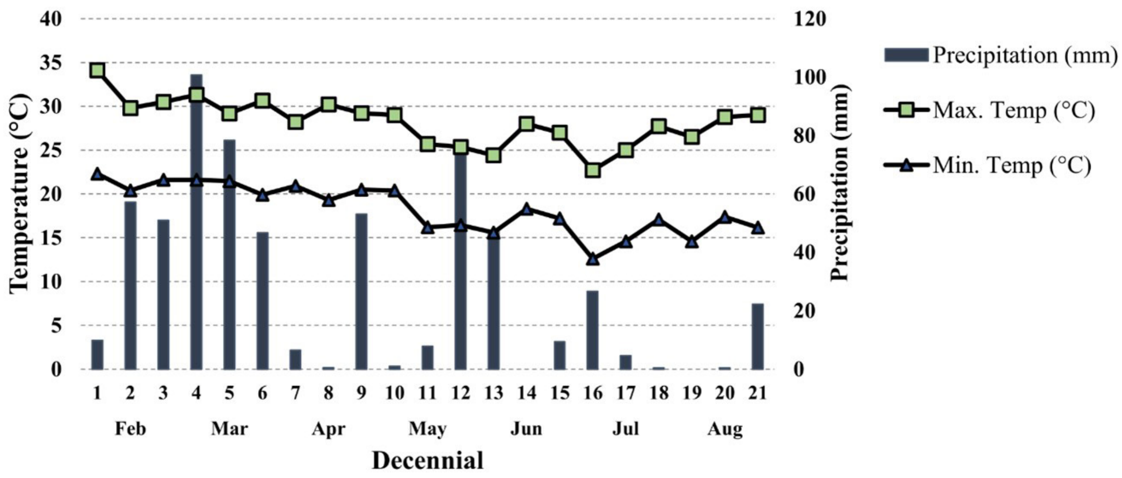

Figure 1: Field climatic conditions of the agricultural year 2019 from the period from 02/01/19 to 08/10/19. Sowing carried out on 03/01/2019, for field experiment.

Before the sowing of corn, the sandy clay loam soil area was desiccated with glyphosate (1240 g ae ha^{-1}) (14 days before sowing) and paraquat (400 g ai ha^{-1}) (seven days before sowing). For the experiment on clay-sandy soil, while soybeans were cultivated, the area was desiccated with paraquat (400 g ai ha^{-1}), and harvested leaving cultural remains on the soil. Weed control was performed with application of atrazine (750 g ai ha^{-1}) in pre-emergence of corn (one day before sowing), followed by a second application of atrazine (1250 g ha^{-1}) in post-emergence. In addition, manual weeding was carried out, when necessary, until the closure of the crop. The other cultural treatments were conducted during the crop cycle in accordance with the recommendations for culture.

The sowing was carried out on 03/01/2019. The experimental plots had four lines of 5 m (spacing of 0.9 m) for the experiment in sandy loam-clay texture and eight lines of 5m (spacing of 0.45 m) for the experiment in textured sandy-clay soil, totaling 18 m² in both.

In the installation, 300 kg ha^{-1} of the formulated NPK 10-20-20 was used and between the stages V4-V5 50 kg ha^{-1} of urea (45% N) were applied between the lines as top-dressing fertilization.

Herbicide applications were carried out in the apply-plant[3] system, using a CO_2 sprayer pressurized, equipped with a three-tip bar for the greenhouse experiment and six tips for the field experiment, fan type ST 110.015 (30 Psi), spaced at 50 cm, at an application speed of 1.0 m s^{-1}, resulting in an application rate of 150 L ha^{-1}. During applications, the temperature ranged from 24 to 32 ºC, the relative humidity was between 56 and 78% and the wind speed from 3 to 7 km h^{-1}.

