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Metsulfuron-methyl soil persistence influence in corn grown in succession

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ABSTRACT: The metsulfuron-methyl is a soil persistent herbicide and can affect the development and yield of sensitive crops grown in succession. The objective this study was evaluate the effect of the application of metsulfuron-methyl at different intervals before sowing on corn development and yield and determine a safe period between the application of the metsulfuron-methyl and corn sowing. The assay was conducted in the 2017/18 and 2018/19 seasons. The experimental design was of randomized blocks, with thirteen treatments and four replicates. The treatments were arranged in factorial scheme (2 × 6) + 1. The first factor consisted in doses of metsulfuron-methyl (1.98 and 3.96 g ha^{-1}). The second factor in intervals between the application of the herbicide and corn sowing (0, 15, 30, 45, 60, and 75 days), plus a control with no herbicide application. The phytotoxicity, yield, and yield components of corn were assessed. The highest phytotoxicity occurred at 3.96 g ha^{-1}, when the herbicide was applied on the day of sowing. Metsulfuron-methyl caused phytotoxicity and reduced corn yield. The safe interval between metsulfuron-methyl application and corn sowing was 15 and 30 days for the doses of 1.98 and 3.96 g ha^{-1}, respectively.

Key words: carryover; sulfonylureias; *Zea mays*

Persistência no solo de metsulfuron-methyl influencia no milho cultivado em sucessão

RESUMO: O metsulfuron-methyl é um herbicida persistente no solo que pode afetar o desenvolvimento e a produtividade de culturas sensíveis cultivadas em sucessão. O objetivo deste estudo foi avaliar o efeito da aplicação de metsulfuron-methyl em diferentes intervalos antes da semeadura sobre o desenvolvimento e produtividade do milho e determinar o período seguro entre a aplicação de metsulfuron-methyl e a semeadura do milho. O ensaio foi realizado nas safras 2017/18 e 2018/19. O delineamento experimental foi em blocos ao acaso, com treze tratamentos e quatro repetições. Os tratamentos foram arranjados em esquema fatorial (2 × 6) + 1. O primeiro fator consistiu em doses de metsulfuron-methyl (1,98 e 3,96 g ha^{-1}). O segundo fator consistiu em intervalos entre a aplicação do herbicida e a semeadura do milho (0, 15, 30, 45, 60 e 75 dias), além de uma testemunha sem aplicação do herbicida. Os componentes de fitotoxicidade, rendimento e produtividade do milho foram avaliados. A maior fitotoxicidade ocorreu com 3,96 g ha^{-1}, quando o herbicida foi aplicado no dia da semeadura. Metsulfuron-methyl causou fitotoxicidade e reduziu a produtividade do milho. O intervalo seguro entre a aplicação de metsulfuron-methyl e a semeadura do milho foi de 15 e 30 dias para as doses de 1,98 e 3,96 g ha^{-1}, respectivamente.

Palavras-chave: carryover; sulfonilureas; *Zea mays*

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Introduction

Among the factors, that most interfere with the yield of annual crops is the occurrence of weeds, which can cause direct and indirect interference in crop yield (Helvig et al., 2020). A measure adopted for weed control is chemical control by herbicides application, which can cause phytotoxicity in cultivated plants when used during the crop cycle, or in crops grown in succession due to the persistence of some herbicides in the soil, often compromising yield (Constantin et al., 2018; Rector et al., 2019). The residual effect of herbicides in the soil is linked with the chemical and physical characteristics of the soil and herbicide depending on climatic conditions, which will determine the speed of dissipation of the herbicide (Souza et al., 2020).

The herbicides of the sulfonylureas chemical group act by inhibiting the enzyme acetolactate synthetase (ALS), which, in turn, inhibits the synthesis of amino acids valine, leucine, and isoleucine, disrupting protein synthesis and, consequently, DNA synthesis and cell division (Mantu et al., 2020). Metsulfuron-methyl is an ALS-inhibitor herbicide, from the sulfonylureas group, used in Brazil in winter cereals, rice, pasture, coffee, and sugarcane, and during the autumn for managing weeds, such as *Conyza* spp. (Oliveira Neto et al., 2017; Rodrigues & Almeida, 2018; Oliveira Neto et al., 2019; Silva et al., 2020). This herbicide controls Magnoliopsida species, with the occurrence of plant death within two weeks after application (Albrecht et al., 2017). It is characterized by high biological activity, is effective in very low doses, and has a large spectrum of action (Rodrigues & Almeida, 2018).

The presence of metsulfuron-methyl residues in the soil may affect the development and yield of several sensitive crops grown in succession (Mehdizadeh et al., 2017), such soybean (Alonso et al., 2013; Guerra et al., 2020; Silva et al., 2020; Silva et al., 2021), and corn (Santos et al., 2009; Alonso et al., 2013; Carvalho et al., 2015), requiring a safe period between application and sowing. Its persistence in the soil can vary from 30 to 120 days depending on the edafoclimatic characteristics (Zanini et al., 2009). Metsulfuron-methyl residues can cause phytotoxicity symptoms in corn plants depending on the dose used and local edafoclimatic conditions (Santos et al., 2009; Carvalho et al., 2015). However, there is no information in the literature regarding the effect of this herbicide's residues in the soil on corn yield, nor on the safe interval between herbicide application and corn sowing, prioritizing the effects on yield.

