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Weed germination and growth in soil covered with maize straw

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Abstract: **Background**: The presence of straw on the soil contributes to the management of weeds in several production systems and this understanding needs to be extended to annual crops under no-tillage systems.

Objective: This study aimed to evaluate the effect of covering the soil with 5 Mg ha^{-1} of maize straw on the germination and growth of *Digitaria insularis*, *Conyza* spp., *Bidens pilosa*, *Amaranthus hybridus*, *Euphorbia heterophylla*, and *Eleusine indica*.

Methods: For this purpose, completely randomized design was used with sixteen and third two replicates. Four assays were conducted between the years 2019 and 2020 in a greenhouse. The number of emerged seedlings was evaluated at 7, 14, and 21 days after sowing (DAS) and the shoot dry weight of the seedlings and the correlation between these variables were evaluated at 21 DAS.

Results: The covering of the soil with straw decreased the weed infestation of all species, except *E. heterophylla*, which presented positive correlation for the variables evaluated, denoting that the straw had no effect on the germination and growth of this species. The variables evaluated showed no correlation for the other species, denoting that the soil cover with straw suppress the germination and growth of plants.

Conclusions: We conclude that soil cover with 5 Mg ha^{-1} of maize straw is a tool for the control of weeds of the species evaluated, except *E. heterophylla*, and an option for integrated weed managements that can complement the residual effect of herbicides.

Keywords: *Amaranthus hybridus; Bidens pilosa; Conyza* spp.*; Digitaria insularis; Eleusine indica; Euphorbia heterophylla.*

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1. Introduction

Soybean (*Glycine max* (L.) Merrill) and maize (*Zea mays* L.) are the most important crops in the world. Brazil is the highest soybean, and third highest maize producing country, with a production of 124 million, and 101 million Mg, respectively, in the 2019/2020 crop season (Companhia Nacional de Abastecimento, 2019). Reaching these production levels requires managements of soil fertility and plant health protection, mainly from weeds. Weeds can decrease the yield of these crops in more than 80% when not properly controlled (Karam et al., 2006; Silva et al., 2008).

No-tillage system is widely adopted for different crops; thus, mechanical control of weeds is an unviable alternative, since the soil is not turned before nor after sowing in this system, making herbicides the main weed control method. However, the straw left by grass crops is a barrier for the transport of pre-emergent herbicides to the soil surface, which is also affected by rainfall, irrigation, and the herbicide solubility and formulation (Maciel, Velini, 2005).

This physical barrier generated by the straw changes the weed population dynamics by decreasing the light reaching the soil and the soil thermal amplitude, the release of compounds with allelopathic effect, and by serving as a shelter to animals and microorganisms that can decompose weed seeds (Rice, 1984; Correia, Durigan, 2004). However, this effect is specific and depends on the type, quantity, distribution uniformity, permanence time, and decomposition level of the straw in the soil, and the sensitivity of weed species (Araldi, 2014). In addition, weed germination, emergence, and growth standards are complex and often different between weed and between crop species (Ghersa et al., 1994).

Several studies show the effect of using soil cover with grass straw, winter crops, and sugarcane crops on the suppression of weeds (Theisen, Vidal, 1999; Correia, Durigan, 2004; Jabran et al., 2015). However, these information are not frequently found for areas under no-tillage system with succession of crops, mainly soybean, with maize as a second crop. Approximately 33 million hectares in Brazil are managed under no-tillage system (Instituto Brasileiro de Geografia e Estatística, 2017); therefore, understanding the effect of maize straw as a soil cover on weeds in this system is important. In this context, the objective of this work was to evaluate the effect of covering the soil with 5 Mg ha^{-1} of maize straw on the germination and growth of

Digitaria insularis, *Conyza* spp., *Bidens pilosa*, *Amaranthus hybridus*, *Euphorbia heterophylla*, and *Eleusine indica* plants.

2. Material and methods

Four greenhouse experiments were conducted in 2019 and 2020. The quantity of seeds of each species was defined by their weights — 0.200 g for *D. insularis*; 0.400 g for *Conyza* spp.; 0.350 g for *B. pilosa*; 0.050 g for *A. hybridus*; 0.400 g for *E. heterophylla*; and 0.070 g for *E. indica*. The seeds of all species were mixed in paper bags and sowed in 27×41 cm plastic trays with capacity for 7.5 L.