Plant phytotoxicity (visual evaluation from 0 to 100%, 0 with no symptoms of phytotoxicity and 100% death of the crop) (Gazziero, 1995) at 7 DAE; the stand (counting the number of plants) at 21 DAE, the height of the plants (measured from the soil until the insertion of the last expanded leaf) at 21 DAE, and the yield were evaluated. To evaluate the yield, the useful area of the plots was manually harvested and the ears obtained were threshed. From it the yield was obtained by weighing on an analytical balance. The weight of the grains was corrected to 14% of moisture, and the grain yield was calculated later in kg ha^{-1}.

All response variables were expressed as a percentage based on the control results without herbicide application, as well as on the greenhouse experiment methodology. Then, the data were subjected to analysis of variance, by the F test at 5% probability and, when significant, the means were compared with the additional treatment by the Dunnett test ($p \leq 0.05$). Additionally, for field experiments, the averages were compared with each other using the T test ($p \leq 0.05$) with the aid of the computer program Assistat.

RESULTS AND DISCUSSION

Greenhouse experiments

As for phytointoxication, it is observed that regardless of the date of assessment (3 or 21 DAE), for soil with a

[3] Apply-plant – Is a system where the sowing is done immediately after the herbicide applied.

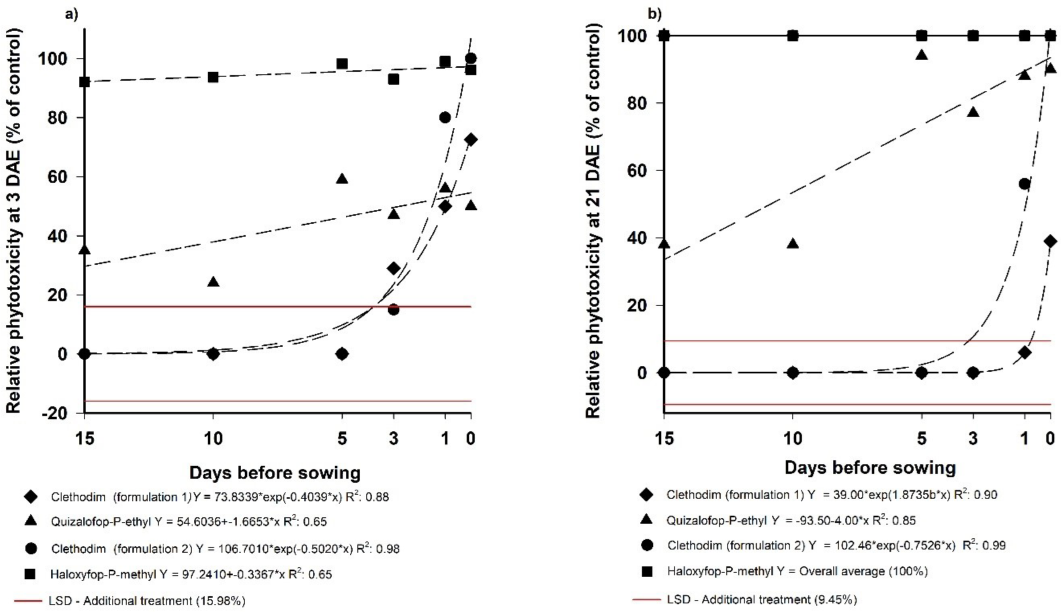

Figure 2: Phytointoxication of corn plants at 3 DAE (a) and at 21 DAE (b) depending on the application of ACCase-inhibiting herbicides between 0 and 15 days before the sowing of corn in sandy loam soil in greenhouse conditions.

sand loam texture, all herbicides were harmful to the plants when the application was carried out on the day of sowing (Figures 2a and 2b). The herbicide haloxyfop presented 100% phytointoxication at 21 DAE. On the other hand, the two formulations of clethodim had the lowest damage than the others herbicides, mainly in relation to the longest periods between application and sowing. For the herbicide quizalofop-P-ethyl, the phytointoxication values were higher than the control in all application periods, however, there is a decreasing behavior as the interval between application and sowing increases.

