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Persistence of Biological Activity and Leaching Potential of Herbicides Aminocyclopyrachlor and Indaziflam in Soils with Different Textures[1]

Persistência da Atividade Biológica e Potencial de Lixiviação dos Herbicidas Aminocyclopyrachlor e Indaziflam em Solos com Diferentes Texturas

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ABSTRACT – Herbicides aminocyclopyrachlor and indaziflam are under development in Brazil. Information about the behaviors in Brazilian soils and climate is scarce. Thus, the present work has aimed to evaluate the persistence of biological activity and leaching potential of aminocyclopyrachlor and indaziflam in contrasting textured soils by means of bioassays. For the evaluation of persistence, four experiments were performed, in which soils with different textures were studied in different time periods between herbicide application and bioindicator sowing (beet and soybeans). To determine leaching potential, three blades of rainfall (0, 30 and 60 mm) were simulated, each constituting a single experiment in soils with different textures and five bands of depth in the columns. The bioindicator used for the leaching tests was beet. The persistence of biological activity of aminocyclopyrachlor and indaziflam was greater than 150 days. In clayey soil there was less persistent aminocyclopyrachlor than in the loam texture. For indaziflam there was no difference in persistence between the two soils. Regarding the leaching potential, it was observed that the precipitations have the capacity to interfere with the leaching of herbicides aminocyclopyrachlor and indaziflam. Aminocyclopyrachlor has greater potential for leaching than indaziflam. The first one has its mobility increased when applied to soil of loam texture in relation to very clayey soil. As for indaziflam, marked differences between soils with different textures have not been noticed.

Keywords: residual activity, bioassay, organic matter.

RESUMO – Os herbicidas aminocyclopyrachlor e indaziflam encontram-se em fase de desenvolvimento no Brasil. Informações a respeito do comportamento deles em condições edafoclimáticas brasileiras são escassas. O presente trabalho foi desenvolvido com o objetivo de avaliar a persistência da atividade biológica e o potencial de lixiviação do aminocyclopyrachlor e indaziflam em solos de texturas contrastantes, por meio de bioensaios. Para avaliação da persistência foram realizados quatro experimentos, em que foram estudados solos com texturas distintas em diferentes períodos de tempo entre a aplicação dos herbicidas e a semeadura do bioindicador (beterraba e soja). Para determinação do potencial de lixiviação, simularam-se três lâminas de precipitação (0, 30 e 60 mm), cada uma constituindo um experimento isolado, em solos com diferentes texturas e cinco faixas de profundidades nas colunas. O bioindicador utilizado para os

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ensaios de lixiviação foi a beterraba. A persistência da atividade biológica do aminocyclopyrachlor e indaziflam foi superior a 150 dias. No solo de textura muito argilosa, verificou-se menor persistência do aminocyclopyrachlor do que no de textura franco-argiloarenosa. Para o indaziflam, não se observou diferença na persistência entre os dois solos estudados. Com relação ao potencial de lixiviação, observou-se que as precipitações possuem capacidade de interferir na lixiviação dos herbicidas aminocyclopyrachlor e indaziflam. O aminocyclopyrachlor possui maior potencial de lixiviação do que o indaziflam; o primeiro tem sua mobilidade aumentada quando aplicado em solo de textura franco-argiloarenosa, em relação ao solo de textura muito argilosa. Quanto ao indaziflam, não foram notadas diferenças marcantes entre os solos com diferentes texturas.

Palavras-chave: atividade residual, bioensaio, matéria orgânica.

INTRODUCTION

Soil is the likely final destination of most of the chemicals used in agriculture, whether applied preemergence or postemergence. On contact with soil, herbicides are subject to physical and chemical processes that govern their destination in the environment (Oliveira & Brighenti, 2011). Among the processes that can occur with the herbicide in the soil, persistence and leaching are highlighted.

The persistence of a herbicide is the compound ability to show its residual effect, preventing the development of weeds in a certain area. Moreover, herbicides with very long bioactivity can cause injury to sensitive plants in a crop rotation system or intercropped crops (Dan et al., 2012a, b). There are many processes that influence the persistence of a herbicide. Dissipation, evaporation, leaching, surface runoff, plant uptake and molecule physical, chemical and biological degradation rate are highlighted (Silva et al., 2007), in addition to the initial dose (Blanco & Oliveira, 1987).

