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Emergence of *Rottboellia exaltata* influenced by sowing depth, amount of sugarcane straw on the soil surface, and residual herbicide use

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ABSTRACT. Mechanical sugarcane harvest without burning and continuous straw on the soil surface may affect the *Rottboellia exaltata* infestation dynamics in sugarcane fields. Three greenhouse experiments were conducted with the aim of studying the effects of sowing depth (0, 2.5, 5, 7.5, and 10 cm), amount of sugarcane straw on the soil surface (0, 5, 10, and 15 ton ha^{-1}), and residual herbicide (clomazone, flumioxazin, imazapyr, isoxaflutole, and s-metolachlor) on the emergence of *Rottboellia exaltata*. For each experiment, a completely randomized design with four replicates was applied. The combination of mulch on soil surface (especially with larger amounts of straw) with deeper sowing depths provides less emergence and mass accumulation of *R. exaltata*. In bare soil, the sowing depth did not affect the weed dynamics. Clomazone and imazapyr were effective herbicides controlling *R. exaltata* regardless of the amount of straw on the soil surface. Flumioxazin was also effective in controlling *R. exaltata* but only under bare soil conditions. Even with 60 mm of accumulated rainfall over the 4 day period after application, the amount of flumioxazin leached to the soil was not enough to ensure the same control observed when applying the herbicide on bare soil.

Keywords: itchgrass, mulch, herbicide retention, weed dynamics.

Emergência de *Rottboellia exaltata* influenciada pela profundidade de semeadura, quantidade de palha de cana sobre o solo e aplicação de herbicidas residuais

RESUMO. Diante do corte mecanizado sem queima da cana-de-açúcar e a manutenção de palha na superfície do solo, a dinâmica de infestação de *Rottboellia exaltata* nos canaviais pode ser afetada. Três experimentos foram desenvolvidos com o objetivo de estudar os efeitos da profundidade de semeadura (0; 2,5; 5; 7,5 e 10), quantidade de palha (0, 5, 10 e 15 t ha^{-1}) de cana sobre solo e a aplicação de herbicidas residuais (clomazone, flumioxazin, imazapyr, isoxaflutole e s-metolachlor) na emergência de *Rottboellia exaltata*. Para os três experimentos o delineamento experimental foi o inteiramente casualizado, com quatro repetições. Com a cobertura do solo, principalmente nos maiores níveis de palha, associada às maiores profundidades de semeadura, houve menor emergência e acúmulo de massa pelas plantas. Sem palha na superfície, a profundidade de semeadura não afetou a dinâmica da planta daninha. Os herbicidas clomazone e imazapyr foram eficazes no controle da planta daninha, independentemente do nível de palha sobre o solo. O mesmo ocorreu para flumioxazin na condição sem palha. Mesmo com a ocorrência de 60 mm de chuva acumulada no decorrer de 4 dias após a aplicação, a quantidade de flumioxazin removida para o solo não foi suficiente para garantir o mesmo controle observado com a sua aplicação em solo sem cobertura.

Palavras chave: capim-camalote, cobertura morta, retenção de herbicidas, dinâmica de plantas daninhas.

Introduction

Rottboellia exaltata L.f. (synonym *R. cochinchinensis* (Lour.) Clayton) is an annual or perennial species depending on environmental conditions, and it is reproduced by seeds produced from stem fragments with budding nodes (KISSMANN, 1997). In addition to the damage caused by competition for water, light, nutrients, and space, decomposing plant residues from this species release totoxic compounds in the soil that may inhibit germination and/or growth of adjacent species, including weeds and cultivated crops (KOBAYASHI et al., 2008; MEKSAWAT; PORNPROM, 2010). *R. exaltata* is the main weed for at least 18 crops in Africa, Central America, South America, Unites States, Australia, and Papua New Guinea (ANNING; GYAN-YEBOAH, 2007; HOLM et al., 1991; KISSMANN, 1997). This weed frequently occurs in Brazilian sugarcane crops in Rio de Janeiro (OLIVEIRA;

FREITAS, 2008) in focal infestations in São Paulo, Paraná e Mato Grosso do Sul. There are also reports of its occurrence in northern and central-western regions of Brazil (KISSMANN, 1997).