For the clayey soil, the results were similar to those observed in the sandy loam soil, that is, when the application was made on the day of sowing, all herbicides demonstrated high levels of phytointoxication (Figures 3a and 3b). After absorption of the herbicides, occurs translocates to proliferating meristematic tissues through the phloem where it damages the cell membrane structure, inhibits meristematic activity, and restricts the growth of new leaves (Kukorelli *et al.*, 2013). In addition, the phytotoxic values were higher for haloxyfop when compared to clethodim-based herbicides. Evaluating different corn hybrids, Mendes *et al.* (2020), also have seen higher damage potential of haloxyfop-methyl than clethodim.

The plant stand was significantly affected by the application of haloxyfop in both soils used in the experiment (Figures 4a and 4b). In soil with sand texture at 21 DAE, the application of the herbicide haloxyfop resulted in the death of 100% of the corn plants (Figure 4a). The quizalofop-P-ethyl also caused a drastic reduction in the stand with an aggravated effect as the applications approached the sowing. Even in clayey soil, it is worth mentioning that no application of quizalofop-P-ethyl provided a satisfactory plant stand, showing the phytotoxic potential of this herbicide (Figure 4b).

Herbicides based on clethodim were the ones that had the least impact on reducing the stand, with the values matching that of the control in both evaluations in the different soils. These results corroborate the data on phytointoxication of herbicides based on clethodim, which were the least harmful to the establishment of the culture. In study that evaluated the effect of clethodim (196.8 g ha^{-1}) on the germination of different corn hybrids, the application of the herbicide one day before sowing negatively affected corn emergence (Becker *et al.*, 2019). However, Spader *et al.* (2012) found no reduction in corn emergence when clethodim (96 g ha^{-1}) was applied two days before sowing.

The results of dry mass in sandy loam soil reinforce the phytotoxic effect to the corn crop caused by the application of the herbicide quizalofop-P-ethyl since 15 DBS, on the occasion of necrotic symptoms and consequently drastic reduction of dry mass (Figure 5a). Necrotic symptoms can

