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Management of volunteer plants in cultivation systems of soybeans, corn and cotton resistant to glyphosate[1]

Manejo de plantas voluntárias em sistemas de cultivo com soja, milho e algodão resistentes ao glyphosate

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Abstract - The introduction of new cultivation technologies for soybean, corn and cotton contributed to a significant increase in the productivity of these crops. A highlight among these technological advances is the resistance of these crops to glyphosate, which initially provided for better weed control, especially in areas with a great diversity of species. Additionally, from a practical point of view it can also be highlighted that the increased time span for weed control, looking at the possibility of applying glyphosate at various growth stages of RR® crops. However, the "convenience" provided by the possibility to apply glyphosate post-emergence for crops such as soybeans, corn and cotton, increased consumption of this molecule, resulting in continuous use by producers. The effect resulting from the use was an increased pressure for selection and consequently for the selection of biotypes resistant to this molecule. In addition to this, the presence of volunteer plants of soybean, corn and cotton resistant to glyphosate has been established in management systems, mainly in the succession of soybean-corn and soybean-cotton. This fact brings high control costs and demanded the use of alternatives for the management of these volunteer plants. In this context, the aim of this work to address and present some management strategies to control voluntary RR® soybean, corn and cotton in cultivation systems in succession of soybean-corn and soy-cotton.
Keywords: *Glycine max*; *Zea mays*; *Gossypium hirsutum*; weeds; herbicides

Resumo - A introdução de novas tecnologias de cultivo em lavouras de soja, milho e algodão contribuíram para um aumento significativo da produtividade dessas culturas. Dentre os avanços tecnológicos, pode-se destacar a resistência dessas culturas ao herbicida glyphosate, que a princípio proporcionou um melhor controle de plantas daninhas, sobretudo em áreas com uma grande diversidade de espécies. Adicionalmente, também se pode destacar do ponto de vista prático, o aumento do lapso temporal para o controle das plantas daninhas, visto a possibilidade de aplicação do glyphosate em vários estádios fenológicos da cultura RR®. Entretanto, a “comodidade” proporcionada pela possibilidade de aplicação em pós-emergência de glyphosate em culturas como

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a soja, o milho e algodão, elevou o consumo dessa molécula, acarretando em uso contínuo por parte dos produtores. Tal efeito decorrente desse uso foi o aumento de pressão de seleção e consequentemente a seleção de biótipos resistentes a essa molécula. Adicionalmente a esse aspecto, recentemente têm se verificado a presença de plantas voluntárias de soja, milho e algodão resistentes ao glyphosate em sistemas de manejo principalmente em sucessão de soja-milho e soja-algodão. Tal fato tem elevado os custos de controle e demandado o uso de alternativas para o manejo dessas plantas voluntárias. Nesse contexto, objetivou-se com esse trabalho abordar e apresentar algumas estratégias de manejo para o controle de soja, milho e algodão RR® voluntário em sistemas de cultivo em sucessão soja-milho e soja-algodão.

Palavras-chaves: *Glycine max*; *Zea mays*; *Gossypium hirsutum*; plantas daninhas; herbicidas

Introduction

In Brazil, in recent decades the large-scale agriculture has undergone significant changes in management techniques, especially for major crops such as soybeans, corn and cotton. A highlight among these techniques is the introduction of no-till farming (NTF), which became a consolidated system of cultivation mainly due to the efficiency of the glyphosate herbicide in the management of weeds and cover crops. The use of glyphosate in NTF even had as a premise the application in desiccation and postharvest management. However, with the introduction of new technologies involving the use of this herbicide, in particular the RR® transgenic to some crops such as soybeans, the use of glyphosate, already extensive, has become even greater, with the possibility of post emergence application (Petter et al., 2007). Recently, the use of this herbicide gained further market with the recent release of the cultivation on a commercial scale of corn and cotton resistant to glyphosate (Petter et al., 2015).