Leaching or percolation of a herbicide is the downward movement in the soil matrix, provided it is in the soil solution (Oliveira & Brighenti, 2011). This form of movement will take place together with the water flow by the water potential difference between two points (Prata et al., 2003). The downward movement of the herbicides in the soil is influenced by several factors such as the content and composition of organic matter, texture, pH, soil density, and size and distribution of pores, besides the physical and chemical properties of the herbicide, such as solubility, sorption coefficient normalized by organic carbon content (K_{oc}), and acid ionization equilibrium constant (pKa), among others (Oliveira Júnior & Regitano, 2009; Oliveira & Brighenti, 2011).

Persistence and leaching of a herbicide in the soil can be identified and quantified by analytical techniques such as the use of radioisotopes and liquid or gas chromatography (Inoue et al., 2002). An alternative technique is the use of plant species that have high sensitivity to the herbicide of interest (bioindicators) – this technique is known as bioassay (Inoue et al., 2002; Nunes & Vidal, 2009). Its advantages over others are simplicity, low cost and the possibility of detecting the biologically active amount of the herbicide, being directly applicable in field conditions (Lima et al., 1999).

Because of lower cost, higher efficiency, large extension of agricultural areas and availability of registration of various products in the culture of sugarcane (*Saccharum* spp.), the chemical method of weed control has been preferred by farmers (Monquero et al., 2008). Most herbicides recommended for this culture are to be applied in preemergence or initial postemergence, so that the destination of most molecules is the soil (Christoffoleti et al., 2009).

Herbicides aminocyclopyrachlor and indaziflam are molecules that are under development in Brazil for the cultivation of sugarcane (Guerra et al., 2013). In the United States, aminocyclopyrachlor is registered for weed control in non-agricultural areas, pastures, forest plantations and nurseries (Turner et al., 2009; Mc Closkey et al., 2011); as for indaziflam, in the United States it is recommended for use on lawns (Kaapro & Hall, 2012) and in Canada for cultivation of some fruit trees (Bayer..., 2012). Both herbicides have activity in preemergence and postemergence, with a long residual activity period (Turner et al., 2009; USEPA., 2010). In the literature, practically, there is no information on the behavior of herbicides in soil, especially for subtropical and tropical edaphic climatic conditions, such as those occurring in Brazil. Thus, this work was developed to evaluate the persistence of biological activity and leaching potential of herbicides aminocyclopyrachlor and indaziflam in contrasting texture soils by means of bioassays.

MATERIAL AND METHODS

All experiments were conducted in a greenhouse belonging to Faculdade Integrado de Campo Mourão, in the Brazilian municipality of Campo Mourão, PR. Its geographical coordinates are: latitude 23°99'04" south, longitude 52°36'37" west and average altitude 508 m.

Persistence of biological activity

Experiments of biological activity persistence were carried out during the months from June to December 2012. Soils used as substrates were collected at a depth of 0-10 cm. Before being used in the experiments, the samples were air dried and passed through a 2 mm mesh sieve.

The first soil was classified as distroferric yellow latosol, loam textured, consisting of 72% sand, 23% clay and 5% silt. Regarding the chemical characteristics, presented pH (H_2O) of 5.30; 4.61 $cmol_c$ dm^{-3} of H^++Al^{3+}; 4.17 $cmol_c$ dm^{-3} of Ca^{+2}; 1.02 $cmol_c$ dm^{-3} of Mg^{+2}; 0.66 $cmol_c$ dm^{-3} of K^+; 108.7 mg dm^{-3} of P; and 12.28 g dm^{-3} of organic carbon. The second one, distroferric red latosol, was very clayey, consisting of 17% sand, 73% clay and 10% silt. Regarding the chemical characteristics, presents pH (H_2O) of 6.20; 3.68 $cmol_c$ dm^{-3} of H^++Al^{3+}; 7.09 $cmol_c$ dm^{-3} of Ca^{+2}; 2.81 $cmol_c$ dm^{-3} of Mg^{+2}; 0.36 $cmol_c$ dm^{-3} of K^+; 6.3 mg dm^{-3} of P; and 18.42 g dm^{-3} of organic carbon.

Four experiments were simultaneously conducted, being two for aminocyclopyrachlor and two for indaziflam, using beet and soybean as bioindicators. These bioindicator species were chosen based on preliminary studies (Guerra et al., 2014). The doses of aminocyclopyrachlor and indaziflam used in these experiments corresponded to 90 and 100 g ha^{-1}, respectively.