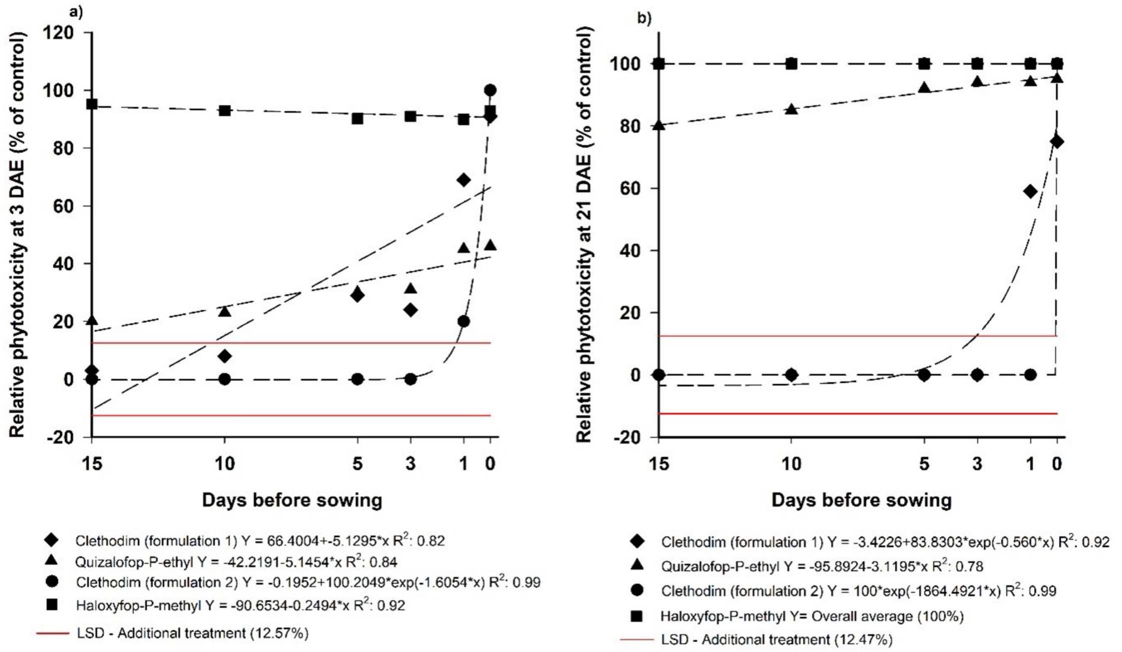

Figure 3: Phytointoxication of corn plants at 3 DAE (a) and at 21 DAE (b) depending on the application of ACCase inhibiting herbicides between 0 and 15 days before sowing the corn crop grown in clayey soil in greenhouse conditions.

be observed in growing tissues after one week of application with initial chlorosis and subsequent disintegration of the leaves (Dayan *et al.*, 2019). On the other hand, the herbicides based on clethodim were comparable to the control, not compromising the accumulation of dry mass when applied up to 4 DBS in soil with sand texture and when applied up to 3 DBS (formulation 2) and 5 DBS (formulation 1) in clayey soil (Figure 5b).

The symptoms observed in the applications of haloxyfop and quizalofop-P-ethyl at 21 DAE were of seedlings emerging purplish, deformed and with few roots and with the passing of days they died. Despite the tendency of ACCase herbicide molecules to bind strongly to soil particles, after application they can be converted to their acid form, resulting in absorption by plant roots and damage (Takano *et al.*, 2021). However, the potential for carryover varies from one species to another, soil characteristics, and herbicide dosage, but residual activity was not observed for more than 14 days (Lancaster *et al.*, 2018).

In general, the effects observed in the greenhouse showed that all herbicides tested are potentially harmful when applied on the day of corn sowing, affecting all variables tested, regardless of the soil used. The differences between the results of the two soils tested are punctual, however, they show tendencies that in the clayey soil there is a greater phytotoxic effect than in the sandy loam soil, mainly in the evaluations at 3 DAE.

Field experiments

The results for the area with sandy clay soil demonstrated that for the phytointoxication variable, no effect of the herbicides on the corn seedlings was observed in the application at 15 DBS, whereas at 7 DBS, only the herbicide clethodim was not harmful to the crop, being the only one comparable to the control. Regardless of the formulation, data on phytointoxication of clethodim-based herbicides suggest a tendency to increase the incidence of plants with symptoms as the applications occurred closer to sowing. Meanwhile, for applications with haloxyfop and quizalofop-P-ethyl, the phytotoxic effect provided to the 7 DBS remained practically unchanged until the last period (Table 1).

Phytointoxication data obtained from seedlings in the field corroborate the crop response observed in the greenhouse. On the other hand, the stand data and plant height contradict the initial results of the greenhouse. In the case of field trials, in both soils studied, no effects of the applications of graminicides on the stand and plant height were observed. This difference in performance can be attributed to the leaching potential provided by each of the experimental methodology, since in the greenhouse no water depth was applied to the soil until the time of sowing, whereas in the field, rain precipitation was recorded at the amount of 62.6 and 42.8 mm for periods 15 and 7 DBS, respectively.