The increased use of glyphosate has been remarkable, especially in areas with good rainfall distribution, where soybean cultivation in summer and corn in the off-season is possible. In this succession system, the cultivation of RR® soybean and corn usually required heavy use of glyphosate, contributing to the emergence of more resistant weeds. Additionally, another recent problem that has been observed in this management system, is the occurrence of volunteer plants, characterized by mostly voluntary RR® soybean amid RR® corn crops off-season, the presence of voluntary RR® corn amid RR® soy crops in subsequent harvest, and also voluntary RR® soybean crops in RR® cotton crops densely grown off-season.

This situation has required the use of already established management systems with the purpose of controlling weeds and volunteer plants, through the use of cover crops (Queiroz et al, 2010;. Pacheco et al, 2013.), rotation of herbicides (Vidal et al., 2006) and more recently the search for new technologies, which include the introduction of new cultivars with new events with transgenic resistant to more than one molecule, such as cultivars resistant to glyphosate, 2,4-D and glufosinate ammonium.

These new technologies require the combination of different management practices, and above all the awareness of the producer about their rational use. Among these practices is the cultural management, with the concomitant use of cover crops and herbicides, the alternate use of conventional cultivars with resistance technology, the rotation of events with different transgenic, rotation of active ingredients, among others. In this sense, this review aims to address some management alternatives for the control of volunteer plants in the cultivation systems of soybean, corn and cotton resistant to glyphosate.

Management of Volunteer Plants in Cultivation System of Soybean-Corn

In several regions of Brazil, soybean cultivation in summer and corn in the off-season in succession has been the predominant farming system. Currently, this system has enabled the use of glyphosate in desiccation management and also in post-emergence RR® soybean and RR® corn. Thus, volunteer plants of RR® corn and RR® soybean in the system is a new problem to be solved, since glyphosate used for desiccation and post-emergence doesn't control these volunteer plants. In this sense, Marquardt et al. (2013) highlighted that the presence of cultivars resistant to glyphosate may become difficult to control, since it limits the chemical management efficiency for desiccation in both pre-planting and post-harvest.

Soybean or corn plants that are transgenic resistant to glyphosate herbicide are the result of the germination of lost grains during mechanical harvesting, and can be considered weeds. In corn, this effect is even more prominent, since at harvest there are losses of free grains, grains connected to the shank (cob) and grains connected to the shank surrounded by straw. This feature of losses provides different flows of emergence, thus hampering control of voluntary RR® corn. Like real weeds, these voluntary transgenic plants can interfere with the productivity and quality of crop rotation or succession, as is the case in the succession system of RR® corn-soybean (Davis et al., 2008; Marquardt et al., 2012).

With use of RR® technology for both soybean and corn, challenges have presented themselves in the control of volunteer soybean plants in corn crops and vice versa, since glyphosate has no control effect on either of these. Studies by Marquardt et al. (2012) observed that the presence of volunteer RR® corn plants can reduce soybean yields. This information is based on research results, in which 0.5 plant m^{-2} of volunteer RR® corn reduced soybean productivity by approximately 12%. When the infestation was 16 plants m^{-2}, the reduction of soybean yield was even higher (41%). Other studies have also noted reductions in corn yields due to the presence of transgenic volunteer plants with loss rates as high as 40% (Stahl et al., 2007, Alms et al., 2008).

In soybean farming areas infested with volunteer RR® corn plants, studies show an alternative use of the ACCase-inhibiting herbicides in both desiccation and post-emergence management. This management option has also been successfully used in areas where there is occurrence of weeds resistant to glyphosate, like ryegrass (*Lolium multiflorum*) and sourgrass (*Digitaria insularis*) (Maciel et al., 2013). Studies by Petter et al. (2015) pointed out that the joint application of glyphosate+haloxyfop-R (1080 + 260 g ha^{-1}) in post-emergence for soybeans presented a control of between 90 and 100% of volunteer corn plants. In the same study, mixing glyphosate+fluazifop-p-butyl (1080 + 187 g ha^{-1}) showed an average control of about 75% to 90%.