Mechanical sugarcane harvest without burning and continuous straw on the soil surface may affect the *R. exaltata* infestation dynamics in sugarcane fields. A reduced occurrence of weeds, mainly grasses has been observed in this harvest system. Correia and Durigan (2004) reported that sugarcane straw has an inhibitory effect on the emergence of *Brachiaria decumbens* and *Digitaria horizontalis* and reduced seed viability of such seeds since they do not germinate in the presence of straw or after its removal due to the physical, chemical, and/or biological effects of mulch. Thus, large amounts of sugarcane straw are effective in controlling *R. exaltata* (OLIVEIRA; FREITAS, 2009).

In contrast, straw can also compromise the ability of residual herbicide to reach the soil and, consequently, its ability to control weeds before their emergence. Depending on the physical and chemical attributes of herbicides, such as solubility, vapor pressure, and polarity, straw can have a differential influence on herbicide efficacy (RODRIGUES, 1993). After herbicide application, the amount and period when rainfall or irrigation occurs, as well as modifications occurring in the decomposing plant residues, are also important factors regarding the retention of the herbicide by the crop residue (CORREIA et al., 2007). If herbicides do not leach from the straw to the soil, they are exposed to losses by photodegradation, volatilization, and adsorption into plant residues. The degree of decomposition or aging of plant residues can also affect their capacity to absorb herbicides (MERSIE et al., 2006).

So far, information on the chemical control of *R. exaltata* in sugarcane crops is scarce, especially for herbicides applied pre-emergence. However, it is known that the chemical control of *R. exaltata* is costly because of the need to use up to six herbicide applications throughout the crop cycle (OLIVEIRA; FREITAS, 2009).

This study was conducted to test the hypothesis that (i) sowing depth does not affect the emergence of *R. exaltata*; (ii) large amounts of straw may inhibit the emergence of *R. exaltata* (iii) and impair herbicides applied pre-emergence, (iv) especially herbicides that are affected by the presence of sugarcane straw on the soil surface. The aim of this study was to study the effects of sowing depth, amount of sugarcane straw on the soil surface, and pre-emergence herbicide application on the emergence of *R. exaltata*.

Material and methods

Three experiments were conducted in pots inside a greenhouse between May 21, 2010 and May 7, 2011 at the Department of Phytosanitary Sciences at São Paulo State University (Universidade Estadual Paulista - UNESP), Jaboticabal Campus, São Paulo State, Brazil.

For the three experiments, a completely randomized design with four replicates was applied. In the first experiment (4 x 5 factorial design), four amounts of straw on the soil (0, 5, 10, and 15 ton ha^{-1}) and five sowing depths (0, 2.5, 5, 7.5, and 10 cm) of *R. exaltata* seeds were studied. In the second experiment (4 x 6 factorial design), four amounts of straw (0, 5, 10, and 15 ton ha^{-1}), five herbicides (clomazone at 1.20 kg ha^{-1}, flumioxazin at 0.25 kg ha^{-1}, imazapyr at 0.20 kg ha^{-1}, isoxaflutole at 0.225 kg ha^{-1}, and s-metolachlor at 2.88 kg ha^{-1}) applied pre-emergence, and an untreated control were studied. In the third experiment (4 x 3 + 4 factorial design), flumioxazin (250 g ha^{-1}) applied to four levels of soil cover by sugarcane straw (0, 5, 10, and 15 ton ha^{-1}) with simulated rain (20, 40, and 60 mm rainfall after application), and four untreated controls (0, 5, 10, or 15 ton ha^{-1} straw on the soil) were studied.

Each experimental unit consisted of 8 dm^{-3} plastic pots filled with substrate. The substrate was a mixture of soil, sand, and organic compost at a ratio of 3:1:1, respectively. The textural analysis of the substrate indicated 679, 261 and 61 g kg^{-1} of sand, silt and clay, respectively, as well as 28 g dm^{-3} of organic matter.

After mechanical harvest of sugarcane plants (var. RB 867515 third cut for the first experiment; var. RB 855453 sixth cut for the second experiment; and var. RB 835054 first cut for the third experiment), the straw remaining on the soil was collected and taken to the greenhouse, where it was dried completely.

In all experiments, 2.0 g of *R. exaltata* seeds was sown per pot. In the first experiment, a portion of the substrate in the pots was removed to plant the seeds at the depths indicated for each treatment (a ruler was used to measure the depths). In the second and third experiments, seeds were homogeneously distributed in each pot and sown at a 1 cm depth from the soil surface. For treatments with straw, a uniform layer of sugarcane straw in the respective quantity for each treatment was placed on soil surface of each pot after sowing. Straw was cut into smaller fragments less than or equal to the pot diameter.