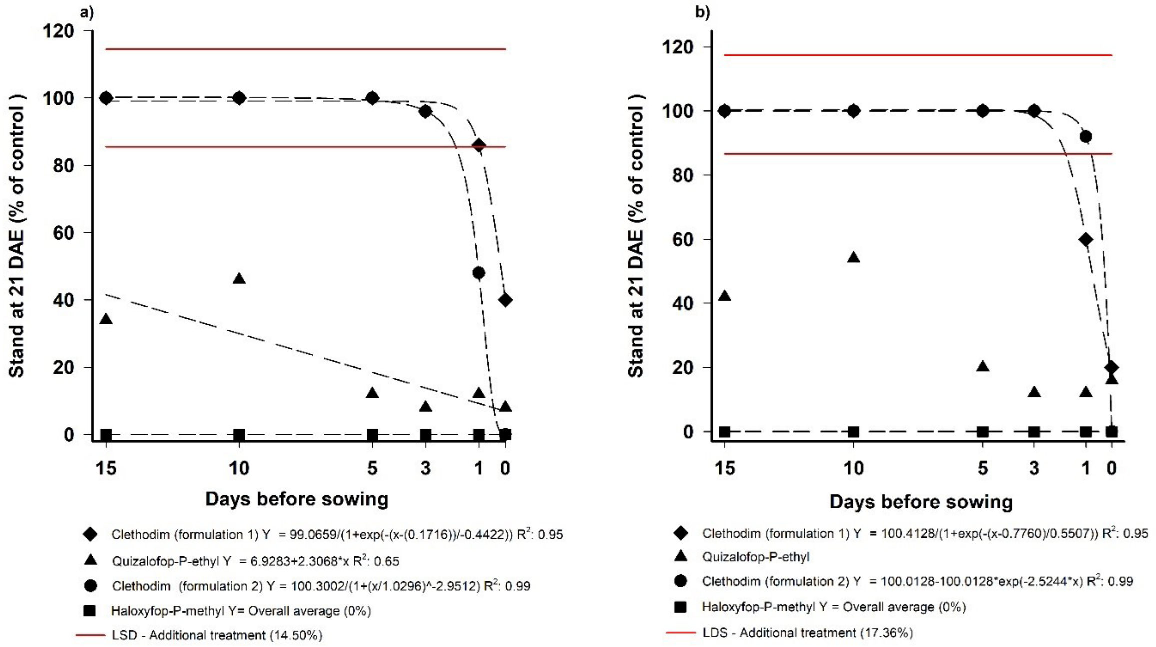

Figure 4: Corn plant stand at 21 DAE in sandy loam sand soil (a) and clayey soil (b) depending on the application of ACCase-inhibiting herbicides between 0 and 15 days before sowing the corn crop in greenhouse conditions.