The soil used was fertilized and stored in plastic bags for forty days until the sowing day. The soil physical-chemical characteristics were: 281, 87, and 632 g dm^{-3} of clay, silt, and sand, respectively; pH (CaCl2) of 5.3; 11 g dm^{-3} of organic matter; 18 mg dm^{-3} of P (resin); 2 mmolc dm^{-3} of Al^{3+}; 40 mmolc dm^{-3} of H+Al; 0.8 mmolc dm^{-3} of K^{+}; 21 mmolc dm^{-3} of Ca^{2+}; 9 mmolc dm^{-3} of Mg^{2+}; 31 mmolc dm^{-3} of sum of bases; 70 mmolc dm^{-3} of cation exchange capacity; 56 mg dm^{-3} of S, and base saturation of 42.

The straw used was collected form hybrid maize crops (Pioneer® P3707 VYH, Forseed® FS 587 PWU, and Dekalb® DKB 345 PRO3) without history of herbicide application. Leaves were collected from plants at the senescence stage; they were cut in pieces of approximately 5×3 cm and homogenized forming-se a mixture of the hybrids.

The treatments consisted of soil cover with and without 5 Mg ha^{-1} of maize straw. A 24×38 cm metallic frame was placed center of trays filled with 3.5 L of dry sieved soil where the mixed seeds were uniformly distributed. They were then covered with 1.5 L of soil and the frame was removed, keeping the seeds at approximately 1 cm depth in the evaluation area within the frame. The frame was used to prevent that the physical effect of the straw was cancelled by the growth of the weed species over the edges of trays. The same procedure was used for the treatments containing straw; the straw was placed uniformly on the soil after the removal of frame.

After the sowing, all plots were subjected to a 10-mm rainfall simulation using a stationary sprayer consisted of a metallic structure that runs through an area of 6.0 m^2, pulled by an electric motor with a frequency modulator that controls the work speed. A spray boom was coupled to the system and positioned longitudinally to the experimental units, contained ten nozzles (DG 9505 EVS; Teejet®) spaced 6.5 cm apart at 0.5 m height from the target. The system was set to a work pressure of 2.0 kgf cm^{-2} generating an accumulated water depth of 2.5 mm per run. The plots were irrigated with 10 mm of water during the experiment, according to the need of the plants and the temperature was constantly monitored.

The effect of covering the soil with maize straw on the weed germination and growth was assessed considering the number of emerged seedlings at 7, 14, and 21 days after the sowing (DAS) and the shoot dry weight was evaluated at 21 DAS. The weeds were cut and dried in a forced air circulation oven at 60 °C until constant weight and weighed in a 0.0001 g precision balance.

2.1 Statistical analysis

A completely randomized design with 8 and 4 replications was used for the treatments with and without soil cover with maize straw, respectively. The number of emerged seedlings was evaluated in a 2×5 factorial arrangement, represented by the factors: straw (with and without) and evaluation time (days after sowing). The homogeneity of the data was met by the evaluation of residual mean squares and the experiments were grouped, totaling 32 and 16 replications for the treatments with and without soil cover with maize straw, respectively.

The results of the number of emerged seedlings and shoot dry weight of each weed species were subjected to analysis of variance by the F test and compared by the Tukey test (p£0.05). The results were converted into percentages relative to the treatment without maize straw (control).

The correlation between weed germination and growth was determined by applying the Pearson linear correlation to the number of emerged seedlings and shoot dry weight.

The statistical analyses were done using the SAS 9.1.3 program (Statistical Analysis System; SAS Institute, Carry, USA).

3. Results and discussion

The mean temperature inside the greenhouse during the experiments showed little oscillation (Figure 1); the hydrological conditions were similar to all experimental units (10 mm rainfall simulation + 10 mm water depth irrigations, according to need of the plants). The soil used was fertilized, the soil acidity was corrected individually for each experimental unit, and the seeds of all weed species were sowed to the same depth (1 cm).

Monitoring these experimental variables is essential to minimize external factors that can affect the results, since the weed biology is affected by environmental and edaphic factors (Brighenti, Oliveira, 2011). Therefore, climate and edaphic variabilities were eliminated to ensure that changes in weed germination and growth were related only to the soil cover with or without maize straw.