For all persistence experiments, a completely randomized arrangement with five replications in a (2x6) + 2 factorial design was used. The first factor studied was the soil. The second one was the period of time between herbicide application and bioindicator sowing (0, 30, 60, 90, 120 and 150 days after herbicide application – DAA), besides two controls (one for each soil texture) without herbicide application.

Experimental units consisted of polyethylene pots with a capacity of 3 dm^3 of soil. The first herbicide application was held on 7/10/2012 and every 30 days a new application was held. In all applications a knapsack sprayer pressurized at CO_2 was used, equipped with four nozzles XR110.02, kept at a work pressure of 206.8 kPa, which resulted in a spray mix volume proportional to 200 L ha^{-1}. At the time of application, average environmental conditions were of a temperature between 25 and 28 °C, air relative humidity between 65 and 82%, wind speeds ranging between 0.3 and 1.5 km h^{-1} and moist soil.

During the period of time between herbicide application and bioindicator sowing, the experimental units awaiting seeding received weekly irrigation which simulated 15 mm of rainfall. At the end of every season of predetermined applications (11/26/2012), four soybean seeds or eight beet seeds were sown per each experimental unit at a depth of 1.5 cm.

After 21 days of bioindicator sowing (DAS), the number of live plants was recorded and then the shoots were cut. This material was weighed on a precision scale in order to obtain the shoots fresh matter. With this data, the inhibition percentages related to the respective control without herbicide was calculated for each soil texture.

The results were submitted to analysis of variance by the F-test and regression analysis ($p \leq 0.05$). The models were chosen considering the coefficient of determination and also the representativity of the biological behavior of the phenomenon evaluated.

Leaching potential

Experiments to assess leaching potential were developed between the months of August and October 2013 using soil samples collected from a depth of 0-20 cm, then air-dried and sieved (2 mm).

The first soil, classified as loam textured, consisted of 67% sand, 29% clay and 4% silt. Regarding the chemical characteristics, presented pH (H_2O) of 5.50; 4.61 $cmol_c\ dm^{-3}$ of $H^{+}+Al^{3+}$; 3.54 $cmol_c\ dm^{-3}$ of Ca^{+2}; 0.75 $cmol_c\ dm^{-3}$ of Mg^{+2}; 1.34 $cmol_c\ dm^{-3}$ of K^{+}; 30.61 mg dm^{-3} of P; and 18.95 g dm^{-3} of organic carbon. The second one was classified as very clayey textured, consisting of 13% sand, 76% clay and 11% silt. Regarding the chemical characteristics, presented pH (H_2O) of 5.70; 5.00 $cmol_c\ dm^{-3}$ of $H^{+}+Al^{3+}$; 2.47 $cmol_c\ dm^{-3}$ of Ca^{+2}; 1.44 $cmol_c\ dm^{-3}$ of Mg^{+2}; 0.1 $cmol_c\ dm^{-3}$ of K^{+}; 1.34 mg dm^{-3} of P; and 13.37 g dm^{-3} of organic carbon.

Two experiments were simultaneously conducted with herbicides aminocyclopyrachlor (90 g ha^{-1}) and the other with indaziflam (100 g ha^{-1}). For each herbicide, three different rainfall blades were simulated (0, 30 and 60 mm), each constituting a separate experiment.

Leaching experiments were conducted in a completely randomized arrangement with four replications in a (2x5) + 2 factorial design. The first factor consisted of soils with different textures (loam and very clayey), and the second one of five bands of depths in the columns (0-5, 5-10, 10-15, 15-20 and 20-25 cm). The two additional treatments consisted of two controls (one for each soil texture) without herbicide application to serve as a comparison standard.

The experimental units consisted of soil columns mounted on 10-cm diameter and 30 cm high PVC (poly(vinyl chloride)) tubes, previously split lengthwise. To keep the two halves together, an adhesive tape and a flat wire were used. At the bottom of the column, a polyethylene screen was positioned with a 1-mm mesh attached by rubber in order to prevent soil loss. Each column received approximately 3 kg of soil. After the soil conditioning, the columns were wetted by capillary action until the top of the soil column became saturated. Then the columns were kept on workbenches in a greenhouse for 24 hours so that excess water were drained.

Herbicides aminocyclopyrachlor and indaziflam were applied on top of the columns on 08/13/2013. For this, a knapsack sprayer pressurized with CO_2 was used in the same manner as in the persistence experiment of the biological activity. At the time of application, the soils were moist and environmental conditions were 27.1 °C, air relative humidity of 55% and winds of 1.5 km h^{-1}.

