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Dynamics of preemergent herbicides in production systems with straw[1]

Dinâmica de herbicidas em pré-emergência em sistemas de produção com palha

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Abstract - The use of production management systems with the implementation of cultures in the straw provides many benefits, including protection against soil erosion, increase in organic carbon content, increasing the microbial population, soil moisture conservation and emergence inhibition of some weeds. Given these changes, the preemergent herbicides used in the systems with straw are intercepted before reaching the ground and when leached from the straw they may present differences in their dynamics in the soil. It is important to consider the dynamics of herbicides both in the straw and in the soil, taking into consideration the straw origin, quantity and distribution, as well as the herbicides physicochemical characteristics and the intensity and the period without rain after application of the herbicide. All these factors determine the amount of the herbicide intercepted by straw and its behavior in the soil. Thus, the aim of this review is to understand the dynamic of preemergent herbicides applied in straw and soil in no-till systems, raw sugarcane and minimum tillage. The maintenance of straw on the ground can both intercept and retain the preemergent herbicides applied, reducing their ability to reach the straw layer and causing a reduction in weed control. The longer the time interval between the application and the occurrence of rain or irrigation, the lower the amount of herbicide leached to the soil. Therefore, in crops with soil covered with straw, herbicides that are less vulnerable to losses by volatilization and photodecomposition should preferably be used, in other words, herbicides with higher solubility, low vapor pressure and octanol-water partition coefficient.
Keywords: raw sugarcane; no-tillage; persistence; leaching; rainfall

Resumo - A utilização de sistemas de manejo de produção com a implantação de culturas sobre a palha proporciona muitos benefícios, incluindo a proteção contra a erosão dos solos, elevação no teor de carbono orgânico, aumento da população microbiana, conservação da umidade do solo e inibição da emergência de algumas plantas daninhas. Considerando essas alterações, os herbicidas utilizados em pré-emergência nos sistemas com palha são interceptados antes de alcançarem o solo e quando lixiviados da palha podem apresentar diferenças na sua dinâmica no solo. É importante

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considerar a dinâmica dos herbicidas tanto na palha quanto no solo, levando em consideração a origem, quantidade e distribuição da palha, bem como, as características físico-químicas dos herbicidas e a intensidade e o período sem chuva após a aplicação do herbicida. Todos estes fatores determinam a quantidade do herbicida interceptado pela palha e o seu comportamento no solo. Diante disso, o objetivo desta revisão é a compreensão da dinâmica de herbicidas aplicados em pré-emergência na palha e no solo em sistemas de plantio direto, cana crua e cultivo mínimo. A manutenção de palha sobre o solo pode tanto interceptar quanto reter os herbicidas aplicados em pré-emergência, diminuindo a sua transposição da camada de palha e acarretando redução no controle das plantas daninhas. Quanto maior o intervalo entre a aplicação e a ocorrência de chuva ou irrigação menor será a quantidade de herbicida lixiviada para o solo. Portanto, em cultivos com a cobertura do solo com palha deve-se utilizar preferencialmente os herbicidas que serão menos vulneráveis as perdas por volatilização e fotodecomposição, ou seja, aos herbicidas com maior solubilidade e baixa pressão de vapor e coeficiente de partição octanol-água.
Palavras-chaves: cana crua; plantio direto; persistência; lixiviação; precipitação pluvial

Introduction

In Brazil, the adoption of production systems in which crops are implanted on some kind of stubble has increased in many regions due to the numerous benefits attributed to mulch. Among typical examples, raw sugarcane production system, direct planting of annual crops and minimum tillage in reforestation areas can be mentioned. It is estimated that about 32 million hectares are occupied by the direct planting system (Motter and Almeida, 2015).

Stubble placed on the soil directly affects the weed community by the change in temperature range and soil water (Egley and Duke, 1985) and in the balance of solar radiation that reaches it (Taylorson and Borthwich, 1969) by the release of allelopathic compounds and by representing a physical barrier for the emergence of some weeds. However, these changes are very specific and dynamic, for they depend in the straw quantity and uniformity of distribution and especially the weed species, which may be favored or not by mulch.

