Residual effect of herbicides 2,4-D and Glyphosate on soybeans in a Brazilian Cerrado Ultisol

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The use of herbicides for weed desiccation is what enables the no-tillage system, which increasingly stimulates the growth of the agrochemical market, in particular the class of herbicides. This study aimed to assess 2,4-dichlorophenoxycetic acid and Glyphosate (N-phosphonomethyl-glycine) herbicides mixture persistence in soybeans of Ultisol in the Brazilian Cerrado. The study was conducted in a greenhouse with a randomized blocks design, in a factorial 6×5, being six application times (0, 3, 5, 7, 10 and 14 days before sowing) and five herbicide doses (0, 750, 1500, 2250 and 3000 g a.e. ha⁻¹) in four replications. Herbicides were sprayed with a manual knapsack sprayer. The residual effect was assessed through emergence speed index (ESI), plant height and dry weight of shoots (DWS) and roots (DWR). The residual effect of mixtures of herbicides 2,4-D and Glyphosate on soybean in a Brazilian Cerrado Ultisol showed greater damage to plants when applied at sowing. The doses 2250 and 3000 g a.e. ha⁻¹ were the most severe for the development of soybean plants.

Key words: Bioindicator, Glycine max, Herbicide, Persistence.

INTRODUCTION

In 2013, the world population was 7.2 billion people, and studies show that it may reach 9.6 billion by 2050 (UN REPORT, 2013). With this estimate, being able to meet the food demand with the least possible impact on the environment will be a major challenge. There are different methods for weed control. In soybean, chemical control has been most widely used for various reasons, including the extensive cultivated areas. When it comes to no-tillage, weed control depends on the use of herbicides, as crops and hoeing are incompatible with the technology used in the system. Thus, a more sustainable and optimized production becomes necessary to produce more in already explored areas, minimizing at most the opening of new areas. Although it is necessary to adopt techniques aimed at soil recuperation and conservation, many producers opted for the No-Tillage System (NTS), in which there is no soil disturbance, vegetation cover is maintained and crop rotation takes place (Heckler, 2002). This system is one of the sustainable agricultural technologies covered by the agriculture plan for low

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carbon emission (Cordeiro et al., 2012), being justified by the application of herbicides to eliminate existing vegetation in the area before sowing, a practice known as desiccation (Carvalho, 2009). Vegetation cover desiccation and weed management are conducted in such a way that eliminates the damage caused by them, as competition for water, light, nutrients and space (Vasconcelos et al., 2012). Brazil is the country that produces more grains, with 58.5 million hectares in planted area, and the Brazilian production was 210.3 million tons in the 2015/16 crop. This increase amounts to 1.3% or 2.6 million tons compared to the 2014/15 crop, which was 207.7 million tons (Conab, 2016). Because of its extent and availability of arable lands, it has great potential to help meet this demand (Casarin, 2012). Soybean is the most produced grain in Brazil. According to Conab (2016), soybean has the highest absolute growth, with estimated increase of 4.9 million tons, being estimated at 101.2 million tons, 5 million more than in the previous harvest. The increase in production has been accompanied by the use of herbicides (Peres, 2009), and the use of pesticides increases the risk of poisoning, phytotoxicity and environmental pollution if not used correctly, regardless of product class. Thus, spraying these products requires proper application of technology because, when used correctly, there is minimization of risks and reduction of economic losses, improving field efficiency (Peres-oliveira and Antuniasi, 2012; Gazziero, 1984). In weed control, persistent herbicides are commonly used. These herbicides may cause toxic effects in sensitive species such as soybeans, beans, cotton and other dicotyledonous plants, when grown in sequence (Silva, 1999; Gonçalves, 2001; Silva, 2006). 2,4-D is the first organic compound industrially synthesized to be used as a selective herbicide (Barbera, 1976). According to Silva et al. (2007), it has a short to average persistence in soils and at normal doses, the residual activity does not exceed four weeks in clay soils and hot weather. Notwithstanding, even though its degradation in soil is considered fast, its residual effect will depend on the edaphoclimatic conditions, with the possibility of lasting longer and intoxicating the successor culture. Glyphosate is one of the most widely used herbicides in the world (Ghisi, 2013). It is commonly associated with 2,4-D, targeting more species to be controlled; the greatest risks of poisoning have been linked to the first due to the effect at extremely low doses (Constantin, 2007; Oliveira, 2007). The residual effect of mixing 2,4-D with glyphosate will also depend on the soil type used, the chosen dose and the period between application and implementation of the crop.

This study aimed to assess the persistence of herbicides 2,4-D and Glyphosate in an Eutrophic Ultisol, and their effects on soybean.