The hypothesis of this research is that the short intervals between the application of metsulfuron-methyl and corn sowing can affect the yield of this cereal. Thus, the present study objective to evaluate the application of metsulfuron-methyl at different intervals before sowing, on the corn development and yield, and determine a safe period between the application of the herbicide and corn sowing.

Materials and Methods

The same experiment was conducted in two growing seasons, 2017/18 and 2018/19. The crop was grown in the experimental area the Universidade Federal de Santa Catarina, Campus Curitibanos, located at latitude 27°16'26.55" S and longitude 50°30'14.11" W, at an average altitude of 1,000 m. The soil of the experimental area is classified as Haplic Cambisol of clayey texture with slightly wavy topography and good drainage, consisting of 525 g kg^{-1} of clay, 238 g kg^{-1} silt, 237 g kg^{-1} of sand, 47.52 g dm^{-3} of organic matter, and pH ($CaCl_2$) of 5.4 (analysis of the 0-20 cm layer).

The predominant climate in the region is the cfb - humid subtropical climate. The precipitation and maximum and minimum temperatures during the experimentation period are presented in Figures 1A and 1B and were obtained from the meteorological station of the Universidade Federal de

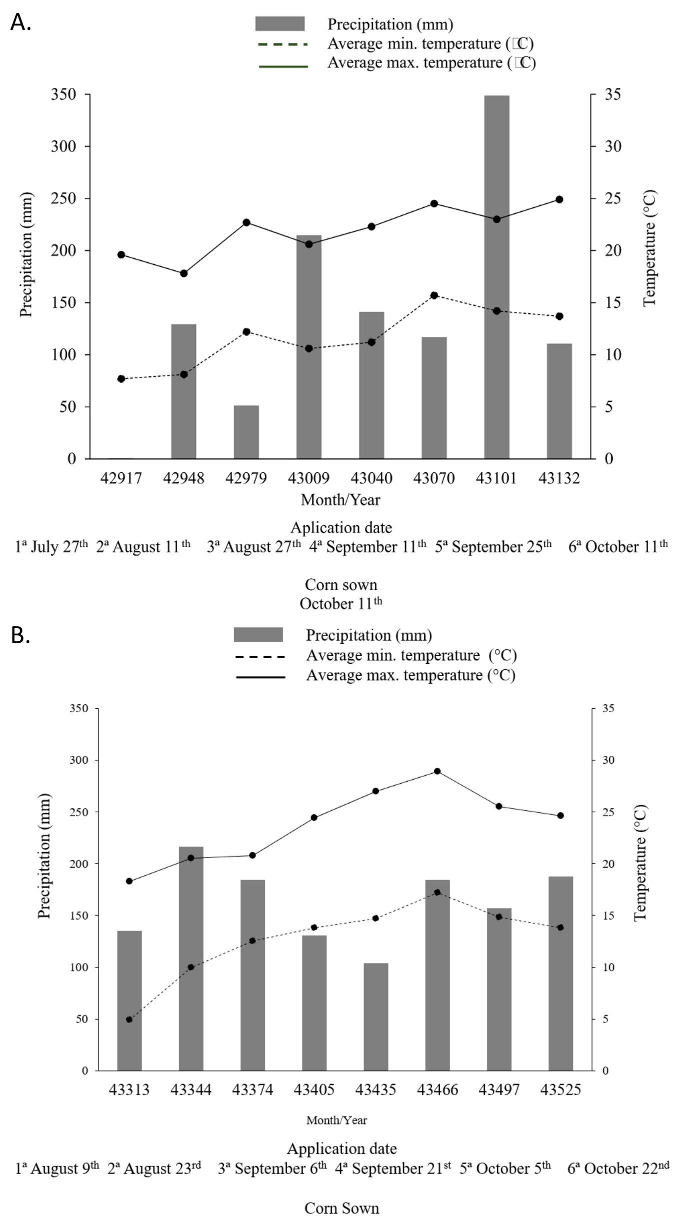

Figure 1. Precipitation, minimum average temperature, and maximum average temperature of the months of experimentation. 2017/18 (A) and 2018/19 (B) seasons. Curitibanos, SC, Brazil, 2022.

Santa Catarina, Campus Curitibanos, located approximately 500 m from the experimental area.

The experimental design was of randomized blocks, with thirteen treatments and four replicates. The treatments were arranged in factorial scheme (2 × 6) + 1. The first factor consisted of two doses of metsulfuron-methyl (1.98 and 3.96 g ha^{-1} of active ingredient - a.i.), and the second in six intervals between the application of the herbicide and corn sowing (0, 15, 30, 45, 60, and 75 days), plus a control with no metsulfuron-methyl application. Each experiment totaled 52 plots with dimensions of 2.8 m wide and 3.0 m long (11.2 m^2 per plot), with a total design area of 582.4 m^2. Each plot contained five corn sowing lines, considering the three central lines as useful area for the evaluations, disregarding 0.5 m from the end of each line.