Seventy-two hours after herbicide application, rainfalls equivalent to 0, 30 and 60 mm were simulated on top of the columns. Three days after the simulated rainfalls, the columns had the two halves longitudinally separated. Each half was divided into five 5 cm sections from the surface where the herbicide was applied (0-5, 5-10, 10-15, 15-20 and 20-25 cm deep). The soil of each of these sections was transferred to polyethylene pots with a 250 cm^3 capacity, and then five beet seeds were seeded per pot. This species is sensitive to the herbicides used (Guerra et al., 2014). In Figures containing experimental results, every 5 cm range of the columns is numerically represented by the largest absolute value.

Irrigations for moisture maintenance of the pots were performed daily in all treatments. Twenty-one days after emergence of the bioindicator, the beet plants shoots were cut close to the ground. This material was weighed on a precision scale in order to obtain the shoots fresh matter. From these data, the percentage of inhibition compared to the respective control without herbicide was calculated for each layer of depth in the soil column.

Data were submitted to analysis of variance by the F-test and regression analysis ($p \leq 0.05$). The models were chosen considering the coefficient of determination and biological significance.

RESULTS AND DISCUSSION

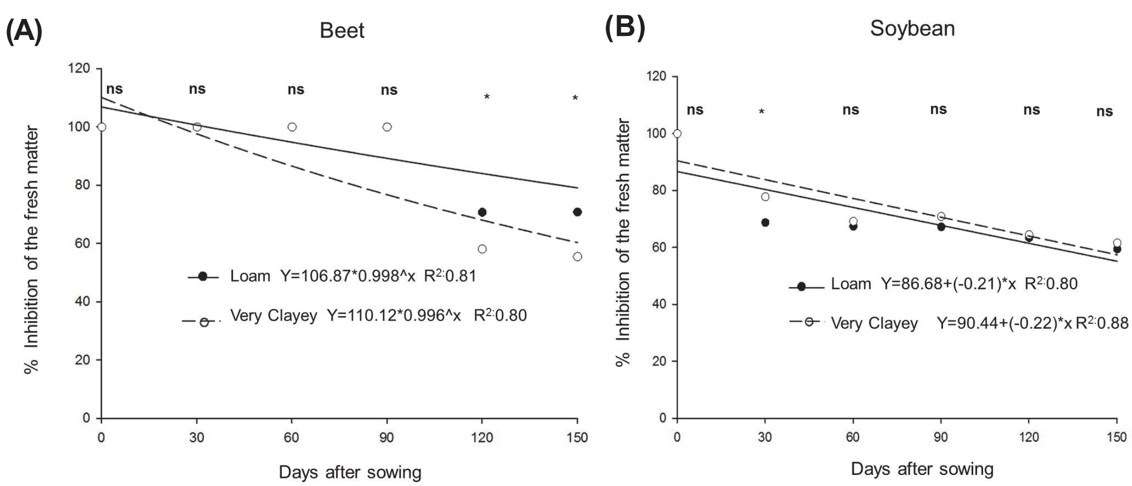
Persistence of biological activity

Regardless of soil texture, high persistence of the aminocyclopyrachlor biological activity was observed. Even after 150 days of its application, there were inhibition percentages of the bioindicator fresh matter higher than 55% (Figures 1A and B).

Aminocyclopyrachlor biological activity, detected by means of beet plants, indicated that when it was applied in soil with loam texture, persistence was longer than when applied to very clayey soil. Analyzing the results, it was found that when beets were sown within the range from 0 to 90 DAA of the aminocyclopyrachlor, there was no emergence, occurring 100% inhibition of fresh matter. As for sowing performed at 120 and 150 DAA, they resulted in inhibition of 70.7% and 70.8% for the loam soil and 58.1% and 55.5% for the clayey one, respectively. That is, to be reduced by 30% (loam texture) and 42-45% (very clayey) in the aminocyclopyrachlor residual activity, a minimum of 120 days and accumulated rainfall were needed during the waiting period of the bioindicator sowing, equivalent to 260 mm (Figure 1A).

The lower persistence in the very clayey soil is probably due to greater sorption of this herbicide to clay colloids, which are more abundant in this soil than in the loam textured. Oliveira Júnior et al. (2013) have found that in soils with higher clay content there is greater sorption of this herbicide. In addition to the clay content, organic carbon content is also higher in very clayey soil, which may also have contributed to the greater sorption of the herbicide, for the sorption of aminocyclopyrachlor has a positive correlation with clay and organic carbon contents of the soil (Oliveira Júnior et al., 2011). Lindenmayer (2012) has also noted that the sorption of aminocyclopyrachlor has a positive relationship with the organic matter.