### MATERIALS AND METHODS

The experiment was conducted in a greenhouse located at 16° 28' South latitude, 50° 34' West longitude and altitude of 284 m. The experimental design was a randomized block with a factorial 6×5, with six application times before sowing (0, 3, 5, 7, 10 and 14 days before sowing), five doses of herbicide 2,4-D (0, 750, 1500, 2250 and 3000 g a.e. ha⁻¹) and a constant dose of Glyphosate (4000 g a.e. ha⁻¹), in four replications. Each experimental unit consisted of pots with 5 dm³ soil capacity with eight soybean plants, cv. TMG 4182 (seeded at 5 cm depth). The soil used was Red-Yellow Ultisol (Embrapa, 2013), collected in the region of Rondonópolis, MT, in the depth of 0 to 0.20 m. The soil was sieved on a 4 mm mesh for insertion in the experimental units, characterized by chemical and granulometric analyses according to the methodology of Embrapa (1997) (Table 1). The soil was maintained at 80% field capacity moisture content throughout the test, according to the methodology of Bonfim-Silva et al. (2011). The spraying of herbicides was carried out with a manual knapsack sprayer equipped with XR 11002 and syrup consumption corresponding to 200 L ha⁻¹. The persistence of these herbicides in the soil was evaluated through emergences percentage (%), emergence speed index (ESI), plant height (cm), dry weight of shoot and their effects on soybean.

### RESULTS AND DISCUSSION

The variables that showed a significant difference were adjusted to linear and quadratic regression models. The emergence speed index (ESI) was influenced at all doses and times studied (Figure 1). The only situation when the emergence speed index was not affected was under dose 0, due to the absence of herbicides (Figure 1a). Under the other doses (750, 1500, 2250 and 3000 g a.e. ha⁻¹) plant number gradually reduced as spraying period approached the sowing date with doses 2250 and 3000 g a.e. ha⁻¹ being the most severely affected. In some studies with sorghum, according to Petter et al. (2011), regardless of application time, all studied doses of 2,4-D caused phytotoxic effect to the crop, the effect being progressive as the herbicide doses increased. Regarding application time (0, 3, 5, 7, 10 and 14 days before sowing) and doses applied, the higher the dose, the lower were the

<table>
<thead>
<tr>
<th>pH</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>H</th>
<th>Al</th>
<th>SB</th>
<th>CTC</th>
<th>V</th>
<th>O.M.</th>
<th>Sand</th>
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<td>1.1</td>
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<td>0.6</td>
<td>7.0</td>
<td>59.0</td>
<td>28.7</td>
<td>640</td>
<td>83</td>
<td>277</td>
</tr>
</tbody>
</table>

### Table 1. Chemical and granulometric characterization of the Eutrophic Ultisol in the layer of 0.0 - 0.20 m.
Figure 1. Emergence speed index of soybean seedlings in Red-Yellow Ultisol. Interaction of treatments in the analysis of doses over periods (A) and interaction of treatments in the analysis of periods between sowing and spraying as a function of increasing doses (B). ***, **, *: significant at 0.1%, 1% and 5%, respectively.
number of plants. Generally the most critical time occurred when the sowing and spraying took place on the same day (0 days before sowing) which all doses of the herbicide reduced the number of plants per pot (Figure 1b). The application times five and fourteen days before sowing were the ones, which provided the highest emergence speed indexes, results also obtained by Peres-oliveira et al. (2016). According to Reis et al. (2010), herbicide 2,4-D is a growth regulator which has a similar effect to the hormone auxin, therefore, it can be used as a plant growth regulator.

For soybean plant height (Figure 2), with increasing doses over periods (Figure 2), the 2,4-D doses 750, 1500, 2250 and 3000 g a.e. ha$^{-1}$ were significant and, in general, caused a reduction in plant height as the spraying approached the sowing date. The dose 3000 g a.e. ha$^{-1}$ was the one which reduced plant height the most in the application time where spraying and sowing took place on the same day; however, in the interim period, it was the dose which provided the greatest plant height. A fact confirmed by Farinelli et al. (2005), where the higher the dose of herbicide 2,4-D, the larger the increase in plant height of millet (Pennisetum americanum (L.)). Yamashita et al. (2009) worked with 2,4-D alone at a dose of 335 g a.e. ha$^{-1}$ in kapok (Ceiba Pentandra) obtained increase in plant height. This increase is caused by auxin concentration in younger branches, and is a characteristic effect of the auxinic herbicides (Deuber, 1992). Pacheco et al. (2007) using higher doses of 2,4-D in millet (Pennisetum americanum (L.)) obtained a reduction in plant height.

In the analysis of application times as a function of increasing doses (Figure 2b), the only significant time to plant height was 0 days before sowing, linearly reducing height as doses were increased. Similar results were found by Petter et al. (2011), in which increasing doses of 2,4-D linearly decreased the height of sorghum plants (Sorghum bicolor (L.)). This reduction in plant height caused by mixing the herbicides 2,4-D and glyphosate was also observed in kapok (Ceiba Pentandra) until 21 days after application, with subsequent stabilization (Yamashita et al., 2009).