Maciel et al. (2013) emphasizes that the use of R-haloxyfop (25 to 62 g ha^{-1}) and clethodin (85 g ha^{-1}) alone or in combination with 2,4-D (670 g ha^{-1}) were effective in controlling volunteer plants of four hybrids of RR® corn. In the same study it was evident that the less developed the corn plants are, the better the control; evidenced by the faster action of herbicides when used in the phenological stage V_5. When these herbicides were applied to the same RR® corn plants at V_7 stage, the phytotoxic effect was only observed after 14 to 21 days after application.

In Brazil and other countries, the use of 2,4-D in combination with ACCase inhibitors and glyphosate in desiccation management has been recommended in situations of occurrences of weed biotypes resistant to glyphosate, such as fleabane (*Conyza* sp.), spiderwort (*Commelina* sp.), rope-glory (*Ipomoea* sp.), wild poinsettia (*Euphorbia heterophylla*), winged false buttonweed (*Spermacoce latifolia*) and Brazilian calla-lily (*Richardia brasiliensis*). This action allows the action spectrum to increase, resulting in better control.

In the corn crops contaminated with volunteer RR® soybean plants, some studies have shown some options. Dan et al. (2011) observed that applying atrazine (1500g ha^{-1}), paraquat+diuron (500 + 250g ha^{-1}), diquat (300g ha^{-1}) and 2,4-D (1340g ha^{-1}) showed a control greater than 95% of voluntary RR® soybean plants in phenological stage V_3. In the same study, it is important to note that the nicosulfuron, a herbicide of the sulfonylurea group and widely used post-emergence in corn, didn't show satisfactory results in the control of voluntary RR® soybean plants. Bond and Walker (2009) also observed that the herbicides paraquat and glufosinate ammonium show appropriate levels of control of volunteer RR® soybean plants in the early stage of development.

Another relevant issue with respect to the soybean-corn off-season system refers to the residual herbicides used to control volunteer plants of corn in soybeans over the corn planted in succession. Petter et al. (2015) observed that the combination glyphosate+imazethapyr (1080 + 106 g ha^{-1}) showed satisfactory control rates (80%) of volunteer corn plants in soybean crops. However, studies by Dan et al. (2012) showed that the use of imazethapyr (100 g ha^{-1}) in post-emergence and diclosulan (35 g ha^{-1}) in pre-emergence for soya (desiccation) caused reductions in corn yield in succession.

In the case of imazethapyr, the ideal is to have a range of at least 100 days between the application and the subsequent planting of corn, this way the use of imazethapyr in the management of desiccation can be a viable alternative, as reported by Petter et al. (2015). However, the increasing use of soybean cultivars in early and very early stages of maturity, combined with harvest anticipation techniques, has promoted the reduction in the time interval between the application of herbicides in soybeans and sowing of corn off-season. Thus, it increases the risk of any adverse effects caused by the presence of residues of some herbicides on corn in succession.

The interval between desiccation management with glyphosate and sowing soybean or corn that isn't resistant to this herbicide is another important factor to reduce the residual effect of herbicides on plant development (Silva et al., 2006). Santos et al. (2007) observed that an interval of between 7 and 21 days between the desiccation management with glyphosate and sowing showed the best results in the development and soybean productivity.

In general, it is important to use the integrated management of volunteer plants, using cultural techniques (sowing at the appropriate time, spacing and plant population according to the recommendation, fertilization, etc.), choosing a plan that includes herbicides with different action mechanisms, with due attention to the residual effect on corn after soybean, and the use of cover crops in no-till farming that can assist in the control of spontaneous and voluntary plants. The set of techniques is crucial in order for the farming system to benefit in all production steps from the management of volunteer plants.

Use of Cover Crops in the Management of Volunteer Plants

No-till farming used in the off-season soybean-corn production systems recommends the use of cover crops for biomass production. The biomass produced on the surface and in the subsurface by the roots of these plants promotes soil fertility by incorporating organic matter, nutrient cycling, reduction of water loss by evaporation and reduces soil erosion (Ram et al., 2009; Pacheco et al., 2011). Moreover, the formation of straw on the ground favors weed control, including the control of volunteer plants of RR® soybean and corn (Pacheco et al., 2009).