The metsulfuron-methyl doses used were based on the lowest (1.96 g ha^{-1}) and highest (3.98 g ha^{-1}) recommended for weed control in wheat crops. The commercial product used was Ally® (600 g kg^{-1} a.i.), with a dose of 3.3 and 6.6 g ha^{-1} of commercial product (c.p.) (Rodrigues & Almeida, 2018).

The metsulfuron-methyl was applied using a precision backpack sprayer, pressurized to CO_2, equipped with a spray boom containing four tips with flat jets model XR 110.015, spaced of 0.5 m, under pressure of 172 kPa, displacement speed of 3.6 m s^{-1}, and application rate of 150 L ha^{-1}. In the 2017/18 season, the applications were conducted on July 27th, August 11th, August 27th, September 11th, September 25th, and October 11th, when the corn was sown. The applications of the 2018/19 seasons were conducted on August, 9th, August 23rd, September 6th, September 21st, October 5th, and October 22nd (day of corn sowing). Environmental conditions at the time of applications were favorable for this operation, with temperature not exceeding 25 °C, minimum relative air humidity of 55%, maximum wind speed of 1.5 km h^{-1}, and moist soil.

The corn hybrid AS1551PRO2 was sown on October 11th, 2017 (2017/18 growing season) and October 22nd, 2018 (2018/19 growing season), through no-tillage sowing, using a spacing of 0.45 m between lines and sowing density of three seeds per linear meter, respecting the plant population of 65,000 plants per hectare indicated for this hybrid.

The corn received base fertilization with 300 kg ha^{-1} of the formulation 09-33-12 (NPK). Cover nitrogen fertilization was performed in the V4 stage using 135 kg ha^{-1} of nitrogen (N), from urea (45% N).

The area was kept with control of weeds during the development of the corn crop. The weed control was conducted with two applications of the glyphosate at a dose of 1,440 g ha^{-1} of acid equivalent. This procedure was used to avoid the interference of weeds in crop yield. Pest was management with imidacloprid + beta-ciflutrina (100 + 12.5 g L^{-1}), was performed following the recommendations for the crop.

The variables assessed were percentage of phytotoxicity of the corn plants, stand, number of ears per plant, number of rows per ear, number of grains per row, mass of one hundred grains, and yield. The percentage of phytotoxicity of corn plants was evaluated at 15, 30, and 45 days after sowing (DAS), assigning scores from 0 to 100, where score 0 (zero) represents plants without intoxication symptoms and 100 (one hundred) represents dead plants (SBCPD, 1995). The stand and number of ears per plant were evaluated in the pre-harvest. The stand was evaluated on two central lines of the plot, each containing two meters in length. The data was subsequently converted to a number of plants per linear meter. The number of ears per plant was evaluated in five randomly chosen plants within the useful area of the plot, later determining the mean for the values obtained in each plot.

At the end of the corn crop cycle, the corn ears present in 1.4 m² per plot were manually harvested. After the harvest, the number of rows per ear and number of grains per row were counted in five randomly chosen ears from the material harvested from each plot. After conducting these evaluations, the ears were threshed on a mechanized thresher coupled to a tractor. Subsequently, the mass of one hundred grains and production was determined on a precision scale, later extrapolated to kg ha^{-1} to obtain the yield values. The hundred grain mass and yield data were corrected for the grain moisture of 13% for standardization.

The results were submitted to the analysis of variance by the F test and its where means compared by the Fischer test (LSD) at 5% probability. Regression analysis or interval of confidence was used, both at 5% probability ($p < 0.05$) when there was a significant effect of the intervals between application and sowing.

Results and Discussion

The symptoms caused by metsulfuron-methyl in corn plants, in both seasons, were characterized by interneval chlorosis (stretch marks) followed by purpling of the leaf veins (Figure 2) and reduction in plant growth, corroborating the studies conducted by Alonso et al. (2013). According to Ivany (1987) metsulfuron-methyl also causes a reduction in the corn seedling root elongation since this herbicide is absorbed quickly after root emission.

The most pronounced injury occurred when sowing was performed on the same day as applying the herbicide (0 DAS) and for the highest dose of metsulfuron-methyl (Figures 3 and 4), confirming the report of Santos et al. (2009).

Figura 2. Symptoms of corn phytotoxicity after sowing in soil with metsulfuron-methyl, 15 days after sowing. Curitibanos, SC, Brazil, 2022.

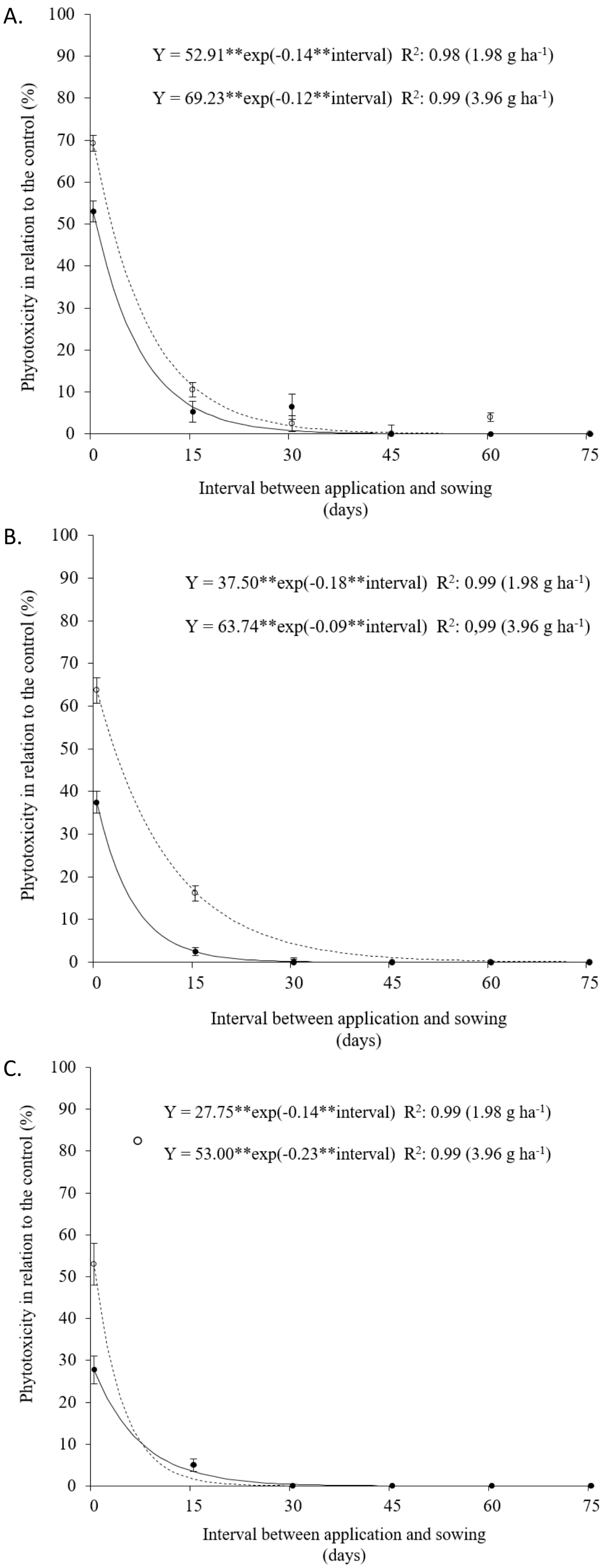

Figure 3. Percentage of phytotoxicity of the corn sown after different intervals of application of metsulfuron-methyl. Evaluations conducted at 15 (A), 30 (B), and 45 (C) DAA, 2017/18 season. Dots indicate mean ± SD (n = 4). Curitibanos, SC, Brazil, 2022.

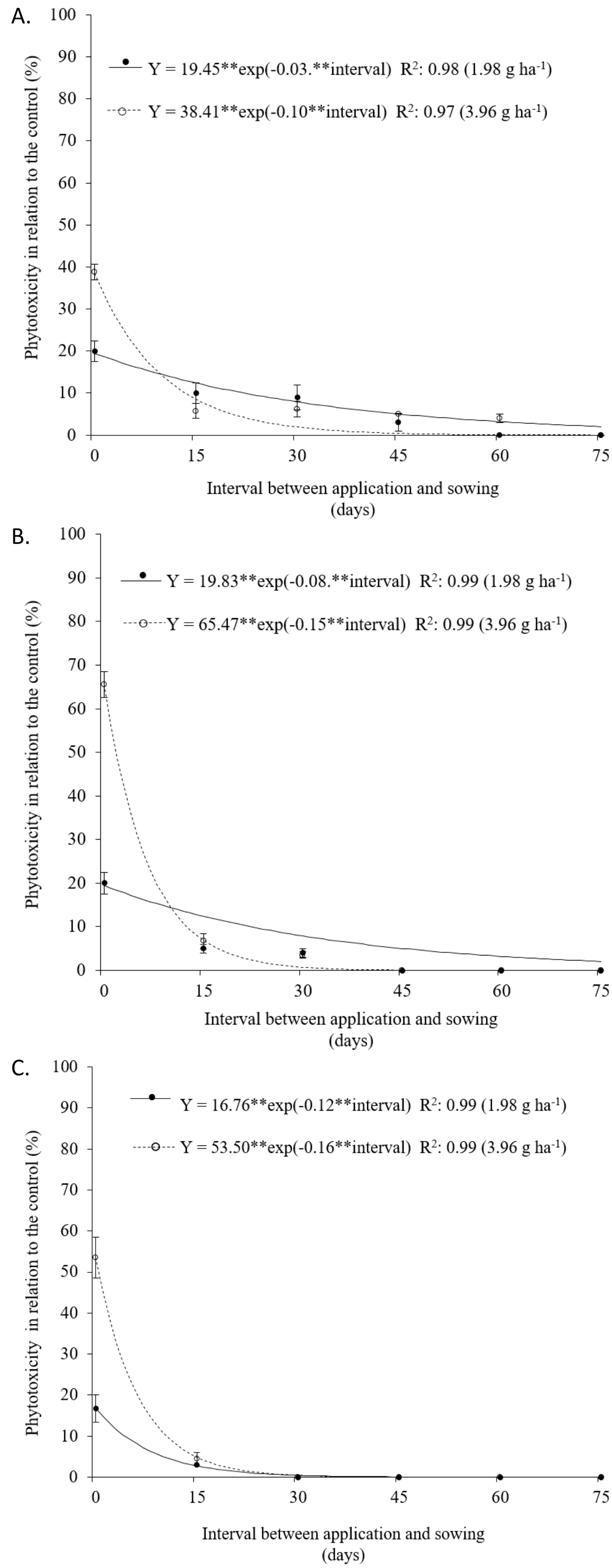

Figure 4. Percentage of phytotoxicity of the corn sown after different intervals of application of metsulfuron-methyl. Evaluations conducted at 15 (A), 30 (B), and 45 (C) DAA, 2018/19 season. Dots indicate mean ± SD (n = 4). Curitibanos, SC, Brazil, 2022.

However, the intensity of the symptoms reduced throughout the evaluations, and all the treatments presented similar to control during the reproductive stage of the corn (Figures 3 and 4).

There was a significant effect between the dose of metsulfuron-methyl and interval between application and corn sowing for the three phytotoxicity evaluations, in both growing seasons.

Phytotoxicity at 15 DAS was higher in plants sown on the same day as herbicide application, and the highest percentages occurred for the highest dose, in both seasons. The symptoms were more intense in the 2017/18 season, with 53.00 and 69.25% for doses of 1.98 and 3.96 g ha^{-1}, respectively. In the following season, the phytotoxicity was 20.00 and 38.75% for the lowest and highest dose, respectively. Phytotoxicity reduced as the interval between application and sowing increased. No significant differences were observed between the doses of metsulfuron-methyl from 16 and 6 days of interval between application and sowing for the 2017/18 and 2018/19 growing seasons, respectively. Symptoms of phytotoxicity were less than 10% from 12 and 17-day intervals for doses of 1.98 and 3.96 g ha^{-1}, respectively, for the 2017/18 season, and from 18 and 13-day intervals for the 2018/19 season (Figures 3A and 4A).

The same trend was maintained in subsequent assessments. The greatest symptoms were observed in the final evaluation (45 DAS) when the application and sowing occurred on the same day. In the 2017/18, the phytotoxicity were less to 10% from 8 days between application and sowing, regardless of the dose of the herbicide. In the 2018/19, percentages less than 10% occurred when the interval between application and sowing was 5 and 11 days, for the lowest and highest dose of metsulfuron-methyl, respectively (Figures 3C and 4C).

Neither the growing season or the isolated factors for corn component yield (stand, number of ears per plant, number of rows per ear, number of grains per row, and mass of one hundred grains) showed an interaction between the dose and interval factors (data not shown).

In the 2017/18, there was a significant effect just for the interval factor between application and sowing for yield. There was a difference between the intervals of confidence if compared to the control only when sowing occurred on the same day of application (0 DAS). The yield reduction around 12.24%, regardless of the metsulfuron-methyl dose applied (Figure 5). Intervals between application and sowing ≥ 15 days did not affect corn yield since they were similar to the control (Figure 5).

There were significant interaction between the factors dose and interval between application and sowing for the 2018/19 season. Corn yield in the 2018/19 season was reduced compared to the control, when the application of the lower dose of metsulfuron-methyl occurred on the same day of sowing (Figure 6). However, there was a reduction for the first two intervals between application and sowing (0 and 15 days) for the dose of 3.96 g ha^{-1}. The reduction in yield was 6.81 and 18.52% for the application of 1.98 and 3.96 g ha^{-1}

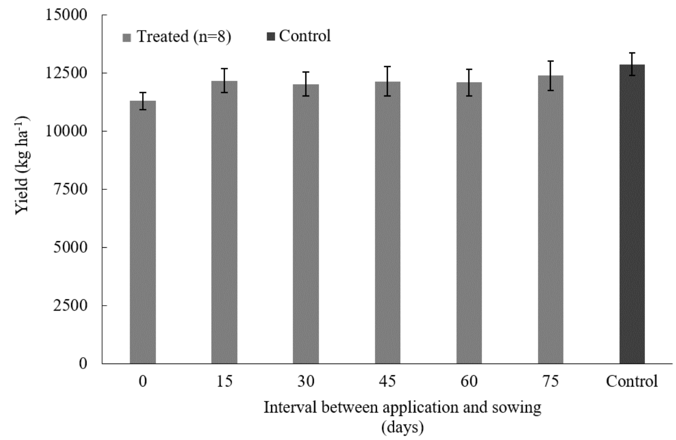

Figure 5. Yield of corn sown after different intervals of application of metsulfuron-methyl in the 2017/18 season. Bars indicate mean ± SD (n = 8). Curitibanos, SC, Brazil, 2022.