The bottoms of the pots were sealed with a sheet of newspaper to prevent soil loss. Each pot was placed on a plastic container with a larger diameter and without holes to maintain the water regime. Soil moisture was monitored daily, and water in the containers was replaced as necessary.

In the second and third experiments, the herbicides were sprayed on pots prior to weed emergence. A backpack sprayer equipped with two flat-fan nozzles (XR 110015) spaced at 0.5 m and calibrated to deliver an equivalent of 200 L ha^{-1} at a constant pressure (maintained by CO_2) of 2.0 kgf cm^{-2} was used. The dates, times, and meteorological conditions for each application are shown in Table 1.

In the first and second experiments, rainfall depth equivalent to 25 mm was simulated after sowing or herbicide application. In the third experiment, rainfall equivalent to 20 mm depth was simulated in all treatments (after flumioxazin spraying), including untreated controls. For the 40 and 60 mm rainfall treatments, a new 20 mm simulation was conducted two days after the initial 20 mm rainfall, and the simulation was repeated once more two days after the 60 mm rainfall treatments. Thus, rainfall was cumulative for the 40 and 60 mm rainfall treatments (with additional 20 mm every two days).

The total number of emerged plants was counted at 14 and 35 days after herbicide application (DAA) for the second and third experiments or days after weed sowing (DAS) for the first experiment. At 35 DAA or DAS, the plants were harvested close to the soil, placed inside paper bags and dried in a convection oven at 50ºC until a constant weight was achieved, and the shoot dry matter was then quantified.

The data were subjected to an F-test. In the first experiment, effects of straw amount and sowing depth or the interaction between them when significant were compared by polynomial fitting of the data. In the second experiment, significant effects of the herbicide treatments and mulch on the soil or the interaction between them were compared by Tukey's test at 5% probability (for herbicide treatments) or by polynomial fitting of the data (mulch on the soil). In the third experiment, significant effects of straw amount and rainfall or the interaction between them were compared by polynomial fitting of the data.

Results and discussion

Emergence of *Rottboellia exaltata* influenced by sowing depth and presence of sugarcane straw on the soil (first experiment)

Each factor (sowing depth and straw amount) and the interaction between them had a significant effect on *R. exaltata* weed density and dry matter.

When analyzing the depth x straw interaction, we observed that for all sowing depths studied, weed density linearly decreased with increasing amount of straw on the soil, except for superficial sowing at 14 DAA (Figure 1). Thus, emergence of *R. exaltata* was reduced with increasing amounts of sugarcane straw regardless of sowing depth. This effect was even more pronounced with increasing depths of seeds planted in the pots.

At depths of 2.5 and 10 cm, weed dry matter linearly decreased with increasing amounts of straw. The same trend occurred when the seeds were distributed on the soil surface (with polynomial fitting of the data). Thus, the least accumulated mass of *R. exaltata* weeds occurred with 15 ton ha^{-1} straw on the soil for the five depths studied. These data corroborated with report by Oliveira and Freitas (2009). Adding rice plant residues (4 and 6 ton ha^{-1}) to the soil surface also reduced the emergence of *R. cochinchinensis* (BOLFREY-ARKU et al., 2011).

Weed emergence was unaffected by sowing depth in bare soil (Figure 2). Moreover, weed density was unaffected by sowing depth in treatments with 5 ton ha^{-1} of straw. For dry matter, values decreased with increasing sowing depth. At 10 and 15 ton ha^{-1} straw, *R. exaltata* density and dry matter decreased linearly with increasing sowing depths.

A previous study has shown that the emergence of *R. cochinchinensis* is higher when the seeds are sown at the soil surface and that the emergence decreases with increasing sowing depths with no weeds emerging from seeds planted at a depth of 10 cm (BOLFREY-ARKU et al., 2011). The soil management conditions (conventional tillage, minimum tillage, and no tillage) for rice crops do not affect the emergence of this species (CHAUHAN; JOHNSON, 2009). Neither soil disturbances, which cause seed distribution throughout the soil profile, nor a complete absence of movement, which causes an accumulation of seeds at the soil surface, affect weed emergence dynamics or the level of infestation.

These results are at least partially explained by the ability of these seeds to germinate both in the light and in the dark (THOMAS; ALLISON, 1975). Although light is not a requirement for seed germination, a light/dark regime stimulates germination of *R. cochinchinensis* (BOLFREY-ARKU et al., 2011).