The analysis of variance of the number of emerged plants of each weed species at 7, 14, and 21 DAS showed significant differences between the treatments with and without soil cover with 5 Mg ha^{-1} of maize straw, except for the species *Euphorbia heterophylla* (Table 1). Regarding the evaluation times, the number of emerged plants was significantly different for all species. The interaction between the factors was not significant for the number of emerged plants of *E. heterophylla* and *Eleusine indica* (Table 1).

A1 = Assay 1; A2 = Assay 2; A3 = Assay 3; A4 = Assay 4

Figure 1 - Temperature inside the greenhouse during the experiment(s)

Table 1 - Analysis of variance for number of emerged plants of each weed species at 7, 14, and 21 days after sowing.

Species	F treatment	F time	F TxT	CV (%)
Digitaria insularis	979.35**	146.51**	103.69**	33.89
Conyza spp.	1353.30**	114.01**	114.01**	37.66
Bidens pilosa	331.31**	263.46**	63.71**	35.15
Amaranthus hybridus	1084.53**	20.32**	8.13**	26.33
Euphorbia heterophylla	0.03^{ns}	66.23**	0.01^{ns}	26.78
Eleusine indica	721.81**	5.37**	0.66^{ns}	35.83

** = significant p £0.01 %, and ^{ns} = not significant by the F test; CV = coefficient of variation.

The use of soil cover plant residues affects the dynamics of weed species by the release of allelochemical compounds of some species, by filtering of quantity and quality of light wavelengths that reach the soil surface, and by maintaining and minimizing oscillations in soil temperature (Pitelli, 1998; Theisen, Vidal, 1999). In addition, it reduces the survival of weeds with small quantity of reserves in the seeds, since these reserves are often not enough to ensure that the seedlings will grow throughout the plant cover and have access to light to start the photosynthetic process (Pitelli, 1998).

The emergence flow of *Digitaria insularis* plants in the soil without cover with maize straw was continuous until the end of the evaluations at 21 DAS, when 100% of the plants had emerged (Figure 2 A). However, in the treatment with soil cover with 5 Mg ha^{-1} of maize straw, it had the highest emergence flow at 7 DAS, representing a relative decrease of 88% in the number of plants (Figure 2 A). The maize straw probably decreased the soil temperature and hindered the passage of light, decreasing the infestation, since seeds of this species are photoblastic positive and the optimal temperature for the germination of their seeds is between 25 and 35 °C (Mendonça et al., 2014).

These results denote the high sensitivity of the species to the soil cover with maize straw. Petter et al. (2015) found similar results for treatments with rates higher than 4 Mg ha^{-1} of wheat straw, with significant relative decreases in emergence of *D. insularis* plants. These results are important because perennial plants of this weed species have high infestation and regrowth capacity, making them very competitive with crop species. Decreases in soybean yield above 40% is commonly found, even with only 4 plants of *D. insularis* per square meter (Adegas et al., 2017). Therefore, control the seed bank and young plants is essential for this species, due to its biology and multiple resistance to herbicides, including glyphosate and ACCase inhibitors of the FOP group (Heap, 2021). Therefore, soil covering with 5 Mg ha^{-1} of maize straw is a management tool to suppress the emergence of this weed species.

Conyza spp. plants emerged up to 21 DAS in the soils without cover with maize straw, and no emergence of plants of this species was found in the soil covered with 5 Mg ha^{-1} of maize straw (Figure 2 B). Plant species of this genus affect annual crops, mainly under no-tillage system, due to their high seed production capacity (Wu et al., 2007). These seeds are light, easily dispersible by wind to large distances, present no dormancy, and can readily germinate after dispersion, mainly when they are on the soil surface. This is because *Conyza* spp. plants are photoblastic positive and their seeds have little quantity of reserves (Constantin et al., 2013).