Some studies have shown reduction in weed population with the presence of mulch on the soil (Azania et al., 2002; Correia and Durigan, 2004). However, if on one hand the straw may have a positive effect on the weed community, on the other it can negatively influence the dynamics of herbicides applied in the straw and promote changes in behavior and efficacy of products.

As the dynamics of weeds occurrence is affected by stubble, the use of preemergent herbicides applied is also changed by the production systems in the presence of mulch, according to the interception, retention and degradation of herbicides deposited in the straw and dependence on rainfall for the herbicide to reach the ground, where it will act to control weeds. The interaction of herbicides with straw depends on several factors such as quantity and source of coverage, straw ability to cover the soil and retain herbicides, physicochemical characteristics of the herbicide and climatic conditions of the region, as well as the period in which the area remains without rainfall or irrigation after application of the herbicide (Rodrigues et al., 1993; Maciel; Velini, 2005; Simoni et al., 2006).

Thus, to obtain the best efficiency in weed control, it is crucial to know the processes involved since the arrival of herbicides in the straw, the dynamics of these on crop residues and herbicides behavior when reaching the ground.

Association of Residual Herbicides with Glyphosate in Burndown

Sequential or associated applications of glyphosate with residual herbicides are a commonly used alternative to improve efficiency in desiccation and provide better weed control, especially in areas with high incidence of glyphosate-resistant biotypes. However, little is known about the behavior and dynamics of release of residual herbicides applied to the crop mulch when applied together with glyphosate on plants that are still green in the management in preplanting.

The association of glyphosate with chlorimuron, metribuzin and flumetsulam can improve control of resistant biotypes of horseweed (*Conyza* spp.) compared to standalone application. Glyphosate associated with such residual herbicides has caused horseweed control higher than 90% two weeks after application, but the application of glyphosate alone controlled about 60 to 75% of horseweed (Davis et al., 2007). The use of residual herbicides associated with desiccant in preplanting allows to extend horseweed control for a longer period of time, leaving the area free of new emergence flows of this species (Norsworthy et al., 2009).

The mixture of glyphosate (900 g a.e. ha^{-1}) with saflufenacil (25 g a.i. ha^{-1}) applied in preplanting has promoted 87% control of horseweed four weeks after herbicide application, while mixtures with metribuzin (1120 g a.i. ha^{-1}), cloransulam (35 g a.i. ha^{-1}) or flumetsulam (70 g a.i. ha^{-1}) have shown greater residual effect controlling 78-99% of horseweed for up to eight weeks (Byker et al., 2013). Similar results were presented by Waggoner et al. (2009), where the application of glyphosate (1061 g a.e. ha^{-1}) associated with saflufenacil (25 and 50 g a.i. ha^{-1}) controlled 95-96% of horseweed thirty days after the application. In applying the mixture of paraquat with saflufenacil (25 and 50 g a.i. ha^{-1}), the percentage of control was 81 and 84%, indicating a greater residual effect of saflufenacil when applied in combination with glyphosate in control of horseweed.

Jaremtchuk et al. (2008) have observed that the association of glyphosate (1080 g a.e. ha^{-1}) and flumioxazin (25 or 40 g a.i. ha^{-1}) promoted rapid biomass desiccation compared to the application of glyphosate alone (1080 g a.e. ha^{-1}), providing better conditions for soybean emergence, besides a residual effect on new emergence flows of weeds, delaying the need for the first application to control in postemergence of the crop.

In a study carried out by Macedo (2015), in management in preseeding in areas with sorghum or millet covers, the joint application of glyphosate (720 g a.e. ha^{-1}) and sulfentrazone (600 g a.i. ha^{-1}) at 10 days before sowing (DBS) intercepted more sulfentrazone and caused lower uniformity in herbicide distribution in the soil, compared to the sequential application of glyphosate (720 g a.e. ha^{-1}) at 20 DBS and sulfentrazone (600 g a.i. ha^{-1}) at 10 DBS or only sulfentrazone (600 g a.i. ha^{-1}) at 10 DBS without the presence of mulch. In this study, the author has associated the increase in interception by straw and in the variation of the herbicide distribution in the soil when glyphosate and sulfentrazone were applied together at 10 DBS to the largest ground cover at the time of application, as this was done when the plants were still green in comparison to sequential management, in which the application was in the straw. These results indicate that, in addition to vegetable residues having the ability to retain the herbicides applied, the different application procedures regarding the coverage can also interfere with the uniform distribution of the herbicide into the soil.