Another hypothesis is that soils with higher organic carbon content have increased activity of microorganisms, which may have favored the degradation of aminocyclopyrachlor, since this is the main form of degradation of this herbicide (Finkelstein et al., 2008; Lindenmayer et al., 2009; Lindenmayer, 2012). In contrast, Conklin & Lym (2013) suggest the



ns nonsignificant at 5% probability and * significant at 5% probability.

Figure 1 - Inhibition of the fresh matter of beet (A) and soybeans (B) plants at 21 days after sowing in contrasting textured soils after applying aminocyclopyrachlor.

opposite, stating that the degradation of aminocyclopyrachlor may be slower in soils with low organic matter content, due to this molecule being sorbed to the organic matter.

When soybean was used as a bioindicator, there was no difference in persistence for the soils with different textures (Figure 1B). Only in sowing performed on the same day of applying aminocyclopyrachlor (0 DAA) there was no emergence of this species for any of the soil textures. In the other sowing dates, there were, for the loam soil, inhibition percentages of fresh matter ranging between 59.4 and 68.7%, whereas for the very clayey soil these values ranged from 61.6 to 77.8% (Figure 1B). The fact that significant differences in the persistence of this herbicide in both soils were not observed when using soybean as a bioindicator species can be attributed to the lower sensitivity of this species to aminocyclopyrachlor compared with beets, as described by Guerra et al. (2014).

According to Kniss & Lyon (2011), aminocyclopyrachlor should be used with caution because it can damage the crops that will be grown later. An example is in the wheat crops, which had no visible signs of injuries after sowing in soils receiving 20 g ha^{-1} of aminocyclopyrachlor 15 days before sowing. However, at harvest time there was a 50% reduction in productivity, which means that its use is risky even when using longer intervals of time between application and planting of species with different sensitivities to aminocyclopyrachlor.

The persistence of the biological activity of indaziflam was noticeable by the bioindicators (beet and soybean) throughout the experiment period, regardless of the soil texture. In all sowing times, there was a complete inhibition of the bioindicators fresh matter (100%), without the emergence of these in any of the sowing times and soils tested (data not shown).

Indaziflam is a herbicide which has a long persistence in the soil, having $t_{1/2}$ around 150 days (USEPA, 2010). In experiments conducted in the state of Florida, USA, this herbicide promoted, in citrus crops, a residual control for three to five months, depending on weather conditions and the pressure of the area infestation (Singh et al., 2011). Gonzales-Delgado et al. (2015), studying leaching and persistence of indaziflam, noticed residues of this herbicide in the soil one year after application.

Amin et al. (2014), evaluating indaziflam control for species *Euphorbia heterophylla* and *Ipomoea grandifolia* in soils with different textures, observed a better level of control in the loam soil compared to sandy and clayey textured soils. As for the species *Rottboellia cochinchinensis*, they found the lowest percentage of control in the clayey soil in relation to the others. According to these authors, the need for a greater dose of indaziflam to obtain a satisfactory control of *R. cochinchinensis* in clayey soil can be explained by the higher content of organic matter present in it, possibly giving it greater herbicide adsorption capacity, since this product has lipophilic characteristics.

Thus, it can be concluded that persistence of biological activity of aminocyclopyrachlor and indaziflam was greater than 150 days. In very clayey soil, there was less persistence of aminocyclopyrachlor than the in the loam soil by higher clay and organic carbon contents. For indaziflam, there was no difference between the two soils studied.

Leaching potential

Figure 2 shows the percentage of inhibition of the beet plants fresh matter after the application of aminocyclopyrachlor and simulation of 0 (Figure 2A), 30 (Figure 2B) and 60 mm (Figure 2C) of precipitation in soils of loam and very clayey textures. Regardless of the precipitation blade evaluated, a linear behavior was observed for the percentage of inhibition of fresh matter over the column.