Therefore, there was less emergence and accumulation of dry mass with mulch on the soil, especially under higher amounts of straw, combined with deeper sowing depths. In bare soil, however, the sowing depth did not affect weed dynamics.

Table 1. Dates, times, and meteorological conditions for each herbicide application in the second and third experiments.

Experiments	Date	Time	Temperature (°C)		Air Relative humidity (%)	Wind speed (km h^{-1})	Cloudiness (%)
			Air	Soil			
Second	09/16/10	4:20 pm	35.7-34.5	35.7-40.4	22-24	zero	zero
Third	04/02/11	1:00 pm	29.4	29.1	66	3.5-4.0	90

Consequently, under bare conditions, there can be seedling emergence from seeds positioned up to a depth of 10 cm in the soil profile. This effect may interfere with the efficacy of herbicides applied during pre-emergence because herbicides should be distributed throughout the soil profile at depths up to 10 cm or be absorbed by seedling shoots. In addition, despite reduced seedling emergence observed with increasing straw amounts, this reduction was not enough to provide adequate control of *R. exaltata*, especially when the seeds were closer to the soil surface.

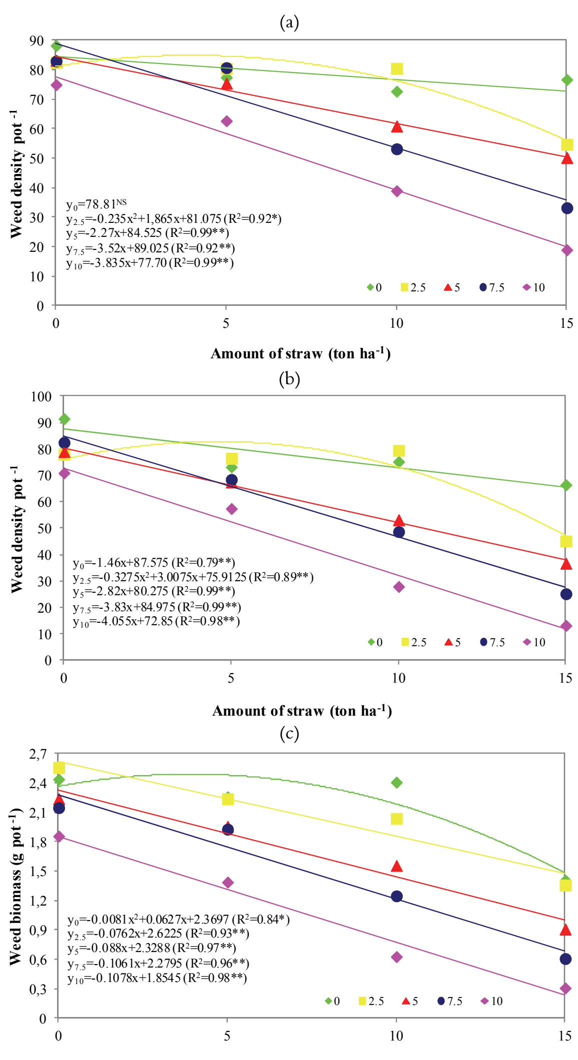

Figure 1. *Rottboellia exaltata* density at 14 (a) and 35 (b) days after sowing (DAS) and shoot dry matter at 35 DAS (c) as function of increasing amounts of sugarcane straw on the soil surface combined with increasing sowing depths.