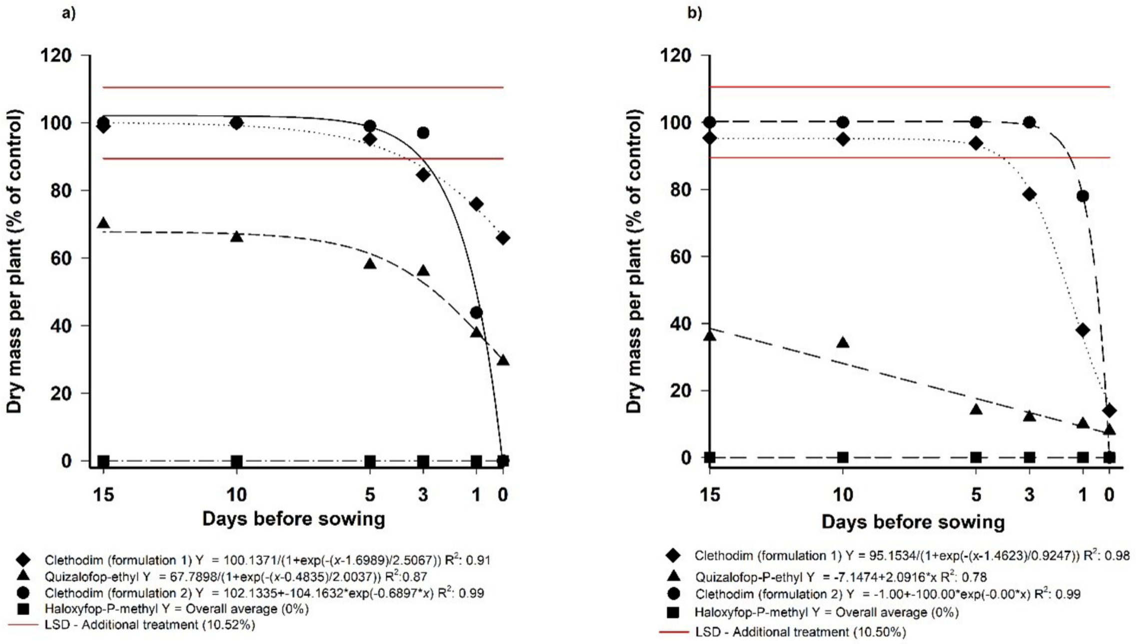

Figure 5: Dry mass of the aerial part per plant in sandy loam soil (a) and dry mass of the aerial part per plant in clayey soil (b) at 21 DAE depending on applications of ACCase-inhibiting herbicides staggered between 0 and 15 days before sowing the corn crop in greenhouse conditions.

For periods of 2 and 0 DBS, despite the absence of rain between herbicide applications and sowing, a precipitation of 100.7 mm was recorded between the fourth and the fifth day after the sowing crop. In addition, the 197.8 mm water depth recorded between the day of sowing and the moment when the parameters were evaluated may have additionally contributed to nullify a possible residual effect of the herbicides. Assessing the impact of different ACCase inhibitors on corn, sorghum and rice crops, Lancaster *et al.* (2018) reported that precipitation after the application of these herbicides impacts the risk of damage to the crop. This occurs due increase absorption and availability of herbicides in soil. Generally, soil-applied herbicides need 1.3 to 1.9 cm of precipitation for optimum activation (Riar *et al.*, 2012).

Table 1: Seedling phytointoxication, stand, plant height, and yield according to applications of ACCase-inhibitor herbicides staggered in four periods before sowing (0, 2, 7 and 15 DBS - days before sowing) of hybrid corn P3380HR in clayey soil in field conditions. All data are expressed as a percentage of the control

Herbicides	15 DBS	7 DBS	2 DBS	0 DBS
	Phytointoxication (%) 7 DAE			
Clethodim (formulation 1)	0.0 aA	4.2 aB	11.0 bC (+)	13.0 bC (+)
Haloxyfop-P-methyl	2.2 aA	6.0 aB (+)	6.0 aB (+)	8.0 aB (+)
Quizalofop-P-ethyl	2.0 aA	6.0 aB (+)	6.0 aB (+)	6.0 aB (+)
Clethodim (formulation 2)	1.2 aA	5.6 aB (+)	10.0 bC (+)	8.0 aBC (+)
Control	0.00%			
CV%	20.4	DMS Dunnet	4.3 DMS t	2.9
Herbicides	**Plant height (%) 21 DAE^{ns}**			
Clethodim (formulation 1)	98.6	97.6	99.4	98.6
Haloxyfop-P-methyl	99.2	97.4	99.4	99.0
Quizalofop-P-ethyl	97.4	98.6	100	98.4
Clethodim (formulation 2)	98.4	98.0	99.0	99.8
Control	100			
CV%	1.5	DMS Dunnet	2.8 DMS t	5.2
Herbicides	**Stand (%) 21 DAE^{ns}**			
Clethodim (formulation 1)	98.2	100	97.2	98.2
Haloxyifop-P-methyl	96.4	96.6	98.0	98.2
Quizalofop-P-ethyl	98.0	100	98.0	100
Clethodim (formulation 2)	97.0	100	98.4	97.0
Control	100			
CV%	3.98	DMS Dunnet	3.7 DMS t	6.3
Herbicides	**Yield (%)**			
Clethodim (formulation 1)	95.8 aA	96.4 aA	92.0 aA	98.0 aA
Haloxyfop-P-methyl	93.6 aAB	98.0 aA	99.6 aA	89.8 bB
Quizalofop-P-ethyl	93.0 aA	94.2 aA	95.6 aA	97.2 aA
Clethodim (formulation 2)	98.2 aA	96.0 aA	94.8 aA	96.0 abA
Control	100			
CV%	5.9	DMS Dunnet	10.5 DMS t	7.1