Even when there was a simulation of precipitation (Figure 2A), there was a movement of aminocyclopyrachlor throughout the length of the column. This suggests the presence of herbicide residues capable of providing over 60% inhibition in the bioindicator fresh matter in depth of 25 cm for both soils at 21 DAE. It also indicates that the application in soil near saturation is enough for the aminocyclopyrachlor to move

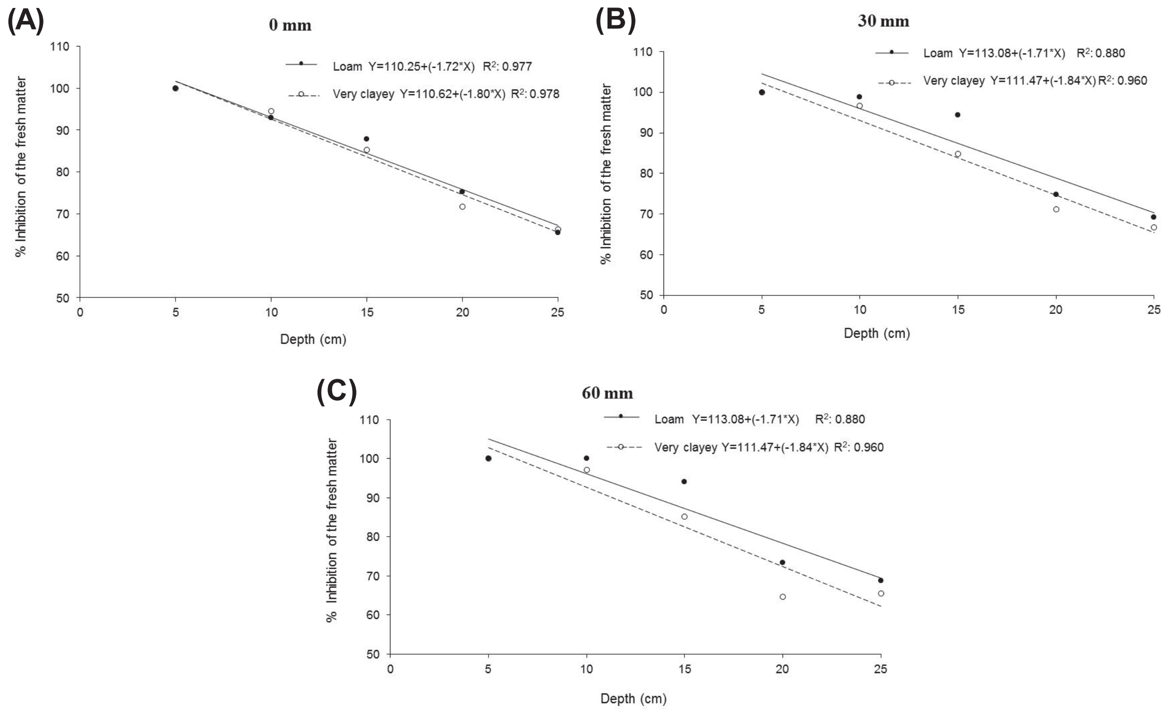


Figure 2 - Percentage of inhibition in fresh matter of beet plants grown in soils with application of aminocyclopyrachlor and precipitation simulation of 0 (A), 30 (B) and 60 mm (C).

significantly on the columns profile, even without the occurrence of precipitation after the application.

When simulation was of 30 and 60 mm, there was an almost total inhibition of fresh matter until the layer of 5-10 cm depth (Figures 2B and C), promoting from that depth a gradual decline, but in a way as to also providing high inhibition of the bioindicators development.

Aminocyclopyrachlor showed a high leaching potential, such that, regardless of the simulated rainfall blade, it was found in the deeper layers of the column. These results corroborate those found Oliveira Jr. et al. (2011, 2013), which, based on the aminocyclopyrachlor sorption coefficients, rated it as very mobile in the soil. Adams & Lym (2015) found leaching of aminocyclopyrachlor throughout the length of the column (70 cm deep) after the 150-mm rainfall simulation. This herbicide was detected at depths of 70-90 cm in the soil after 365 days of its application, indicating that leaching of its residues can also occur (Ryman et al., 2010).

Comparing the soils with different textures, it can be seen that for 30 m and 60 m rainfall blades there was a greater percentage of inhibition of the bioindicator in the soil of loam texture throughout all the column. This shows that in soils with lower clay content there is greater movement of aminocyclopyrachlor molecules.

Aminocyclopyrachlor sorption has a positive correlation with soil clay content (Oliveira Jr. et al., 2011). Oliveira Jr. et al. (2013), studying the sorption and desorption of this herbicide in three different soils of the United States, found that the soil with higher clay content (60%) may have played a significant role in the sorption of aminocyclopyrachlor. Thus, it can be inferred that in the very clayey soil, aminocyclopyrachlor is more sorbed to the clay minerals and, consequently, less amount of the product would be available in the soil solution and prone to leaching.