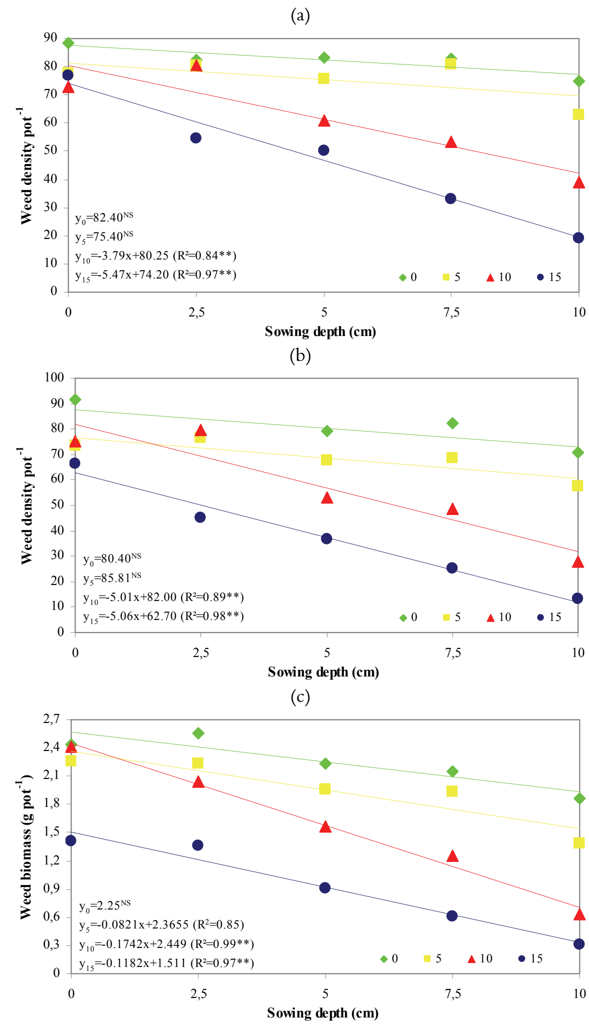

Figure 2. *Rottboellia exaltata* density at 14 (a) and 35 (b) days after sowing (DAS) shoot dry matter at 35 DAS (c) as function of increasing sowing depths combined with increasing amount of sugarcane straw on the soil surface.

Emergence of *Rottboellia exaltata* influenced by herbicide application during pre-emergence and the presence of sugarcane straw on the soil (second experiment)

The herbicide treatments and straw x herbicide interaction were significant for all variables evaluated. The amount of straw only significantly affected *R. exaltata* dry matter.

When analyzing the straw x herbicide interaction, we observed that in bare soil at 14 DAA, there was lower weed density when applying clomazone and flumioxazin compared to other herbicides (Table 2). At 5, 10, and 15 ton ha^{-1} of straw, clomazone was more effective than isoxaflutole combined with 10 ton ha^{-1} of straw. At 35 DAA, clomazone provided decreases in weed density regardless of the presence of mulch on soil surface (Table 3). Combined with 10 ton ha^{-1} of straw, flumioxazin, imazapyr, and isoxaflutole were also effective. Use of clomazone and imazapyr caused less shoot dry matter accumulation for all five straw amounts studied compared to other herbicides (Table 4). Flumioxazin and isoxaflutole were also effective in bare soil.

Although imazapyr did not reduce weed emergence, this herbicide inhibited weed growth and development as reflected in shoot dry matter (Table 4).

Table 2. *Rottboellia exaltata* density (plants pot^{-1}) at 14 days after herbicide application (DAA) pre-emergence with different amounts of sugarcane straw on the soil.

Herbicides/	Doses	Straw (ton ha^{-1})			
Control	(kg ha^{-1})	0	5	10	15
Clomazone	1.20	9.25 a[1]	20.75 a	25.75 a	24.50 a
Flumioxazin	0.25	8.00 a	53.25 b	48.25 ab	57.50 bc
Imazapyr	0.20	69.25 bc	55.00 b	65.25 bc	80.25 c
Isoxaflutole	0.225	58.00 b	50.00 ab	31.25 a	44.25 ab
S-metolachlor	2.88	62.50 bc	71.25 b	84.25 c	53.25 abc
Control	-	90.00 c	79.00 b	85.00 c	77.00 c
LSD (in the column)		31.42			

[1]Averages followed by lowercase letters in the columns indicate significant differences between the herbicide treatments within each amount of straw based on Tukey's test at 5% probability.

Table 3. *Rottboellia exaltata* density (plants pot^{-1}) at 35 days after herbicide application (DAA) pre-emergence with different amounts of sugarcane straw on the soil.

Herbicides/	Doses	Straw (ton ha^{-1})			
Control	(kg ha^{-1})	0	5	10	15
Clomazone	0.25	0.25 a[1]	7.25 a	23.50 a	17.00 a
Flumioxazin	0.225	4.50 ab	61.25 bc	41.50 a	43.50 ab
Imazapyr	1.20	50.00 c	40.25 ab	38.75 a	47.00 ab
Isoxaflutole	0.20	38.00 bc	41.75 b	26.75 a	30.25 ab
S-metolachlor	2.88	58.75 cd	85.75 c	88.75 b	62.25 bc
Control	-	89.00 d	71.75 bc	87.25 b	84.00 c
LSD (in the column)		34.02			

[1]Means followed by lowercase letters in the columns indicate significant differences between the herbicide treatments within each amount of straw based on Tukey's test at 5% probability.