^{ns} Means do not differ from the control without application by the Dunnett test ($p \leq 0.05$).
Means followed by (+) are higher than the control by the Dunnett test ($p \leq 0.05$).
Means followed by equal lower-case letters in the column and equal upper-case letters in the row do not differ by the t test ($p \leq 0.05$).

Regarding the yield parameters, no significant effects of herbicides were observed for applications between 15 and 2 DBS. In study which analyzed the impact on the field of ACCase inhibitors (quizalofop-P-tefuryl, clethodim and tepraloxydim) applied seven and two days before the sowing of corn in sandy clay soil, the authors did not identify losses in the crop yield (Spader *et al.*, 2012). On the other hand, confirming the harmful effect observed in the greenhouse, haloxyfop was the only herbicide to provide reduced yield when applied moments before sowing (apply-plant) (Table 1). It is possible that this finding is associated with the fact that this herbicide has the lowest Koc (28.5-113.5) (Tomlin, 2009) among the evaluated herbicides and, consequently, greater potential to be available for absorption by plants.

In general, the herbicides quizalofop-P-ethyl and haloxyfop already at 15 DBS showed lower grain yields than herbicides based on clethodim, however they were similar to the control without herbicide application.

Meanwhile, in soil with a sandy loam texture, the phytointoxication of corn seedlings was significant only in the two periods of application closest to sowing (Table 2). A different result was observed with the herbicide quizalofop-p-methyl, the only treatment that was comparable to

Table 2: Seedling phytointoxication, stand, plant height, and yield according to applications of ACCase-inhibitor herbicides staggered in four periods before sowing (0, 2, 7 and 15 DBS - days before sowing) of hybrid corn P3380HR in a sandy clay loam soil in field conditions. Data are expressed as a percentage of the control

Herbicides	**15 DBS**	**7 DBS**	**2 DBS**	**0 DBS**
	Phytointoxication (%) 7 DAE			
Clethodim (formulation 1)	0.0 aA	5.0 aA	13.0 aB (+)	14.0 abB(+)
Haloxyfop-P-methyl	4.2 aBA	8.0 aA	15.0 aB (+)	14.0 abB (+)
Quizalofop-P-ethyl	7.6 bA	8.0 aA	10.4 aA (+)	8.0 aA
Clethodim (formulation 2)	4.0 abA	8.0 aAB	14.0 aBC (+)	16.0 bC (+)
Control		0		
CV%	35.7	DMS Dunnet	8.9 DMS t	6.0
Herbicides	**Plant height (%) 21 DAE**[ns]			
Clethodim (formulation 1)	100	95.8	95.4	95.0
Haloxyfop-P-methyl	100	100	96.2	95.0
Quizalofop-P-ethyl	96.4	98.2	96.6	96.4
Clethodim (formulation 2)	99.4	98.4	98.2	96.4
Control		100		
CV%	5.1	DMS Dunnet	9.2 DMS t	8.3
Herbicides	**Stand (%) 21 DAE**[ns]			
Clethodim (formulation 1)	98	97.4	94.6	96
Haloxyfop-P-methyl	98.4	94.4	98.2	100
Quizalofop-P-ethyl	97.2	96.2	95.6	98
Clethodim (formulation 2)	98.4	98.8	99.4	95.4
Control		100		
CV%	5.1	DMS Dunnet	9.2 DMS t	8.3
Herbicides	**Yield (%)**			
Clethodim (formulation 1)	95.8 aA	96.0 aA	94.8 abA	98.4 aA
Haloxyfop-P-methyl	99.4 aA	95.8 aAB	92.8 bB	95.0 aAB
Quizalofop-P-ethyl	95.2 aA	98.0 aA	96.4 abA	95.4 aA
Clethodim (formulation 2)	98.2 aA	96.4 aA	99.2 aA	95.8 aA
Control		100		
CV%	4.5	DMS Dunnet	8.1 DMS t	4.5