Although there are so far few studies evaluating the direct interference of cover crops for the control of transgenic volunteer plants, studies indicate that the suppressive effects on weeds are indicators that cover crops could also aid in the control of volunteer plants of RR® soybean and corn. The production of biomass and soil cover promoted by cover crops are factors that can assist in the control of spontaneous and voluntary plants through chemical (allelopathy) and physical processes (Pacheco et al., 2013).

Based on studies conducted by Pacheco et al. (2009), the cover crops can promote overall soil cover at the time of sowing of soybeans or corn in no-till farming, especially for the species of Brachiaria (*Urochloa* sp.). However, the authors point out that the proper establishment of cover crops in the production system is important to enable the production of a minimum amount of biomass on the soil surface. In this study, the production of 3000 kg ha^{-1} of biomass was enough to significantly reduce the infestation of weeds, including, with satisfactory results, the weed control during the off-season.

When analyzing the studies by Petter et al. (2015), it was found that three species of cover crops, pearl millet (*Pennisetum glaucum*), brachiaria or signalgrass (*Uroclhoa ruziziensis*) and sunnhemp (*Crotalaria spectabilis*) showed similar control of volunteer RR® corn plants during desiccation management for sowing soy. However, in evaluations performed 45 days after soybean emergence, the straw of *U. ruziziensis* showed greater efficiency in the control of the subsequent flow of emergence for desiccation management. This result can be explained by the greater presence of the remaining biomass of desiccation management, enhancing the importance of this cover plant as an option for the integrated control of volunteer plants in agricultural systems.

In areas with corn cultivation the benefits of using cover crops to control weeds have also been observed. In studies conducted in southern Brazil, Moraes et al. (2013) reported that the use of ryegrass (*Lolium multiflorum*) benefited the weed control and increased corn productivity. According to the authors, this kind of hedging plant has the potential to promote the release of allelopathic substances into the ground and provides adequate coverage of the soil.

It is important to note that the implementation of corn crops in Brazil has mainly been done in the off-season period, after the soybean harvest. Thus, the use of plant biomass to control volunteer RR® soybean plants is limited to the presence of crop residues arising from desiccation management for soybean seeding and cultural remains of harvested soybeans, since there isn’t sufficient time to add cover plants in the succession system of soy/corn, or between the soybean harvest and sowing of corn.

Some studies have tried to enable the introduction of cover crops in simultaneous consortium with soybean, in order to allow biomass production shortly after the soybean harvest and to use it in no-till farming of corn in succession. Silva et al. (2004), when evaluating doses of fluazifop-p-butyl to suppress the development of *Uroclhoa brizantha* intercropped with soybean, found that a dose of 54 g ha^{-1} was required in order for there to be no reduction effect on grain yield. However, with this dosage the biomass production of *U. Brizantha* in the soybean crop was severely affected (with a decrease of more than 65%), making it an unviable technique to be used in sequence with corn. Duarte et al. (1995) found, in the consortium of soy with *U. brizantha*, a reduction in the yield of 52%.

Despite a good initial establishment of cover crops like millet ADR300 (*P. glaucum*), *U. ruziziensis* and *U. brizantha* with an over sowing technique for soybean in growth stage R6 (100% grain filling), Pacheco et al. (2008) found that the period between the over sowing and the soybean harvest (30 days) was insufficient for these cover plants to show a significant accumulation of biomass. Thus, it would be necessary to wait at least 30 days after the soybean harvest to plant the second crop of corn, which in practice is not feasible. An alternative would be the anticipation of over sowing of soybean in cover crops. Accordingly, Smith et al. (2013) found that the anticipation of over sowed *U. ruziziensis* at the phenological stage R5.3 could be a viable alternative for the better use of moisture and consequently a higher biomass production. However, most biomass production would take place faster in its accumulation after the soybean harvest due to the more developed root system. But, however small, there is a required period between the harvest of the soybean and the corn planting.