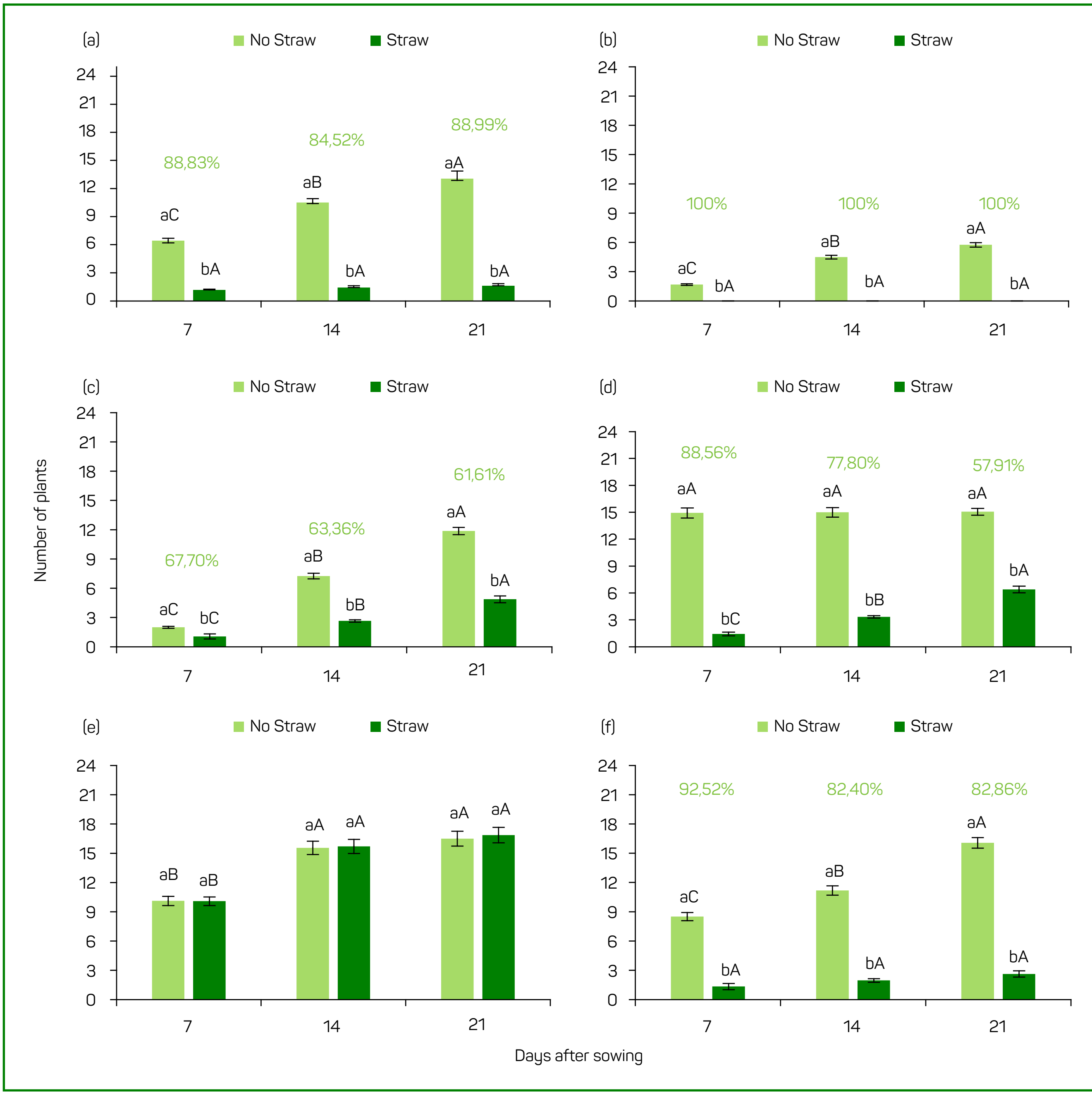
Soil cover with plant residues affect weed germination because it generates a physical barrier and decrease the intensity of light on the soil. However, a proper quantity of residues and a good distribution on the soil surface is required, since small uncovered points will enable seed germination. According to Constantin et al. (2013) 6 Mg ha^{-1} of straw decreased the number of emerged *Conyza* spp. plants, but was not enough to fully inhibit their emergence because of flaws in the straw distribution on the soil surface. The 5 Mg ha^{-1} of maize straw used in the present work was fully distributed on the soil, inhibiting 100% of the emergence of *Conyza* spp. plants, confirming the importance of a uniform distribution (Figure 2 B). The use of soil cover plants is important for the control of *Conyza* spp. due to the many reports of multiple resistance to several herbicides in Brazil (Heap, 2021).

The results found for *Bidens pilosa* plants was different than those for the other species evaluated; their emerged continuously up to 21 DAS in the soil with and without cover with maize straw (Figure 2 C). However, the soil cover with straw had lower emergence, with a relative decrease of 61% in the number of emerged plants at 21 DAS (Figure 2 C). Similar results were found by Santos et al. (2020) for *B. pilosa* seeds planted at 2 cm depth in soils covered with 6 Mg ha^{-1} of maize straw, with a relative decrease of 80% in germination.