Table 4. *Rottboellia exaltata* shoot dry matter (g pot^{-1}) at 35 days after herbicide application (DAA) pre-emergence with different amounts of sugarcane straw on the soil.

Herbicides/	Doses	Straw (ton ha^{-1})			
Control	(kg ha^{-1})	0	5	10	15
Clomazone	0.25	0.03 a[1]	1.68 a	2.66 a	1.68 a
Flumioxazin	0.225	0.81 a	9.19 bc	7.96 bc	8.07 bc
Imazapyr	1.20	1.03 a	0.38 a	0.68 a	0.71 a
Isoxaflutole	0.20	4.71 a	5.51 ab	4.03 ab	3.48 ab
S-metolachlor	2.88	10.39 b	14.03 cd	13.16 cd	12.03 cd
Control	-	16.26 c	15.34 d	16.48 d	16.13 d
LSD (in the column)		5.20			

[1]Averages followed by lowercase letters in the columns indicate significant differences between the herbicide treatments within each amount of straw based on Tukey's test at 5% probability.

For the control treatment and the clomazone, isoxaflutole and imazapyr herbicides, weed density and dry matter did not vary with increasing amounts of straw on the soil surface (Figure 3). These results indicated that weeds did not germinate and/or emergence was inhibited by the presence of sugarcane straw and that herbicides were not affected by mulch on the soil. The 25 mm rainfall simulation after herbicide application was enough to leach herbicides from the straw to the soil, as the biological control of *R. exaltata* remained unaffected.

For flumioxazin and s-metolachlor, however, weed density varied with increasing amounts of straw (with polynomial fitting of the data), which resulted in less emergence in bare soil. The same behavior occurred for shoot dry matter when flumioxazin was applied. In contrast, there was no difference between the straw amounts when using s-metolachlor.

Among the factors that influence herbicide retention by the straw, the chemical and physical attributes of the molecules, especially their solubility and polarity, are essential for leaching herbicide to the soil via rainfall or irrigation. The solubility of the herbicides has been previously reported as follows: clomazone and imazapyr exhibit very high water solubility (1,100 and 11,272 mg L^{-1}, respectively); s-metolachlor and isoxaflutole (active metabolite DKN) exhibit high water solubility (480 and 326 mg L^{-1}, respectively); and flumioxazin exhibits low water solubility (1.79 mg L^{-1}) (RODRIGUES; ALMEIDA, 2011). The herbicide remaining on the straw (i.e., portion that was not leached to the soil) may be absorbed by surviving seedlings when they were growing up through the straw layer. However, this is possible only for herbicides that are absorbed by the mesocotyl and coleoptile of seedlings before they emerge above soil surface.

Although flumioxazin resulted in satisfactory control of *R. exaltata* under bare soil conditions, the level of weed control was compromised by mulch on the soil. The simulated 25 mm of rainfall after spraying was not enough to leach herbicide from the straw to the soil. This finding motivated us to conduct the third experiment to test the ability of flumioxazin to control *R. exaltata* with increasing rainfall intensities after application and with different straw amounts on the soil surface.

Control of *Rottboellia exaltata* by flumioxazin combined with rainfall intensity after application and presence of sugarcane straw on the soil (third experiment)

The amounts of straw and rainfall intensities significantly affected all of the variables evaluated. The straw x rainfall interaction was significant for weed density and shoot dry matter at 35 DAA.