There were significant differences between the dry weight of shoots of soybean plants (Figure 3) between the interaction of doses over periods and for the periods within each dose. Except for the dose 0, all other doses (750, 1500, 2250 and 3000 g a.e. ha$^{-1}$) severely reduced the dry weight of shoots of plants especially when application was close to the sowing date. Reduction in the dry weight of shoots was linearly correlated to the increase in dosages applied (Figure 3a). At 7 and 10 days before sowing, 1500 g a.e. ha$^{-1}$ dose provided greater dry matter production of shoots, results that were similar to those obtained by Reis et al. (2010), who using doses of 1.5 and 2 L a.e. ha$^{-1}$, found a greater increasing trend of the dry weight of shoots of corn (Zea mays); yet Pacheco et al. (2007) noted that the increase in 2,4-D doses resulted in lower production of dry matter of shoots of millet (Pennisetum glaucum), reduction from 13% to 33% between the doses of 335 g.ha$^{-1}$ and 1005 g.ha$^{-1}$. Farinelli et al. (2005) found increased dry weight of shoots of millet (Pennisetum glaucum), with increasing doses of 2,4-D; and Yamashita et al. (2009) obtained a reduction of at least 26% compared to the control treatment for the dry weight of plants of the forest species Schizolobium amazonicum at a dose of 335 g a.e. ha$^{-1}$. According to Mortensen et al. (2012), 2,4-D acts as a herbicide for the control of dicotyledonous weeds, and yet it also has a beneficial effect, depending on the time and dose used. In the evaluation of the application times, with increasing doses applied over the days, the lowest dry weight index was verified at 0 days before sowing. Thus, the closer the spraying and sowing periods are, the lower the crop development also with the increase in application of doses. The application times 3 and 5 days before sowing had no significant impact on the dry weight of shoots. The highest dry weight of shoots was observed at 7 days before sowing. At 14 days before sowing, the dry weight of shoots underwent a gradual decrease with increasing doses (Figure 3b).

The dry weight of roots of soybean plants (Figure 4) was significant in the interaction of doses over periods and for the periods within each dose. In the analysis of doses over the days (Figure 4a), the dose 0 g a.e. ha$^{-1}$ had no significant impact. All other doses (750, 1500, 2250 and 3000 g a.e. ha$^{-1}$) severely reduced the dry weight of roots on the days near the sowing date, reduction occurring linearly according to the increase in dosage. The dose of 1500 g a.e ha$^{-1}$ provided the highest increase in dry weight of roots, i.e. it most impacted this variable in all evaluated times. The gradual increase of doses caused a significant reduction in the dry weight of roots on the dates near sowing, a fact that was repeated at 14 days. The trend was similar to that reported by Reis et al. (2010), where there was increase in the dry weight of roots between the control treatment and the dose 2 L a.e. ha$^{-1}$.

Nonetheless, there was a significant difference between the doses of 2 and 3 L a.e. ha$^{-1}$, with a 38% reduction in the dry weight of roots. Yet the results of Farinelli et al. (2005) showed greater dry weight of the root system with increasing doses (402, 536, 670 g a.e. ha$^{-1}$) compared to the control. In the analysis of application times as a function of increasing doses (Figure 4b), dry weight of roots was least at 0 days before sowing, decreasing gradually, as a function of increasing doses. For the application times 3, 5 and 14 days before sowing, the higher the dose used, the lower the dry weight of roots were also. The application time 10 days before sowing showed no significant differences among the doses. Application at 7 days before sowing, the 1500g a.e. ha$^{-1}$ dose provided higher dry weight of roots, showing the hormonal capacity of herbicide 2,4-D in a given dose and application time.
Figure 2. Height of soybean plants in Red-Yellow Ultisol. Interaction of treatments in the analysis of doses over periods (A) and interaction of treatments in the analysis of periods between sowing and spraying as a function of increasing doses (B). ***, **, *:significant at 0.1, 1 e 5% respectively.
Figure 3. Dry weight of shoots of soybean in Red-Yellow Ultisol. Interaction of treatments in the analysis of doses over periods (A) and interaction of treatments in the analysis of periods between sowing and spraying as a function of increasing doses (B). ***, **, *: significant at 0.1, 1 and 5%, respectively.
**Root dry matter (g. vase⁻¹)**

<table>
<thead>
<tr>
<th>Herbicide Dose (g.ea.ha⁻¹)</th>
<th>Period 0</th>
<th>Period 3</th>
<th>Period 5</th>
<th>Period 7</th>
<th>Period 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose 750</td>
<td>▲</td>
<td>△</td>
<td>▲</td>
<td>△</td>
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<tr>
<td>Dose 1500</td>
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</tr>
<tr>
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<td>▲</td>
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<td>▲</td>
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<tr>
<td>Dose 3000</td>
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<td>□</td>
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**Figure 4.** Dry weight of roots of soybean in Red-Yellow Ultisol. Interaction of treatments in the analysis of doses over periods (A) and interaction of treatments in the analysis of periods between sowing and spraying as a function of increasing doses (B). ***, **, *: significant at 0.1, 1 and 5%, respectively.
Conclusions

The residual effect of mixtures of herbicides 2,4-D and Glyphosate on soybean in a Brazilian Cerrado Ultisol showed greater damage to plants when applied at sowing. The doses 2250 and 3000 g a.e. ha\(^{-1}\) were the most severe for the development of soybean plants.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES