Weed control in different germination fluxes with pre-emergent herbicides on sugarcane straw under dry periods

Control de malezas en diferentes flujos de germinación a través de herbicidas preemergentes en aplicaciones sobre paja de caña de azúcar y períodos de seco

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Abstract

Preemergent herbicides are a frequent weed control strategy. Considering different crop germinative fluxes, these products must present long-lasting weed control. This study evaluated preemergent herbicides in different germination fluxes of *Merremia aegyptia*, *Mucuna aterrima* and *Ricinus communis* when applied to different quantities of straw and different simulated dry periods. The experiment was conducted in a 4 × 2 × 2 factorial design with four replications. The treatments included four dry periods (0, 30, 60, and 90 days), two straw quantities (0 and 10 t ha^{-1}), and two germination fluxes. The herbicides amicarbazone (1225 g ha^{-1}), imazapic (147 g ha^{-1}), sulfentrazone (800 g ha^{-1}), and tebuthiuron (900 g ha^{-1}) were applied for preemergence weed control, and germination flush fluxes were evaluated at 7, 14, 21, 28, and 35 days after emergence (DAE) while verifying plant dry mass. Amicarbazone controlled less than 80% of the studied species at the 90-day dry period in the presence of straw. Imazapic did not present control residue for any of the species analyzed. Sulfentrazone showed the same control pattern at all germination fluxes, regardless of the amount of straw. Tebuthiuron successfully controlled all species in the first germination flush, exceeding 80% regardless of the amount of straw. Herbicides associated with straw quantities and dry periods have a significant impact on *M. aegyptiaca*, *M. aterrima* and *R. communis*.

Keywords
amicarbazone • flush • germination • imazapic • precipitation • residue • straw • sulfentrazone • tebuthiuron

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Resumen

La aplicación de herbicidas preemergentes es una estrategia de control de malezas, sin embargo, estos productos deben presentar residualidad para el control de diferentes flujos germinativos. Este estudio tuvo como objetivo evaluar la eficacia de herbicidas preemergentes en diferentes flujos de germinación de *Merremia aegyptia*, *Mucuna aterrima* y *Ricinus communis*, cuando se aplican sobre diferentes cantidades de paja y diferentes períodos secos simulados. El experimento se realizó en un diseño factorial 4 × 2 × 2 con cuatro repeticiones, el tratamiento incluye cuatro períodos secos (0, 30, 60 y 90), dos cantidades de paja (0 y 10 t ha^{-1}) y dos flujos de germinación. Los herbicidas amicarbazona (1225 g ha^{-1}); imazapic (147 g ha^{-1}), sulfentrazona (800 g ha^{-1}) y tebuthiuron (900 g ha^{-1}), se aplicaron para el control de malezas antes de la emergencia, y los flujos de flujo de germinación se evaluaron a los 7, 14, 21, 28 y 35 días después de la emergencia de especies (DAE), mientras se verifica la masa seca. La amicarbazona presentó una reducción del control para todas las especies en los periodos secos más prolongados y presencia de paja. La amicarbazona mostró menos del 80% de control para todas las especies a los 90 días del período seco en presencia de paja. Imazapic no presentó residuo control para ninguna de las especies analizadas. Para sulfentrazona, la cantidad de paja no afectó el control de las malezas en diferentes flujos de germinación, mostrando el mismo patrón de control independientemente de la cantidad de paja. porcentajes de control superiores al 80% independientemente de la cantidad de paja. Los herbicidas asociados a cantidades de paja y periodos secos tienen impacto sobre las especies de malezas *M.aegyptia*, *M.aterrima* y *R. communis*.

Palabras claves:
amicarbazone • flush • germinación • imazapic • precipitación • residuo • paja • sulfentrazone • tebuthiuron

Introduction

Raw sugarcane straw (without preburning) on the soil surface promotes a favorable environment for seed germination and weed development, such as *Merremia aegyptia* (L.) Urb., *Mucuna aterrima* Piper & Tracy, and *Ricinus communis* L. (12, 13). In these productive systems in Brazil, these three weed species are popularly known as "the three M's" (MMM-castor bean, *morning glory,* and mucuna). These species are adapted to sugarcane production systems with straw deposition on the soil surface. These systems hinder weed control with herbicides, causing serious damage to sugarcane production (2, 5, 18, 28, 33).

In addition to favoring the establishment of these species, the straw that remains on the soil surface represents a physical barrier to the action of preemergent herbicides (29), that once intercepted by the straw, becomes vulnerable to volatilization and/or photodegradation (7, 17) before reaching the soil (9). Another important aspect is the permanence period of a product on the straw. In Brazilian sugarcane plantations, products are applied during the winter season, characterized by low rainfall, especially in the southeast region (23). In addition, the longer the herbicide stays in the straw, the more susceptible it will be to degradation, consequently decreasing its transport and bioavailability for weed control (9, 27, 29, 30).

Some specific physical-chemical characteristics of the herbicides may facilitate an efficient straw-soil transport of these products. This, in addition to high solubility in water, absence of photodegradation (being preferentially degraded by microorganisms), and low K_{ow} (octanol/water partition coefficient, *i.e.* not having lipophilic character), (10) constitute key features for a successful product. Some herbicides have these physical-chemical characteristics. Among these herbicides, amicarbazone, presents high water solubility of 4.6 g L^{-1} at pH 4-9 and a low K_{ow} (1.23); sulfentrazone, has medium water solubility of 780 mg L^{-1} at pH 7 and medium K_{ow} (9.8 at pH 7); imazapic, has high water solubility of 2.200 mg L^{-1} at 25°C and a low K_{ow} of 0.16; and tebuthiuron, high solubility in water of 2.500 ml L^{-1} at 25°C and a high K_{ow} of 67.1 (26).

Several studies have reported effective control results in dry periods with the use of amicarbazone, imazapic, sulfentrazone and tebuthiuron herbicides (6, 11, 20, 22, 23, 30). Based on the above, this study evaluated the efficacy of preemergent herbicides in different germination flushes of *M. aegyptia*, *M. aterrima,* and *R. communis* when applied on different quantities of straw and with different simulated dry periods.

Materials and methods

The study was conducted under a greenhouse in the Department of Natural Resources of the Federal University of Sao Carlos at the agricultural science campus. The experiment was replicated twice, June/July 2016 and June/July 2017.

The herbicides were applied in preemergence in a completely randomized design following a 4 × 2 × 2 factorial scheme with four replications. The variables were four dry periods, two quantities of straw, and two germination fluxes. These factors were adopted for each of the three weed species (*M. aegyptia*, *M. aterrima*, and *R. communis* L.) and the four herbicide treatments (amicarbazone, imazapic, sulfentrazone, and tebuthiuron), individually. The experimental units were composed of 25 L polyethylene pots filled with soil from the arable layer of an Eutrophic Red Latosol (table 1).

Unit: Al, H+Al, K, Ca, Mg, SB and CTC (mmolc dm $^{-3}$); P (resina) (mg dm^{-3}); V, clay, silt, sand (%).

Unidad: Al, H + Al, K, Ca, Mg, SB y CTC (mmolc dm^{-3}); P (resina) (mg dm^{-3}); V, arcilla, limo, arena (%).

Table 1. Soil chemical analysis (0 to 20 cm).

Tabla 1. Análisis químico del suelo (0 a 20 cm).

pH	M.O.	P	K	Ca	Mg	Al+H	SB	CTC	V	Argil	Silt	Sand
($CaCl_2$)	(g dm^{-3})	(mg dm^{-3})	(mmolc dm^{-3})						(%)	(g kg^{-1})		
5.2	15	12	1.9	15	4	20	20.9	40.9	51	175	55	770

After filling the pots, 0 and 10 t ha^{-1} of sugar cane straw ('RB966928' variety) were allocated on the pot surface. Then, the herbicides amicarbazone (1225 g ha^{-1}), imazapic (147 g ha^{-1}), sulfentrazone (800 g ha^{-1}), or tebuthiuron (900 g ha^{-1}) were applied using a CO_2 pressurized, constant-pressure spray with fan-type tips (XR 110.02) at a pressure of 2.0 x 10^5 Pa with a syrup volume of 200 L ha^{-1}. During applications, the temperature was 17.1°C, the relative air humidity was 85%, and the wind velocity was 0.2 m s^{-1}.

After treatment application, the pots were submitted to four different periods without rain (0, 30, 60, and 90 days after herbicide treatment). After these periods, the pots received a rainfall simulation of 30 mm (flow rate of 1 L min^{-1}). Finally, the pots stood for 72 hours, enough time for the straw to dry and be carefully removed.

After removing the straw, the weed species *M. aegyptia*, *M. aterrima,* and *R. communis* were individually and carefully planted in the pots at 5 cm depth, aiming for minimum soil turnover and five plants per pot. Concerning *M. aterrima,* mechanical scarification broke dormancy.

The germination flux factor consisted of two different weed sowing times in the same experimental unit (pot). The first flux occurred immediately after rainfall simulation for each of the four dry periods (0, 30, 60, and 90 DAT with no water). At 35 days after emergence, for each dry period and first germination flow, the weeds were cut and removed for dry mass analysis. At this moment, a new germination flow began. For this purpose, in the same experimental units, the weed species *M. aegyptia*, *M. aterrima*, and *R. communis* were re-sown. Thus, for each dry period and experimental unit, two germination fluxes were simulated. The first one was related to weed sowing immediately after a 30 mm rain simulation (for each dry period: 0, 30, 60, and 90 days), and the second germination flux was sown after the first flush of germination.

Weed control percentage at each germination flux and within each dry period was evaluated at 7, 14, 21, 28, and 35 days after emergence (DAE) where 0 (zero) corresponded to no injury and 100 corresponded to plant death (1).

At 35 DAE for each germination flux and within each dry period, weeds were cut, packed in cardboard bags, taken to a greenhouse, and stored at 60°C for 72 hours. After those periods, the samples were weighed. For data analysis, dry mass values were expressed as reduction percentages in relation to the control without herbicide.

Statistics consisted of the reparametrized version of the logistic model with three parameters (3, 26) (Eq. 1):

$$Y = D/\{1+exp[B(log\ X - log\ E)]\} \quad (1)$$

where:
Y = Control and Biomass Reduction percentages
X = dry period
D = maximum estimate of the response variable
Parameter E = dry days estimates at 50% response
B = slope of the curve fitting at the inflexion point.

All statistical analyses were performed in R software (2022). The *ggplot2* (33) and *drc* (25) packages were used for graphical presentation and for fitting the Equation 1 model, respectively.

Results

According to ALAM (1974) and Vanhala *et al.* (2004), weed control percentages of 81-90% are classified as very good and 91-100% as excellent. For flow 1, control and biomass reduction of *M. aegypta* with amicarbazone were below 80% at 90 days of drought and on straw (figure 1, page XXX). The other treatments controlled more than 90%, regardless of the amount of straw. For amicarbazone, in flow 2 with straw, control of *M. aegypta* was superior to 80% at 0 and 30 dry periods, but at 60 and 90, it was under 80% (ineffective). In the application without straw, control and reduction of *M. aegypta* biomass for the same germination flow was lower than 40% only at 90 dry periods.

In flow 1, control and biomass reduction of *M. aterrima* with amicarbazone was less than 80%, only at 90 days of dry periods, regardless of the amount of straw. At 60 days of dry period biomass reduction was lower than 80%, while for flow 2, control and biomass reduction were greater than 80% at 0 dry periods with and without straw (figure 1, page XXX).

At flow 1, control and biomass reduction of *R. communis* with amicarbazone was below 80% at 90 DAT of drought, with or without straw (figure 1, page XXX). Control of *R. communis* at flow 2 with amicarbazone was greater than 80% in the 0 dry periods without straw. In flow 2, biomass reduction of *R. communis* with amicarbazone was inadequate, with percentages below 80% in all dry periods and amounts of straw. Control of *M. aegyptia* with imazapic at flow 1 was over 80% in all dry periods with straw in the biomass reduction was inadequate with percentages below 80% at 60 and 90 days. Flow 2 without straw showed control over 80% at the 0 dry period, while not exceeding 60% with straw. For flow 2, biomass reduction was less than 60% in all dry periods and amounts of straw (figure 1, page XXX).

In flow 1, control and biomass reduction of *M. aterrima* with imazapic was greater than 80% at 0 dry period, while control of *R. communis* was greater than 80% in the dry period with and without straw, and biomass reduction was over 80% at 0, 30 and 60 days regardless of straw. Flow 2 showed biomass reduction under 80% in all dry periods and amounts of straw (figure 1, page XXX).

Control of M. aegyptia for flow 1 was greater than 80% in all dry periods, regardless of the amount of straw. The reduction of biomass in flow 1 was greater than 80% at 0 and 30 dry periods with straw and 0, 30 and 60 dry periods without straw (figure 1, page XXX). In flow 2, control was over 80% at 0 dry periods without straw, and biomass reduction was greater than 80% at 0 and 30 dry periods with and without straw.

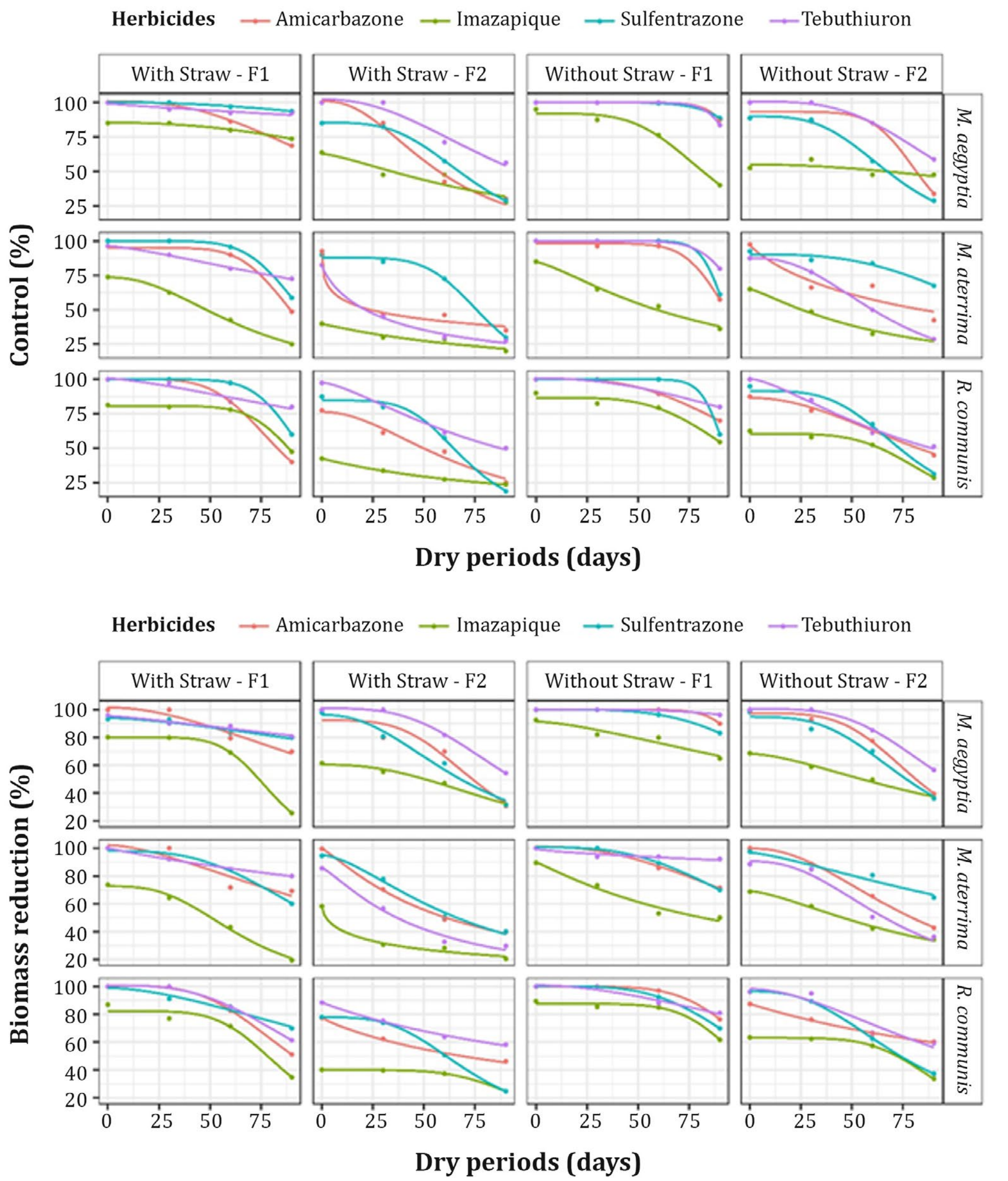

Figure 1. Control and biomass reduction of *Merremia aegyptia*, *Mucuna aterrima* and *Ricinus communis* at 35 DAE with amicarbazone; imazapic; sulfentrazone and tebuthiuron.

Figure 1. Control y reducción de biomasa de *Merremia aegyptia*, *Mucuna aterrima* and *Ricinus communis* a los 35 DAE a través de la amicarbazona; imazapic; sulfentrazona y tebutiuron.

Flow 1 with and without straw, and flow 2 without straw, showed control and biomass reduction of *M. aterrima* with sufentrazone over 80% at 0, 30 and 60 dry periods, regardless of the amount of straw. Flow 2 with straw, resulted in control and biomass reduction of *M. aterrima* over 80% at 0 and 30 dry periods, regardless of the amount of straw (figure 1). Flow 1, had control and biomass reduction of *R. communis* under 80% at the 90 dry period with and without straw. Control of *R. communis* in flow 2, achieved over 80% at 0 dry periods with straw, while without straw, control was superior to 80% at 0 and 30 dry periods. In flow 2, biomass reduction was greater than 80% at 0 and 30 dry periods, with and without straw (figure 1).

Control and biomass reduction of tebuthiuron at flow 1 was greater than 80% in all dry periods regardless of straw, while at flow 2, control and biomass reduction of thebuthiuron were greater than 80% at 0, 30 and 60 dry periods with or without straw (figure 1, page XXX).

In flow 1, control and biomass reduction of *M. aterrima* was greater than 80% at 0 and 30 dry periods with straw, and 0, 30 and 60 dry periods without straw. For flow 1, biomass reduction of *M. aterrima* without straw exceeded 80% at all dry periods while at flow 2, this species control exceeded 80% at 0 and 30 dry periods, regardless of straw. Biomass reduction exceeded 80% at dry periods 0 and 30 without straw and dry period 0 with straw (figure 1, page XXX). For flow 1, control of *R. communis* was over 80% in all dry periods with and without straw, while biomass reduction was less than 80% at 90 dry periods. In flow 2, control exceeded 80% at 0 and 30 dry periods, while biomass reduction was greater than 80% at the 0 dry period (figure 1, page XXX).

Discussion

Weed control efficiency of amicarbazone was gradually reduced with longer dry periods and increasing amounts of straw. This reduction was higher at the 90 dry period and 10 t ha^{-1} sugarcane straw. Thus, it can be noted that longer dry periods and the presence of straw on the soil surface at the time of application, reduced the efficacy of amicarbazone. Contrasting results showed how 90 days after application resulted in over 90% control of *M. aterrima* (14).

Efficacy of pre-emergent amicarbazone over *I. grandifolia, B. plantaginea*, *B. decumbens,* and *C. rotundus* was reduced when applied on sugarcane straw, compared to bare soil applications (19). However, this herbide showed higher efficiencies when leached from the straw by simulated rain after application (19). These results are in agreement with our study, where longer dry periods associated with amicarbazone on straw resulted in reduced weed control efficiency, probably explained by amicarbazone having higher water solubility (4.6 g L^{-1}, pH 4-9) and low Kow (Log Kow of 1.23) (26). This contributes to low absorption and/or retention on straw and easier recovery of herbicide action by rain simulation. Thus, the higher control percentages during the first germination flux when the herbicide was directly applied to soil can be given by lower retention by straw and the consequent higher soil solution availability.

Studies on amicarbazone dynamics in sugarcane straw through HPLC/MS/MS showed that straw quantities equal to or greater than 5 t ha^{-1} retained almost all of the herbicide at the time of application, while increasing straw quantity (mainly at 15 and 20 t ha^{-1} sugarcane straw) reduced herbicide transport from straw to soil (9). The longer the period between herbicide application and the first rain, the lower the transport from straw to soil. However, 20 mm of rainfall at 7 and 14 days after application allowed enough recovery of the intercepted product.

Due to its high solubility, amicarbazone is easily washed from straw to soil. However, longer periods between product application on straw and the first rain may reduce product mobility, reducing weed control effectiveness. Amicarbazone´s solubility can also explain the lower control percentages obtained in the second germination flux, where greater leaching in the soil solution reduced herbicide quantity in the root zone. A second eventual factor related to the lower efficiency in the second germination flux is microbial degradation of amicarbazone influenced by soil humidity and higher temperatures.