Inhibition percentages of the beet plants fresh matter after application of indaziflam and simulation of 0, 30 and 60 mm of

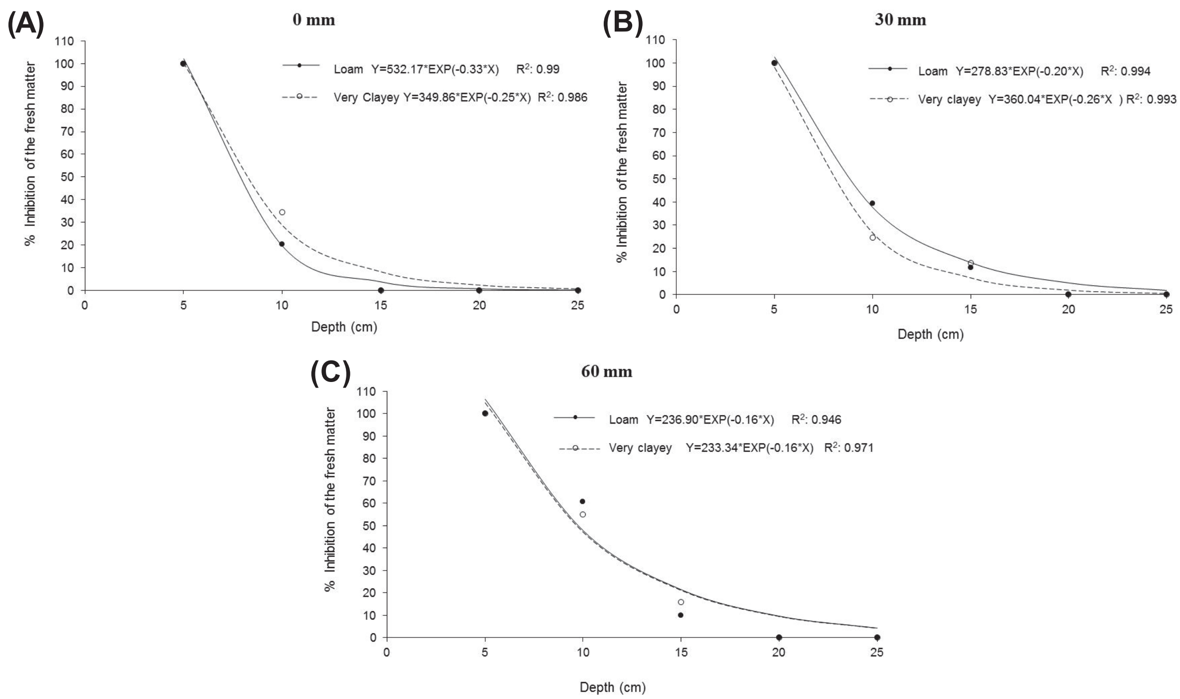


Figure 3 - Percentage of inhibition in fresh matter of beet plants grown in soils with application of indaziflam and precipitation simulation of 0 (A), 30 (B) and 60 mm (C).

precipitation are, respectively, in Figures 3A, 3B and 3C.

When indaziflam was applied and there was no simulated rainfall, most of the product was retained in the upper 10 cm of the column. In the layer between 10 and 20 cm the presence of the herbicide by the beet plant was detected, but the amount found promoted inhibition of less than 20% of the shoots fresh matter. For this condition, there were no marked differences in indaziflam leaching potential in different soil textures (Figure 3A).

The simulation of 30 mm of precipitation (Figure 3B) was sufficient to provide movement of indaziflam molecules to layers slightly deeper than in the absence of precipitation (Figure 3A); still it was not sufficient to achieve the final section of the column (20-25 cm). For this precipitation, higher percolation of indaziflam was noted in the loam texture soil (Figure 3B).

When indaziflam was subjected to 60-mm simulated rainfall (Figure 3C), again it was noted that it concentrated in the surface layers. Only few residues were detected at depths greater than 15 cm, such that the inhibition percentages for this depth were less than 20%, irrespective of the soil studied.