When considering that the amount of biomass and soil cover are key factors for the control of invasive and volunteer plants, it is recommended to use cover crops that enable a high biomass production, and have a slower decomposition rate from desiccation management to the harvesting of soybean or corn. This would favor the cover plants from the desiccation management for soybean sowing which in turn may benefit the control of volunteer RR® soybean plants during the development of the corn grown in succession.

Management of Volunteer Plants in Cultivation System Soy-Cotton

In crops that are part of the succession of soy-cotton off-season and that are resistant to glyphosate (RR®), it is common to observe the presence of volunteer plants in the subsequent culture. Volunteer plants, besides competing with the crops of economic interest, cause direct losses of productivity, and can be hosts for pests and diseases. According to Lee et al. (2009) and Tingle and Beache (2003), a soybean and cotton plant per meter can reduce the yield of cotton and soybeans by 14% and 6% respectively.

Unlike the cultivation management in succession soybean-corn resistant to glyphosate, the control of volunteer RR® soybean plants in cotton crops hasn't represented a major challenge for the producer. Among the latifolicide mixtures with a potential use for the control of volunteer soybean plants in cotton pre-emergence, the use of diuron, which is usually applied in combination with clomazone or triflurarin, has provided good initial control of volunteer RR® soybean plants. Already in post-emergence cotton, the herbicides pyrithiobac-sodium and sodium-trifloxysulfurom, have proven effective in controlling voluntary soybean (York et al., 2005).

The use of nonselective herbicides can also be considered as an alternative for the control of volunteer soybean plants in the pre-sowing or pre-emergence of cotton, since the field stubble has already emerged, or even at the post-emergence of the crop, since they are applied in directed jet to the lines of cotton plants with a height of at least 30 cm (Silva et al., 2015). Among the non-selective registered most used herbicides for use in cotton cultivation the paraquat, paraquat+diuron and MSMA stand out. It is important to stress that herbicides that exhibit low translocation as the abovementioned, are more dependent on the development stage of the target plant and herbicide application technology to achieve good performance (Silva and Concenço, 2014).

The control of volunteer cotton in soybean crops is, however, more complex. Beyond the control of volunteer cotton plants, derived from grain losses during the process of harvesting the crop, producers must carry out the destruction of cultural cotton remains that they don't regrow during the development of soybean sown in succession. The control of cotton sprouts can be accomplished by mechanical and/or chemical destruction, requiring that the producer adjust himself to the reality of his property. But the control of cotton volunteer plants from the seed loss can be accomplished by glyphosate in combination with flumiclorac, imazethapyr, cloransulan, chlorimuron or fomesafem in desiccation management for the subsequent planting of soybean (Silva et al., 2015). In case of escape of volunteer plants and/or germination flows prior to the desiccation management, control of volunteer RR® cotton in the post-emergence RR® soybean is also efficient because the herbicides used during desiccation management can also be used post-emergence.

Future Perspectives on the Management of Volunteer Plants

Due to the increase in frequency of resistant biotypes and species tolerant to glyphosate, biotechnology companies have proposed the use of tolerant cultivars to more than one action mechanism. This fact contributes to the fact that the management of volunteer plants will become even more complex, because in some situations the inserted tolerance gene can reduce herbicide options for control of volunteer plants in cultivation in succession. This is the case for the development of soybean cultivars tolerant to glyphosate herbicides and auxinic or glyphosate tolerant corn and "fops". In this scenario, in the near future, we'll have volunteer plants that are resistant to two or more action mechanism, becoming as problematic as other weeds classified as difficult to control.

Thus, when designing the management strategy for the weed community, the producer should be aware of the diversity of weeds present in his crop, besides the genes of herbicide tolerance of crops sown by him. However, one aspect is already much debated should prevail when proposing the different management strategies, which is the conscious use by the producers of the new technologies available and that may become available, either as herbicides or cultivars with different transgenic. The integrated management with the combination of crop rotation, rotation of active ingredients, cultivars rotation with events of transgenic to more than one herbicide molecule with conventional cultivars and the use of cover crops are promising strategies to prevent future problems in the management of weeds and voluntary plants of soybean, corn and cotton resistant to glyphosate and other molecules.

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