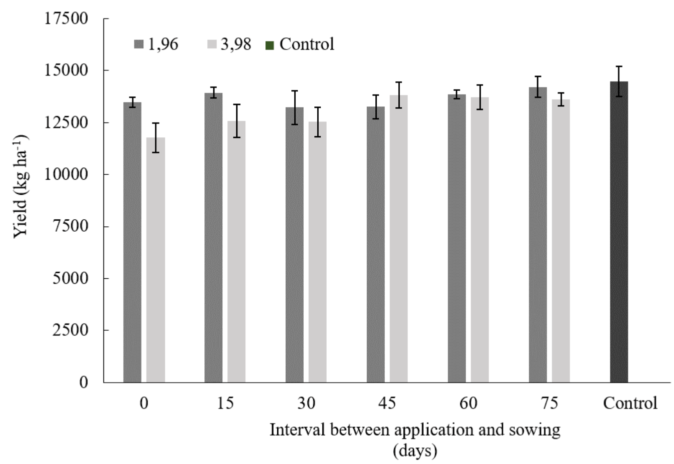

Figure 6. Yield of corn sown after different intervals of application of metsulfuron-methyl in the 2018/19 season. Bars indicate mean ± SD (n = 4). Curitibanos, SC, 2022.

metsulfuron-methyl on the day of sowing, respectively. The interval of 15 days between the application of the highest dose and sowing decreased corn yield by 13.09%. Thus, at least 30 days were necessary to avoid a significant reduction in yield for the dose of 3.96 g ha^{-1} in the 2018/19 season (Figure 6).

The results of both experiments (2017/18 and 2018/19 growing seasons) indicated a difference in the effect of metsulfuron-methyl present in the soil on phytotoxicity and corn yield, but not exceeding 30 days. These results corroborate those obtained by Carvalho et al. (2015) who reported no symptoms of phytotoxicity or reduction in shoot dry matter when corn was sown at 30 DAA with 3.96 g ha^{-1} of metsulfuron-methyl. Ivany (1987) observed a 25.9% reduction in corn root length when sown 30 days after the application of 9 g ha^{-1} metsulfuron-methyl, but with no effects on yield. Guerra et al. (2020) concluded that the 15-day interval was enough not to reduce the yield of the soybean, when evaluating the safe interval between the application of metsulfuron-methyl and the sowing of the soybean season in the 2016/17 season, under the same edafoclimatic conditions as in the corn test.

The cause of the short period of insurance is probably due to the low amount of metsulfuron-methyl residue in the soil. Analyzing the residues of this herbicide in the field of the 2017/18 season, at the depth of 0-15 cm at 10 days after corn sowing using high-performande liquid chromatography (HPLC), De Santo et al. (2019) observed ≤ 0.65 and 1.67 ppb for the doses of 1.98 and the 3.96 g ha^{-1}, respectively, regardless of the interval between the application and the collection of soil samples. Shondia (2008) also evaluated the residues of metsulfuron-methyl in the soil. The author applied doses of 3 to 5 g ha^{-1} and found 9 to 12 µg metsulfuron-methyl kg^{-1} soil at 30 DAA, the residues were gradually decreasing over time, and the values were below the detection limit at 60 DAA. Paul et al. (2009) reported that no metsulfuron-methyl residues were identified in the soil surface layer (0 to 10 cm) at 15 days after the application of 4 g ha^{-1}.

Many studies in the literature report low amounts of metsulfuron-methyl residues in the soil after 30 days of its application. This fact is due to the fast dissipation of the molecule in the environment, identified by the half-life ($t_{1/2}$). Studies with metsulfuron-methyl conducted by Sanyal et al. (2006) showed a $t_{1/2}$ of 10.75 days for doses of 4 and 8 g ha^{-1}, and Paul et al. (2009) found values of 6.3, 7.8, and 17.5 days for doses of 4, 8, and 12 g ha^{-1}, respectively.

The persistence of metsulfuron-methyl in the soil can be affected by pH, organic carbon content, microorganism degradation, soil moisture, and temperature (Zanini et al., 2009), having an increased degradation with high soil temperature and humidity and low pH (Zanini et al., 2009). Thill (1994) reports that chemical hydrolysis occurs faster in acidic soils. Joshi et al. (1985) observed that degradation by microbial action occurs mainly in alkaline soils. There was a probable predominance of microbial degradation because the pH of the soil of the experiment was 5.4 (in $CaCl_2$) and it is a soil with a high content of organic matter (47.52 g dm^{-3}).