[ns] Means do not differ from the control without application by the Dunnett test ($p \leq 0.05$).
Means followed by (+) are higher than the control by the Dunnett test ($p \leq 0.05$).
Means followed by equal lower-case letters in the column and equal upper-case letters in the row do not differ by the t test ($p \leq 0.05$).

the control when applied on the same day of sowing.

Herbicides based on clethodim caused greater phytointoxication in both soils when applied on the day of sowing. Despite this, a higher percentage of phytotoxication was provided with the use of these herbicides in soil with a sandy loam texture. Another study evaluated the application of clethodim (144 g ai L^{-1}) on the day of sowing and no residual effect was observed on the corn hybrid AG7098 PRO in clayey soil, however, in loamy sandy clay soil it caused low phytointoxication (Stasievski, 2015).

As observed in sandy clay soil, in this experiment only the grain yield variable was influenced by the application of the herbicides (Table 2). The application of haloxyfop has shown to have the potential to negatively affect yield, however, against the results of the phytointoxication variable, there is no conclusive interpretation of its effect, despite having reduced productivity to 2 DBS compared to the herbicide formulation 2, haloxyfop did not differ from the others, including the control.

It is plausible that this lack of response from the culture (Table 2) is related to leaching, and or to the degradation of molecules due to precipitation. These processes regulate the rate of absorption, degradation, and consequently their final fate in the environment (Chaplain *et al.*, 2011). However, as both experimental fields were conducted under the same climatic conditions, it is possible to state that in sandy clay soil the phytointoxication symptoms caused by herbicides in corn seedlings are noticeable in applications carried out with 7 or less DBS, while for the sandy clay loam soil the same occurred only in applications from 2 DBS. This difference may be related to the organic matter content of each soil. Organic matter and clay particles have a greater specific surface and are chemically active, so soils rich in clay or organic matter, or both, have a high potential for adsorbing pesticides (Kukorelli *et al.*, 2013). Although that, the Brazil labels specifies at least 7 days of safe plant-back interval for clethodim herbicides in corn (Anonymous 2023a, b), and to quizalofop and haloxyfop does not contain the safe plant-back interval to corn sowing (Anonymous 2023c, d), but to another Poaceae family, such as oats the safe plant-back interval for quizalofop is 7 days (Anonymous 2023c).

CONCLUSIONS

These data emphasize the importance of correct management of weeds in the sequential system of soybean and corn crops. The Poaceae family weeds should be managed correctly to avoid late ACCase-inhibitors applications into soybean crop. ACCase-inhibiting herbicides used before corn sowing can persist in the soil in sufficient quantities to cause damage to the crop and the level of damage varies depending on the herbicide used, the time between application and sowing and the soil texture.

In the greenhouse, the herbicides that least harmed the development of corn were those based on clethodim, followed by quizalofop-P-ethyl and haloxyfop. The greenhouse safety intervals for clethodim-based herbicides were 5 days and greater than 15 days for quizalofop-P-ethyl and haloxyfop, respectively. In field conditions, the herbicides based on clethodim and quizalofop-P-ethyl did not compromise the development and yield of the corn crop even when applied on the day of sowing, but haloxyfop applied on the day of sowing reduced the yield of corn.

Evidence was found that in the clayey soil there was a greater phytotoxic effect after the application of ACCase inhibitors than in the sandy clay loam soil, which raises the need for further studies regarding this conclusion.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

This study was financed in part by the Coordenação de Aperfeiçoamento Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

There is no conflict of interest in conducting the research and publishing the manuscript.

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