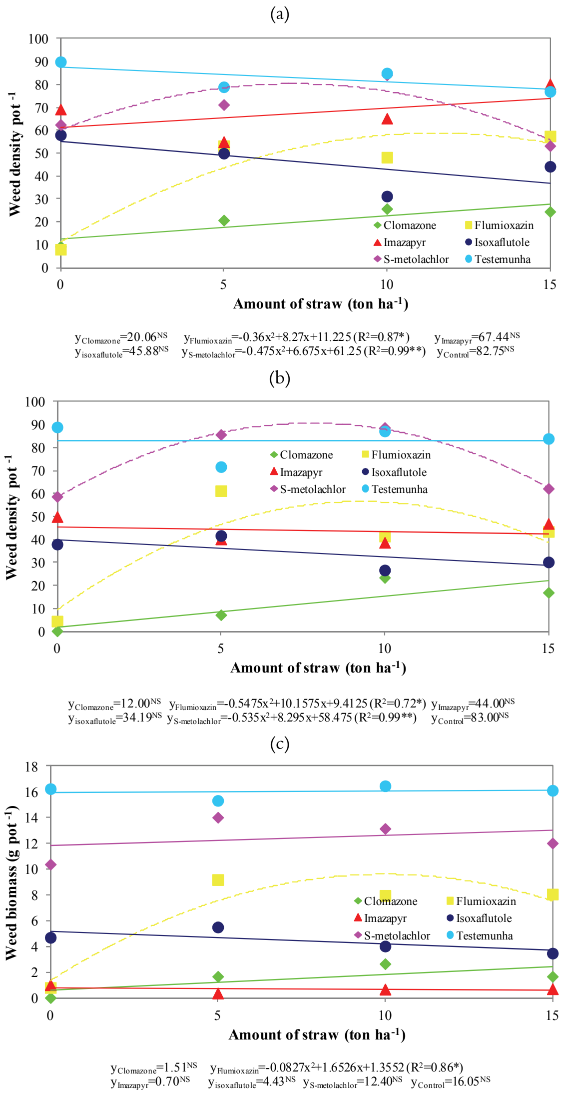

Figure 3. *Rottboellia exaltata* density at 14 (a) and 35 (b) days after herbicide application (DAA) pre-emergence and shoot dry matter at 35 DAA (c) as function of increasing amounts of straw on the soil.

At 14 DAA, weed density increased with increasing amounts of straw on the soil surface with flumioxazin herbicide spraying (Figure 4). In contrast, weed emergence linearly decreased with increasing simulated rainfall intensities after application. This trend was observed for the five straw amounts studied where the straw x rainfall interaction was not significant.

At 35 DAA, weed density and dry matter varied with increasing amounts of straw for the three rainfall intensities (with polynomial fitting of the data) with less emergence and mass accumulation in bare soil (Figure 5).

In untreated controls with straw, higher weed density and amount of dry matter were obtained compared to the flumioxazin treatments regardless of the straw x rainfall combinations studied. However, these data were not statistically analyzed and were only presented as graphs to visualize the potential weed infestation in that particular experimental period. The same set of treatments had already been studied in the first and second experiments but during different seasons and with straw from different origins. Thus, straw from different varieties may have influenced the weed dynamics by variations in allelopathic effects of the plant residues.

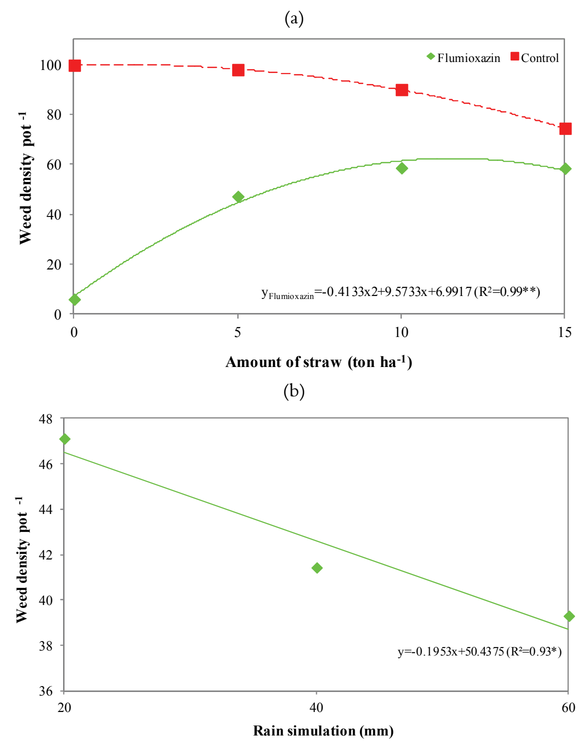

Figure 4. *Rottboellia exaltata* density at 14 days after flumioxazin herbicide application (DAA) with increasing amounts of sugarcane straw on the soil (a) and with increasing rainfall simulation intensities after application (b) in addition to untreated controls with four amounts of straw.

In bare soil, there was no difference between rainfall intensities for the variables evaluated (Figure 6). However, keeping 5, 10, and 15 ton ha^{-1} of straw on the soil linearly decreased weed dry matter with increasing rainfall simulation intensities after applying flumioxazin, thus resulting in less dry matter accumulation with 60 mm of water.