Another characteristic that may have contributed to the short period in which metsulfuron-methyl reduced to corn yield is the high leaching potential of this herbicide. According to Zanini et al. (2009) and Shondia (2009), this molecule is classified as leachable according to the GUS index, presenting high mobility and easy transport by water flows that occur in the soil profile. In our experiment, the precipitation volumes during the 30 days preceding the corn sowing were 174.6 and 154.0 mm for the 2017/18 and 2018/19 seasons, respectively (Figures 1A and 1B). The volume accumulated in the 15 days before sowing was 111.2 and 107.6 mm for the 2017/18 and 2018/19, respectively (Figures 1A and 1B). These volumes may have contributed to leaching and, consequently, the reduction of herbicide residues in the most superficial layers of the soil, leaving them unavailable for absorption by the corn roots. These results corroborate the study conducted by Carvalho et al. (2015), who observed that daily irrigation with 5.0 mm (cumulative value of 150.0 mm) after applying 3.96 g ha^{-1} of metsulfuron-methyl was enough not to affect the dry matter of the plants sown at 30 days after application.

Thus, we can state that the amount of residues present in the area was not enough to reduced corn productivity when the interval between application and sowing was ≥ 15 days for the dose of 1.98 g ha^{-1} and ≥ 30 days for the dose of 3.96 g ha^{-1}.

Conclusion

Metsulfuron-methyl caused phytotoxicity and reduced corn yield. The safe interval between application and corn sowing was 15 and 30 days for the doses of 1.98 and 3.96 g ha^{-1} of metsulfuron-methyl, respectively.

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Compliance with Ethical Standards

Author contributions: Conceptualization: NG, AMON; Data curation: BN, JS, WJ, ASR; Formal analysis: NG, BN, JS, WJ, ASR, AMON; Investigation: NG, AMON; Methodology: NG, AMON; Project administration: NG; Supervision: NG; Writing - original draft: NG, BN, JS, WJ, ASR, AMON; Writing – review & editing: NG, AMON.

Conflict of interest: The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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Literature Cited

Albrecht, A.J.P; Silva, A.F.; Albrecht, L.P.; Pereira, G.C.; Krenchinski, F.H.; Migliavacca, R.A.; Victoria Filho, R. Effect of sulfonylureas application on RR/STS soybean. Brazilian Journal of Agriculture, v.92, n.2, p.37-49, 2017. https://doi.org/10.37856/bja.v92i1.3193.

Alonso, D.G.; Oliveira Júnior, R.S.; Constantin, J. Potencial de *Carryover* de herbicidas com atividade residual usados em manejo outonal. In: Constantin, J., Oliveira Júnior, R.S.; Oliveira Neto, A.M. (Orgs.). Buva: fundamentos e recomendações para o controle. Curitiba: Omnipax, 2013. p.91-104.

Carvalho, S.J.P.; Soares, D.J.; Lopez-Ovejero, R.F.; Christoffoleti, P.J. Soil persistence of chlorimuron-ethyl and metsulfuron-methyl and phytotoxicity to corn seeded as a succeeding crop. Planta Daninha, v.33, n.2, p.331-339, 2015. https://doi.org/10.1590/0100-83582015000200019.

Constantin, J.; Biffe, D.F.; Oliveira Júnior, R.S.; Rosa, E.L.; Gheno, E.A.; Machado, F.G.; Braz, G.B.P. Use of residual herbicides in soybean and impact on corn in succession. Comunicata Scientiae, v.9, n.3, p.481-491, 2018. https://doi.org/10.14295/CS.v9i3.2006.

De Santo, F.B.; Guerra, N.; Vianna, M.S.; Torres, J.P.M.; Marchioro, C.A.; Niemeyer, J.C. Laboratory and field test for risk assessment of metsulfuron-methyl based herbicide for soil fauna. Chemosphere, v.222, p.645-655, 2019. https://doi.org/10.1016/j.chemosphere.2019.01.145.

Guerra, N.; Oliveira Neto, A.M.; Schmitt, J.; Carneiro, A.L.; Kopko, L.B.; Jochem, W. Interval between the application of metsulfuron-methyl and sowing soybean in different production environments. Revista Ciência Agronômica, v.51, n.2, e20186107, 2020. https://doi.org/10.5935/1806-6690.20200032.

Helvig, E.O.; Pinheiro, K.K.G.; Dranca, A.C.; Silva, A.A.P.; Mendes, M.C.; Maciel, C.D. Interference periods of weeds in maize in no-tillage and conventional systems at high altitudes. Planta Daninha, v.38, e020198681, 2020. https://doi.org/10.1590/S0100-83582020380100029.

Ivany, J.A. Metsulfuron-methyl use in barley and residual effect on succeeding crops. Canadian Journal Plant Science, v.67, n.4, p.1083-1088, 1987. https://cdnsciencepub.com/doi/10.4141/cjps87-144.

Joshi, M.M.; Brown, H.M.; Romesser, J.A. Degradation of chlorsulfuron by soil microorganisms. Weed Science, v.33, n.6, p.888-893, 1985. https://www.jstor.org/stable/4044116. 22 Jun. 2021.

Mantu, C.; Renuka, D.; Kanti, M.S. Study of acetolactate synthase and its mechanism of inhibition by sulfonylurea active ingredients: amidosulfuron, nicosulfuron, cyclosulfuron – in-silico approach. International Journal of Chemical and Environmental Science. v.1, n.3, p.7-46, 2020. https://doi.org/10.15864/ijcaes.1301.