Therefore, the associated or sequential applications of glyphosate with residual herbicides differ both in relation to control efficiency of the weeds and in the residual period of herbicides. Moreover, as the application were made on the still green cover plants, there can be an uneven herbicide distribution in the area, hence reducing the percentage of weed control due to the presence of a larger quantity of plant material and the possibility that there is herbicide absorption by plants.

Dynamics of Herbicides in the Straw

Since production, systems with straw have expanded into growing areas with sugarcane, annual and forest crops, understanding the dynamics of preemergent herbicides applied in these areas is necessary for the correct choice and best recommendation of herbicides.

The straw on the soil acts as a physical barrier intercepting preemergent herbicides applied, preventing its arrival in the soil. The interception of herbicides by the straw depends on the amount and capacity of the plant biomass to cover the soil, as, for example, the coverage of 30% or more of the ground surface can retain 40 to 70% of the dose of herbicides metribuzin and atrazine applied in preemergence (Banks and Robinson, 1982; Isensee and Sadeghi, 1994).

The covering of 80 to 90% of the soil surface with wheat crop residues intercepted 60% of atrazine (1.7 kg ha^{-1}) immediately after application of the herbicide, while about 40% were found on the ground surface (Ghadiri et al., 1984). As for the ground cover with 4.5 t ha^{-1} and 9.0 t ha^{-1} of oat straw, it retained approximately 85% of the amount of atrazine applied (Formanolli et al., 1998). In the raw sugarcane system in the presence of 7.5 t ha^{-1} of stubble, concentrations higher than 95% of the herbicide diuron + hexazinone were intercepted (Velini et al., 2004). With the maintenance of 5.0 t ha^{-1} of straw on the ground, interception of 73% of amicarbazone herbicide took place at the time of application, being null the ability to reach in higher amounts of coverage (Cavenaghi et al., 2007).

Knight et al. (2001) have evaluated the interception of herbicides isoxaben, metolachlor and pendimethalin when applied on pine straw residues or pine bark. The results show that pine straw intercepted greater amounts of herbicides (57 to 82%) than pine bark (34 to 88%) and, among the herbicides tested, metolachlor was less retained in both plant materials used.

Straw may exert more or less influence on the effectiveness of herbicides, depending on the amount of biomass produced and accumulated on the soil, chemical constitution of the cover species (Gaston et al., 2001) and the physicochemical characteristics of herbicides, more specifically the polarity of the molecule (Rodrigues, 1993). As a result, poorly soluble herbicides and $logK_{ow}$ greater than 3.0 have the ability to penetrate plant residues, getting trapped in the cell wall structures. Dao (1990) has pointed lignin as the most responsible for the sorption capacity of metribuzin and S-ethyl metribuzin herbicides in wheat straw. This sorption capacity was increased as there was decomposition of the straw associated with a decline in the cellulose concentration and enrichment of lignin in the residue.

In application of atrazine on fresh vegetable residues of maize, only 32% of the dose applied reached the ground while, in the presence of dry aged residues, 52% reached the ground (Sigua et al., 1993). This behavior was attributed to greater hydrophobicity and high sorption capacity of fresh maize residue compared to the aged one.

The nature of the vegetable residues influences the interception and retention of herbicides. For example, hairy vetch (or fodder vetch or winter vetch) (*Vicia villosa* Roth) can retain a larger amount of chlorimuron than rye residues (*Secale cereale* L.) (Reddy et al., 1995). In this case, the greater retention of the herbicide by hairy vetch was related to the differences in the decomposition status and the physicochemical properties of the residue, which offer more surface area for intercepting the herbicide and the higher lignin and functional groups content (amino, amine, amide, carboxylic, among others) compared to rye.

Once intercepted by the straw, for the herbicide molecule to be leached to the soil surface, rain or irrigation after application are essential. However, such transport depends on the period between the application of the herbicide and the first rain, as well as its intensity. About 90% of atrazine was removed from the straw with approximately 50 mm of rainfall between the first and third weeks after the herbicide spraying, indicating that rain is the most important factor affecting the movement of the straw herbicide to the soil surface (Ghadiri et al., 1984).

The period of stay in the straw is important mainly for the cultivation of sugarcane. This is due to some peculiarities of sugarcane cultivation, since it is a culture with long cycle, planted and harvested at different times throughout the year, providing the need for weed management and application of herbicides even in times of low water availability, allowing preemergent herbicides applied to be exposed in the straw before the rainfall. As the application of preemergent herbicides in sugarcane occurs during almost the whole year, spraying these products can occur in both soil and dry straw or with good water availability.

Cavenaghi et al. (2007) have found that the larger the no rain periods after application of amicarbazone, the lower the amount of herbicide leached from the sugarcane straw to the soil. For drought time intervals of 1, 7, 15 and 30 days after application, leaching of 85, 81, 66, 65 and 55% was observed with the simulation of 65 mm, and 81, 61, 57 and 51% for precipitation of 20 mm of rain. Application of herbicide diclosulam (25.2 g a.i. ha^{-1}) on sorghum straw followed by 30 mm of rainfall was effective for herbicide leaching up to 35 days after the application, ensuring efficient control of *Ipomoea grandifolia* and *Sida rhombifolia*. This did not occur when applied in dry and wet straw without rain (Carbonari et al., 2008).

Rossi et al. (2013) have observed that rain simulation of 20 to 35 mm was sufficient to promote implementation higher than 99% of metribuzin in the straw when it remained in drought time intervals of 0, 1 and 7 days after application. However, the herbicide was retained longer when maintained for periods of 14 to 28 days without rainfall, requiring 68.5 mm and 100 mm, respectively, to implement less than 99% of metribuzin.

For sulfentrazone, the first 20 mm of simulated rainfall after application of the herbicide in the straw were sufficient to ensure the arrival of the herbicide to the soil, and even with a 90-day period of drought good levels of weed control were found (Correia et al., 2013). However, when herbicides flumioxazin and clomazone + hexazinone applied to the straw were exposed to 60 days without rainfall there was a downward trend in weed control even after simulation of 20 mm of rain (Carbonari et al., 2010a; Carbonari et al., 2010b). According to the authors, when herbicides are subjected to long periods without rainfall, degradation of the herbicide takes place.

The application of herbicides on sugarcane straw during dry periods can apparently cause herbicide losses by degradation or volatilization (Locke and Bryson, 1997) or provide an increase in the intensity of straw sorption (Reddy et al., 1995). In this sense, herbicides with a high potential for volatilization should be avoided in the application in the straw, such as clomazone ($< 1.92 \times 10^{-2}$ Pa), because when they are in the straw surface they are vulnerable to volatilization and/or photolysis until they are leached into the soil (Silva and Monquero, 2013). Oxyfluorfen applied to plant litter showed a degradation of up to 6% of the total applied, with a half-life of 13.6 days, while in the absence of plant litter this figure was 25 days (Cassamassimo, 2005). The authors attributed these results to further dissipation of the herbicide when exposed to light, since oxyfluorfen is susceptible to photodegradation.

Herbicide solubility in water plays a fundamental role in increasing or reducing the ability of an herbicide to reach the soil when applied in the straw (Rodrigues et al., 1993). For example, it may be more difficult for herbicides diuron and flumioxazin, which have low solubility (42 and 1.79 mg L^{-1}), to reach the straw when compared to hexazinone, metribuzin, amicarbazone, imazapic and tebuthiuron (33000; 1100; 4600, 2150 and 2570 mg L^{-1}, respectively) (Simoni et al., 2006; Rodrigues and Almeida, 2011; Prado et al., 2013).

Therefore, straw increase on the soil surface can affect preemergent herbicides efficacy, as it intercepts and retains them, reducing the ability to reach the straw layer and action on weeds. Moreover, the longer the time interval between the application and the occurrence of rain, the lower the amount of herbicide leaching into the soil. Depending on the time at which the herbicide will be used (dry or rainy season), one should choose products with physicochemical characteristics that allow reaching the straw and are less vulnerable to losses.

Herbicides Dynamics in Soil with Straw

Maintaining straw in direct planting and minimum tillage brings several benefits to the soil, such as the reduction of hydric erosion, conservation of soil moisture, improved physical properties, increasing organic carbon content, increasing diversity and microbial activity of the soil (Reddy et al., 1995; Aon et al., 2001). Such changes in soil properties can influence the dynamics of the herbicides in the soil, increasing the sorption process and reducing leaching. Consequently, they can increase the persistence of the herbicides in the environment and present intoxication risks for subsequent cultures.