Increasing rainfall intensity caused increased leaching of herbicide retained in the straw into the soil, which favored weed control by flumioxazin under such conditions. Even with 60 mm of accumulated rainfall over the 4-days period after application, the amount of flumioxazin leached to the soil was not enough to ensure the same control observed in flumioxazin treatment on bare soil.

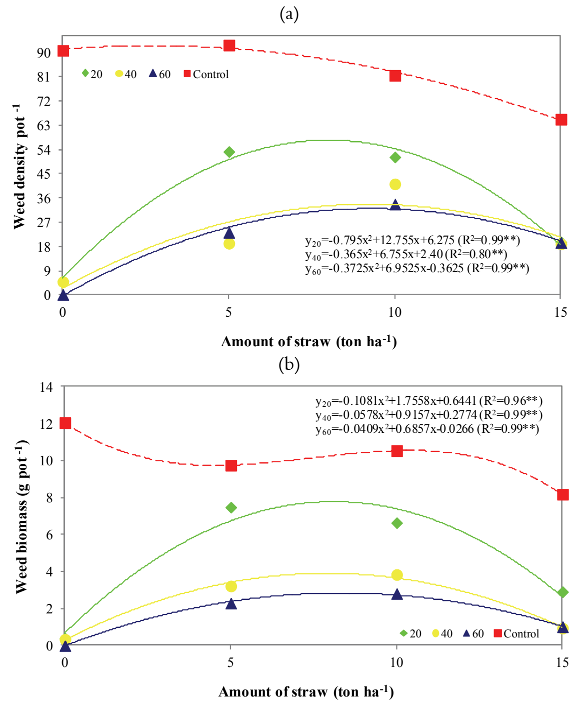

Figure 5. *Rottboellia exaltata* density (a) and shoot dry matter (b) at 35 days after flumioxazin herbicide application (DAA) as function of increasing amounts of sugarcane straw left on the soil combined with increasing rainfall simulation intensities after application in addition to untreated controls with four amounts of straw.

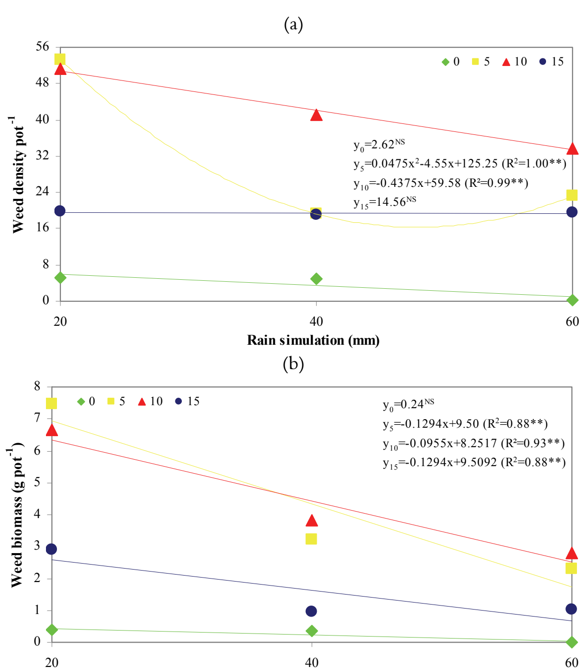

Figure 6. *Rottboellia exaltata* density (a) and shoot dry matter (b) at 35 days after flumioxazin herbicide application (DAA) as function of increasing rainfall simulation intensities combined with increasing amounts of straw left on the soil.

The chemical attributes of the flumioxazin (low solubility) would not contribute to its leaching to the soil in higher concentrations even when increasing the simulated rainfall intensity. However, no studies have been reported on the dynamics of flumioxazin in plant residues.

Conclusion

The combination of mulch on soil surface with deeper sowing depths provides less emergence and mass accumulation of *R. exaltata*. In bare soil, the sowing depth did not affect the weed dynamics.

Clomazone and imazapyr were effective herbicides controlling *R. exaltata* regardless of the amount of straw on the soil. Flumioxazin was also effective in controlling *R. exaltata* under bare soil conditions. Even with 60 mm of accumulated rainfall over the 4 day period after application, the amount of flumioxazin leached to the soil was not enough to ensure the same control observed when applying the herbicide on bare soil.

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