Mehdizadeh, M.; Alebrahim, M. T.; Roushani, M. Determination of two sulfonylurea herbicides residues in soil environment using HPLC and phytotoxicity of these herbicides by lentil bioassay. Bulletin of Environmental Contamination and Toxicology, v.99, n.1, p.93-99, 2017. https://doi.org/10.1007/s00128-017-2076-8.

Oliveira Neto, A.M.; Constantin, C.; Oliveira Júnior, R.S.; Guerra. N.; Blainski, E.; Dan H.A.; Alonso, D.G. Fall management of fleabane based on glyphosate +2,4-D, MSMA and glufosinate applied isolated or in tank mixture with residual herbicides. African Journal of Plant Science, v.11, n.5, p.151-159, 2017. https://doi.org/10.5897/AJPS2017.1537.

Oliveira Neto, A.M.; Constantin, J.; Oliveira Júnior, R.S.; Guerra. N.; Blainski, E.; Dan, H.A. Management of Sumatran fleabane after maize harvest in the fallow period shorter than 60 days. Communications in Plant Science, v.9, p.53-58, 2019. https://doi.org/10.26814/cps2019009.

Paul, R.; Sharma, R.; Kulshrestha, G.; Shashi, B.S. Analysis of metsulfuron-methyl residues in wheat field soil: a comparison of HPLC and bioassay techniques. Pest Management Science, v.65, n.9, p.963-968, 2009. https://doi.org/10.1002/ps.1780.

Rector, L.S.; Pittman, K.B.; Beam, S.C.; Bamber, K.W.; Cahoon, C.W.; Frame, W.H.; Flessner, M.L. Herbicides carryover to various fall-planted cover crop species. Weed Technology, v.34, n.1, p.25-34, 2019. https://doi.org/10.1017/wet.2019.79.

Rodrigues, B.N.; Almeida, F.L.S. Guia de herbicidas. 7.ed., Londrina: MIDIOGRAF, 2018. 764p.

Santos, E.L.; Barros, A.S.R.; Nagashima, G.T.; Ferreira, A.A.; Prete, C.E.C. Efeito do herbicida metsulfuron-methyl no desenvolvimento inicial do milho. Revista Brasileira de Milho e Sorgo, v.8, n.2, p.145-156, 2009. https://doi.org/10.18512/1980-6477/rbms.v8n2p145-156.

Sanyal, N.; Pramanik, S.K.; Pal, R.; Chowdhury, A. Laboratory simulated dissipation of metsulfuron-methyl and chlorimuron ethyl in soils and their residual fate in rice, wheat and soybean at harvest. Journal of Zhejiang University Science B, v.7, p.202-208, 2006. https://doi.org/10.1631/jzus.2006.B0202.

SBCPD - Sociedade Brasileira da Ciência das Plantas Daninhas. Procedimentos para instalação, avaliação e análise de experimentos com herbicidas. Londrina: SBCPD, 1995. 42p.

Shondia, S. Leaching behaviour of metsulfuron-methyl in two texturally different soils. Environmental Monitoring Assessment, v.154, p.111-115, 2009. https://doi.org/10.1007/s10661-008-0381-8.

Shondia, S. Persistence of metsulfuron-methyl in wheat crop and soil. Environmental Monitoring Assessment, v.147, p.463-469, 2008. https://doi.org/10.1007/s10661-007-0132-2.

Silva, A.F.M.; Giraldeli, A.L.; Silva, G.S.; Albrecht, A.J.P.; Albrecht, L.P.; Victoria Filho, R. The residual effect of metsulfuron on soybean tolerant and non-tolerant to sulfonylureas. Revista Facultad Nacional de Agronomía Medellín, v.73, n.2, p.9171-9178, 2020. https://doi.org/10.15446/rfnam.v73n2.79552.

Silva, J.D.G.; Müller, C.; Galon, L.; Pawelkiewicz, A.D.; Brandler, D.; Toso, J.O.; Perin, G.F. Selectivity of metsulfuron applied to soybean before in different intervals and soil. Journal of Environmental Science and Health, Part B, v.56, n.7, p.623-633, 2021. https://doi.org/10.1080/03601234.2021.1929004.

Souza, A.S; Leal, J.F.L.; Langaro, A.C.; Carvalho, G.S.; Pinho, C.F. Leaching and carryover for safrinha corn of the herbicides imazapyr + imazapic in soil under different water conditions. Revista Caatinga, v.33, n.2, p.287-298, 2020. https://doi.org/10.1590/1983-21252020v33n202rc.

Thill, D.C. Sulfonylureas and triazolipyrimidines. In: Purdue University (Ed.). Herbicide action course. West Lafayette: Purdue University, 1994. p.317-343.

Zanini, G.P.; Maneiro, C.; Waiman, C.; Galantini, J.A.; Rosell, R.A. Adsorption of metsulfuron-methyl on soils under no-till system in semiarid Pampean Region, Argentina. Geoderma, v.149, n.1-2, p.110-115, 2009. https://doi.org/10.1016/j.geoderma.2008.11.025.