The emergence *B. pilosa* plants regardless of the soil cover indicate that this species is not dependent on light to start the germination process, confirming the data reported by Klein and Felippe (1999). The effect of soil cover with maize straw on the suppression of this weed was probably related to the decrease in soil temperature, since the optimal germination temperature for *B. pilosa* seeds is between 30 and 35 °C during the day (Voll et al., 2005) and the use of soil cover can contribute significantly to decrease soil temperature. Ribas et al. (2015) evaluated the effect of covering the soil with Sudan grass straw on the soil temperature and found that the use of 5 Mg ha^{-1} decreased it in approximately 8 °C in the first 5 cm of soil at 14 DAS.

B. pilosa plants are present in several producing regions of Brazil and have a high infestation potential, because its seeds are disseminated by wind and have barbed structures at the end of the achenes that adhere to clothes, animals, and agricultural implements (Weber, 2017). These plants produce of 3 to 6 thousand seeds that rapidly germinate after reaching the soil, and present 3 to 4 seed dispersion cycles a year (Weber, 2017). In addition, this species has multiple resistance to the herbicides imazethapyr (ALS) and atrazine (FSII) in Brazil (Heap, 2021). Therefore, the soil cover with 5 Mg ha^{-1} of maize straw can be a complementary tool for the control of these plants with herbicides, with decreases of more than 60% in their infestation (Figure 2 C).

Amaranthus hybridus plants were totally emerged at 7 DAS in soils without cover with maize straw (Figure 2 D). This emergence was continuous up to 21 DAS in soils covered with maize straw (Figure 2 D). This was probably because the effect of light is an additive and not a limiting factor



Error bars represent the standard error of the mean n = 32 and 16, for the treatments with and without soil cover with maize straw, respectively. Bars with the same lowercase letter within the same evaluation time, and uppercase letter different within the evaluation times for without and with straw individually are not different by the Tukey test (p£0.05).

Figure 2 - Number of plants and relative percentage of decrease in emergence of *Digitaria insularis* (A), *Conyza* spp. (B), *Bidens pilosa* (C), *Amaranthus hybridus* (D), *Euphorbia heterophylla* (E), and *Eleusine indica* (F) plants at 7, 14, and 21 days after sowing grown is soils covered with and without 5 Mg ha^{-1} of maize straw

to the germination process in this species. Carvalho and Christoffoleti (2007) found that seeds of *Amaranthus* spp. can germinate in dark conditions. However, the soil cover with straw affected the emergence of these seeds due to their low size and quantity of reserves, with relative decreases of 88.56%, 77.80, and 57.91% at 7, 14, and 21 DAS, respectively (Figure 2 D).

Therefore, the use of soil cover with 5 Mg ha^{-1} of maize straw is a complementary tool for the integrated weed management of *A. hybridus*. This information is important because plants of this genus are frequently found in agricultural areas due to their seeds' high viability, production (reaching 500,000 in large plants), extensive germination period, and fast growth

(Kissmann, Groth, 1999; Horak, Loughin, 2000). In addition, *A. hybridus* present multiple resistance in Brazil, including two of the main mechanisms of action of herbicides used to control these weeds in soybean crops (Chlorimuron – ALS and Glyphosate – EPSPS) (Heap, 2021).

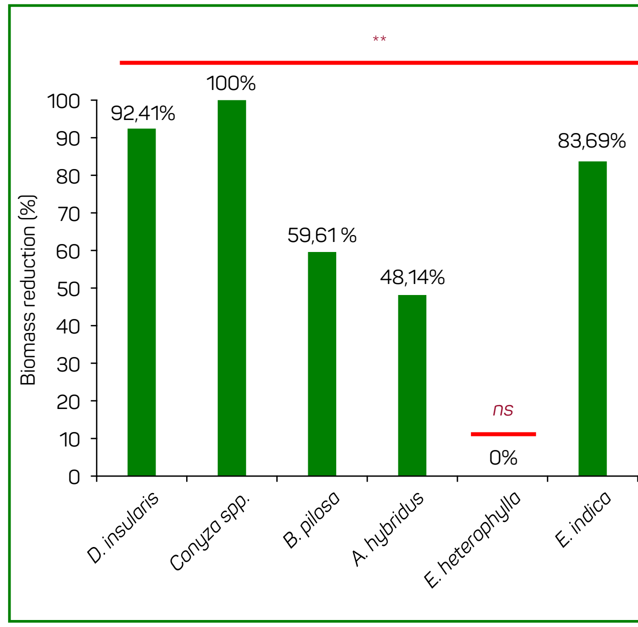
The soil cover with 5 Mg ha^{-1} of maize straw had no suppression effect on the emergence of *E. heterophylla* plants, regardless of the evaluation time (Figure 2 E). The emergence of plants was lower at 7 DAS when compared to the other evaluation times, even in the treatment with soil cover, denoting that the soil cover with maize straw had no suppression effect on the emergence of plants of this species (Figure 2 E). Marques et al. (2012) reported germination of *E. heterophylla* seeds under 16 Mg ha^{-1} of sugarcane straw, because light is not a limiting factor for their germination.