Studies by Jhala & Singh (2012) have shown that indaziflam leached to a depth of 12.5 cm after the simulation of 50 mm of precipitation in soil with 4% clay and 0.5% organic matter. When the irrigation blade was 150 mm, it reached a 27.2 cm depth. Jhala et al. (2012) have also conducted leaching tests with indaziflam using *Lolium multiflorum* as a bioindicator in soils with 4% clay and 0.5% organic matter. These authors found that when using 73 g ha^{-1} of indaziflam, leaching was discernible by the bioindicator up to 15, 20 and 25 cm depth for the precipitation blades of 50, 100 and 150 mm, respectively. As for the higher dose of the herbicide (145 g ha^{-1}), leaching occurred up to 20, 25 and 30 cm, respectively. These results support those obtained in this experiment with indaziflam, since, when increasing the volume of precipitation, greater movement of this herbicide was observed throughout the column profile, but not enough to reach its final section, as the highest amount tested was 60 mm.

For the herbicide indaziflam, it was noticeable that even the simulation of 60 mm of precipitation was sufficient to leach it to deeper layers. Alonso et al. (2011, 2015) have found in sorption and desorption studies that this molecule has the potential of moderate to low mobility in the soil and, once sorbed to the colloids, it hardly returns to the soil solution. Gonzales-Delgado et al. (2015), evaluating indaziflam leaching in orchards, found herbicide residues in 7 to 15 cm deep sections and not on the soil surface; the authors' justification for this behavior is based on the low availability of indaziflam for the biodegradation and in the absence of appropriate environmental conditions to promote the process of degradation and sorption of indaziflam to the organic matter or clay at this depth.

Herbicides aminocyclopyrachlor and indaziflam have different behavior in relation to the potential for leaching; the first one had greater mobility than the latter (Figures 2 and 3).

The difference in mobility of these herbicides may be associated with the physical-chemical characteristics of these molecules such as the acid ionization equilibrium constant (pKa), solubility and the normalized sorption coefficient, according to the organic carbon content (K_{oc}).

The acid ionization equilibrium constant (pKa) expresses the dissociation ability of the herbicide molecule (Oliveira & Brighenti, 2011). Herbicides aminocyclopyrachlor and indaziflam are characterized as weak acid herbicides, i.e., they are those whose molecular forms are those which are capable of donating a proton and forming negatively charged ions. The pKa values of aminocyclopyrachlor and indaziflam are respectively 4.65 and 3.50 (Finkelstein et al., 2008; USEPA, 2011). Since the soils used in this work have pH values above the pKa of the two herbicides, it is possible to infer that the herbicides were in higher concentration in anionic form and thus more likely to leach.

The solubility is defined by the maximum amount of herbicide which dissolves in pure water at a given temperature. Aminocyclopyrachlor solubility is 2,800 mg L^{-1} (pH 7.0 – 9.0) (Finkelstein et al., 2008), while for indaziflam it is 2.2 mg L^{-1} (pH 7.0 – 9.0) (USEPA, 2011). Highly soluble herbicide molecules are rapidly distributed in the water cycle, whereas those with very low solubility may be limited in their transport with water (Oliveira Júnior & Regitano, 2009).

The coefficient of sorption normalized by the organic carbon content (K_{oc}) provides a measure of relative distribution of the herbicide between the adsorbent (clay and organic matter) and the solvent (water), corrected by the organic carbon content of the soil (Silva et al., 2007; Oliveira & Brighenti, 2011). The value of K_{oc} of the aminocyclopyrachlor ranges between 4 and 67 L kg^{-1} (Oliveira Júnior et al., 2011, 2013), and for indaziflam between 271 and 1,339 L kg^{-1} (Alonso et al., 2011, 2015). These values indicate that indaziflam has a greater tendency to bind to soil colloids than aminocyclopyrachlor, explaining again the highest potential of mobility in the last columns of the latter herbicide.

Leaching potential of a herbicide is directly connected to the contamination of water resources in the underground, since, displaced from the surface layers, which concentrate most of the organic matter and microbial activity, its presence in the system is extended (Prata et al., 2001). Indaziflam has lower mobility in the soil than aminocyclopyrachlor, so that, even when exposed to a simulation of 60 mm of precipitation, indaziflam mobility is limited to 20-cm depth, while for aminocyclopyrachlor there is greater percolation along the columns. Thus, it can be inferred that aminocyclopyrachlor has a higher risk of contamination of subsurface waters, compared to indaziflam.

In the case of the leaching potential, it can be concluded that the precipitations have the capacity to interfere with the leaching of herbicides aminocyclopyrachlor and indaziflam, and the first one has higher leaching potential than the second in soil columns. Aminocyclopyrachlor has its mobility increased when applied to loam soil texture in relation to the very clayey soil. As for indaziflam, significant differences were not seen between the soils with different textures.

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