Lavorenti et al. (2003) have found that in the direct planting system the dissipation of diclosulam in the ground was faster than in the conventional tillage system. Thus, at 119 days after application, the herbicidal dissipation rate observed was 73% in direct planting and 62% in the conventional one, obtaining half-life values ($t_{1/2}$) of 67 and 87 days, respectively. The authors point out that the higher microbial activity and increased formation of residue due to the high content of organic matter have favored the faster dissipation of diclosulam in the direct planting system. However, the presence of straw on the ground has contributed to increase the persistence of the herbicide acetochlor. Ferri et al. (2003) have found half-life values for acetochlor in the soil of 29 and 30 days in the presence of straw and 18 and 16 days in the absence of coverage for conventional and direct planting, respectively.

Some studies show that straw can significantly affect the number of active macropores, promoting greater percolation of alachlor and atrazine in direct planting (Malone et al., 2003), probably due to the preferential transport route formed by the higher volume of macropores channels due to the macrofauna activity and decomposed roots (Larsbo et al., 2009). Weed et al. (1993) have found that in the direct planting system, 50% of alachlor and 84% of metribuzin were retained in the first 10 cm of the soil profile and at least 68% of atrazine leached to the 20-cm layer.

Correia et al. (2007), when assessing leaching and the potential for contamination of groundwater with atrazine in Latosol under direct and conventional planting management, have observed that the direct planting system has less loss of atrazine leaching compared to the conventional system of tillage.

In a study on amicarbazone herbicide mobility due to different application modes in conditions of raw or burnt sugarcane, Carbonari (2009) has found higher concentrations of the herbicide in the deeper layers of the soil even in times of low water availability, indicating the high mobility of amicarbazone. The author has also found that when the herbicide application was carried out in the greater water availability period, amicarbazone was found in higher concentrations in treatments applied over or under straw in relation to treatments without straw. These results suggest that the soil cover helps in increased retention of amicarbazone in superficial soil layers for these application conditions, since the lower concentrations obtained with the application on the bare soil can indicate higher leaching of amicarbazone for layers that are deeper than those studied.

Macedo (2015) found similar results, where in management without straw larger amounts of sulfentrazone reached the deepest layers of soil, indicating that the absence of ground cover results in greater leaching. Knight et al. (2001) have indicated that the application of preemergent herbicides in the presence of pine straw or pine bark on the ground reduced 35-74% of leaching of herbicides isoxaben, metolachlor and pendimenthalin in the soil profile (0-25 cm). In soil with plant litter, herbicide oxyfluorfen leached up to 5 cm deep in the soil and 8 cm in the absence of plant litter (Cassamassimo, 2005).

The behavior of herbicides in soil with straw depends on the molecule characteristics, soil properties and climatic conditions of the region in which it is employed. In general, straw favors higher sorption of herbicides, reduces leaching potential even of highly soluble molecules, and may increase their persistence in soil in some cases.

Final Remarks

The use of preemergent herbicides in systems that keep the straw on the soil surface can increase the retention of herbicides and consequently reduce its ability to reach the straw layer to the ground. In handling preplanting, herbicide application associated to glyphosate or in sequence may alter the distribution uniformity of the herbicide in the soil, which can cause variations in weed control efficiency.

The interaction between the physicochemical characteristics of the herbicides and the type of soil coverage influences the mobility and dynamics of the herbicides in the straw and therefore in the soil. Therefore, the selection of the herbicide to be used in areas with straw on the ground is due to the physicochemical properties of the molecule, giving preference to those herbicides with high solubility, low vapor pressure and reduced octanol-water coefficient because these features can ensure greater easiness to reach the layer with straw and reduce losses by volatilization and photodecomposition.

In addition, it is also observed that for most of the herbicides used, especially in sugarcane crops, the greater the time interval between the application and the occurrence of rain, the lower the leaching of the herbicide into the soil will be. Therefore, the herbicides dynamics in systems with straw depends on their physicochemical characteristics, environmental conditions, the straw quantity, quality, and the time interval between the application and rainfall or irrigation.

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