Monquero et al. (2007) reported suppression in germination of these seeds using soil cover with 20 Mg ha^{-1} of sugarcane straw; however, this condition is unlikely in no-tillage system with annual crops. In addition, this quantity of cover plant residues hiders the sowing of crops due to the difficult cutting of the dense phytomass by the discs of sowing machines, the emergence of crop species, and the application of residual herbicides to the soil. Therefore, soil cover with maize straw is not an adequate tool for the control of this species.

E. indica plants presented similar results to *D. insularis* plants, with continuous germination and the highest emergence of plants at 21 DAS in the treatment with uncovered soil (Figure 2 A, F). The use of soil cover with maize straw suppressed the germination in 82%, with the highest number of emerged plants at 7 DAS (Figure 2 F). These results are consistent with those of Chauhan and Johnson (2008), who found that the use of soil cover with 4 to 6 Mg ha^{-1} of straw is enough to reduce the germination of *E. indica* in more than 80%, and that the germination is significantly higher in light environments, denoting the effect of the soil cover.

E. indica is an important and widely disperse weed species in agricultural areas in Brazil. Plants of this species have C4 photosynthetic metabolism, which results in a high growth rate in tropical conditions, and produce high number of seeds (Chauhan, Johnson, 2008). In addition, these plants present multiple resistance, including two of the main herbicides used for their post-emergence control in soybean crops (glyphosate and ACCase inhibitors of the FOP group), and simple resistance to ACCase inhibitor herbicides of the DIM group (Heap, 2021). Therefore, the soil cover with 5 Mg ha^{-1} of maize straw can be used as a tool in integrated weed managements for this species.

Regarding the weed growth, the soil cover with straw significantly decreased the shoot dry weight of the plants evaluated, except those from the *E. heterophylla* species,



F *D. insularis* = 147.26**; F *Conyza* spp. = 574.94**; F *B. pilosa* = 97.06; F *A. hybridus* = 232.87**; F *E. heterophylla* = 0^{ns}; F *E. indica* = 171.12. CV (%) *D. insularis* = 56.62; CV (%) *Conyza* spp. = 33.36; CV (%) *B. pilosa* = 33.05; CV (%) *A. hybridus* = 16.62; CV (%) *E. heterophylla* = 33.95; CV (%) *E. indica* = 44.01. ** = significant p£0.01, and ^{ns} = not significant by the F test; CV = coefficient of variation.

Figure 3 - Relative decrease in shoot dry weight of *A. hybridus* weeds due to the use of soil cover with 5 Mg ha^{-1} of maize straw

with no effect of the soil cover on their development (Figure 3).

D. insularis, *Conyza* spp., *B. pilosa*, *A. hybridus*, and *E. indica* plants grown in soils covered with maize straw had relative decreases in shoot dry weight of 92.41%, 100%, 59.61%, 48, 14%, and 83, 69%, respectively, at 21 DAS (Figure 3). The interaction between number of emerged plants and shoot dry weight was high in the treatment with soil cover with maize straw for all species (Figure 4). These results indicate that most emerged plants could grow and develop, since the higher the number of plants, the higher the shoot dry weight of each species (Figure 4).

The correlation between number of emerged plants and shoot dry weight was not significant when using soil cover with maize straw, except for *E. heterophylla* plants, because the germination and growth was not affected by the treatment (Figure 4). Thus, the use of soil cover with straw decreased the number of plants at 21 DAS (Figure 2) and hindered the development of the plants (Figure 3 A), since most plants that emerged were debilitated due to the energy spent to break the physical barrier generated by the straw. According to Pitelli (1998), the soil cover with straw decreases the survival of weeds from seeds with small quantity of reserves, and these reserves are often not enough to ensure the seedling survival throughout the plant residues to access light and start the photosynthetic process.