The absent residual activity of imazapyr over a second weed emergence flux, regardless of species, dry periods, and/or straw quantities, constitutes a disadvantage considering the critical period of weed infestation in sugarcane exceeding 150 days after planting (21). Therefore, herbicides with prolonged residual activity within this period are more appropriate.

Long dry periods after application of preemergent herbicides resulted in the control efficient control of different species of morning glory (*Ipomoea purpurea*) (23). Control effectiveness of imazapic diminished by 40% between 30 and 60 days of dry periods after application on *M. aegyptia*, presumably due to the high solubility (2.200 mg L^{-1} at 25°C). In addition, this herbicide presents weak acid behavior, and low dissociation in the soil pH range between 5.0 and 7.0 (4, 15, 16). Since soil pH in this experiment was 5.2, dissociation and bioavailability of imazapic would be practically null (16). Additionally, the experimental units received simulations of daily and constant rainfall in the greenhouse solubilizing Imazapic. Other studies showed Imazapic applied to columns with clay soil and pH of 4.7 resulting in an average of approximately 46 and 23% phytotoxicity in cucumber plants at depths of 30 and 40 cm, respectively, through an 80 mm rainfall simulation, showing the high mobility of this herbicide in acidic soils (11). Therefore, interactions between dissociation and solubility of imazapic may have resulted in greater leaching and/or degradation of this herbicide, decreasing weed absorption in the sowing period. Finally, we must also consider the quantity of herbicide absorbed in the first germination flux. This reinforces the possible high mobility of the herbicide beyond the weed seeding zone, a possible reason for the absence of residual herbicide in a second weed germination flush.

Sugarcane straw did not influence sulfentrazone effects in the first and second weed germination fluxes (for all the plants), meaning control was similar in both quantities of straw (0 and 10 t ha^{-1}), regardless of the simulated dry period. This product efficiently controls levels in both the first and second germination fluxes. However, drought influenced weed control efficiency, since in general, control percentages decreased as dry periods increased. Difference abscence between applications may be related to the high solubility (490 mg L^{-1}) and low Kow (1.48) of sulfentrazone, inducing low interception and/or absorption of this herbicide in sugarcane straw, in addition to favoring a good recovery of sulfentrazone initially retained by straw. This behavior results in higher soil solution availability. These results are in agreement with those of Carbonari *et al.* (2016), who found that 20 mm of water released the maximum percentage of sulfentrazone, regardless of straw quantities. For the simulated dry period after sulfentrazone application, the authors obtained recoveries of 76.5, 61.7, and 42.3% for periods of 30 and 60 days after sulfentrazone application and rain simulation.

Tebuthiuron showed excellent control of the three evaluated weeds, *M. aegyptia*, *R. communis* and *M. aterrima*, in the first germination flux. However, a noticeable reduction in control efficiency was observed in the second weed germination flux when the product was positioned on sugarcane straw. The good tebuthiuron performance in the first and second weed germination fluxes may be related to its long half-life (up to 480 days), providing soil herbicide availability for proper control of a first germination flux and residual control of a second weed emergence flux. However, when tebuthiuron is applied on sugarcane straw during dry periods, higher amounts of rain are required for an adequate release from straw to soil.

Tebuthiuron applied at 5 or more t ha^{-1} straw resulted in almost 100% interception (29). The authors also found that lower quantities of straw resulted in higher output of the initially intercepted product. They also observed that for rainfall exceeding 20 mm, there is a tendency for the data to be similar, regardless of the quantity of straw. That is, maximum recovery capacity of the herbicide occurs with 20 mm of rain. Longer dry periods between tebuthiuron application on sugarcane straw and rainfall simulation result in less transport from straw to soil solution. The larger quantities of straw present on the soil surface at the moment of application resulted in greater interception of tebuthiuron. Additionally, longer dry periods between applications and rainfall simulation resulted in less herbicide recovery.

Conclusion

Amicarbazone herbicide presented effective control over the first weed germination flush. Straw quantity had an influence when associated with longer dry periods, while in the second germination flush, residual effects were affected by longer dry periods and the presence of straw. For Imazapic, the species presented variable control over the first germination flush, with residual effect. For Sulfentrazone, straw quantity did not have a significant influence on weed control. For Tebuthiuron, straw associated with longer dry periods reduced control percentages. However, in general, this herbicide presented enough weed control efficacy.

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