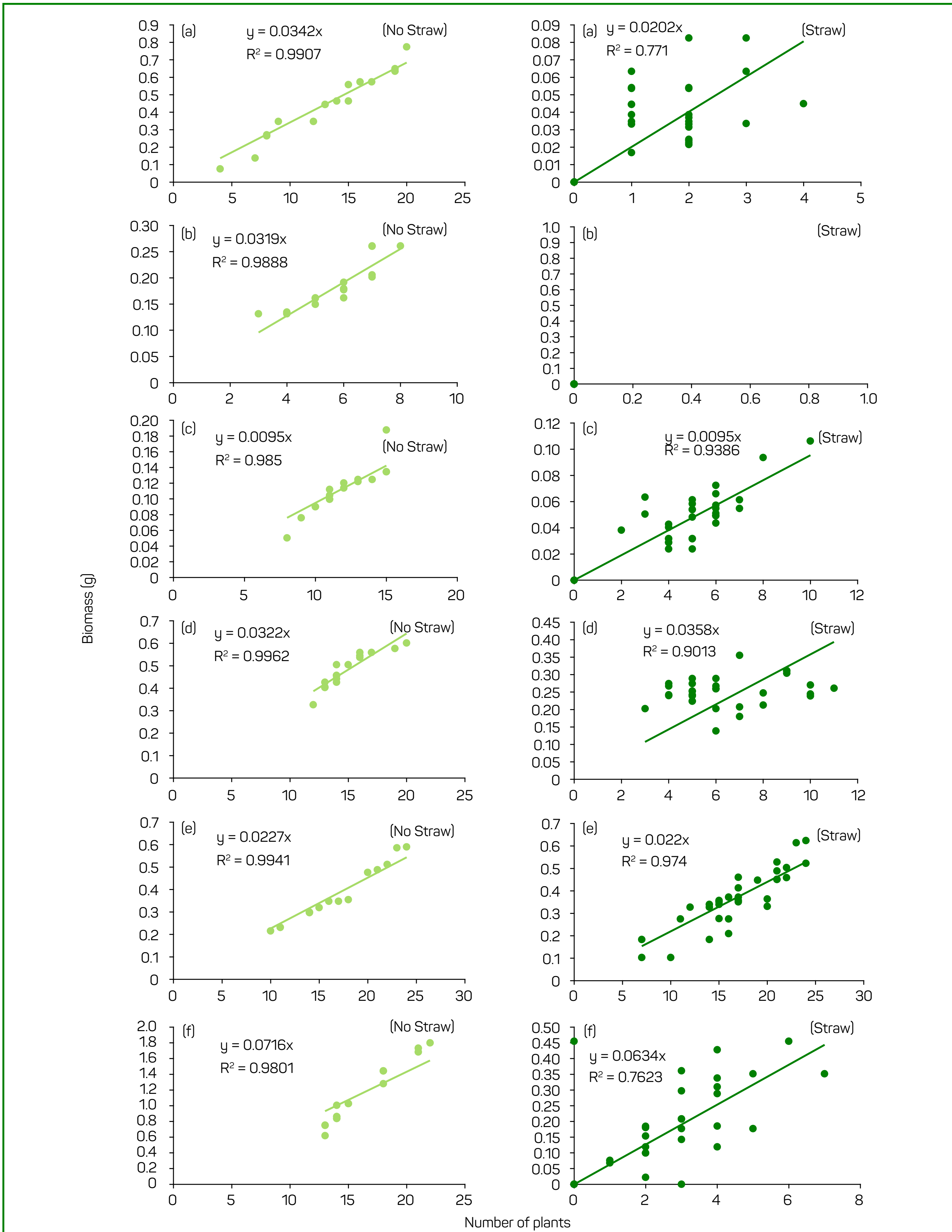


Figure 4 - Pearson's correlation between number of emerged plants and shoot dry weight of *Digitaria insularis* (A), *Conyza* spp. (B), *Bidens pilosa* (C), *Amaranthus hybridus* (D), *Euphorbia heterophylla* (E), and *Eleusine indica* (F) plants at 21 days after sowing as a function of soil cover with 5 Mg ha^{-1} of maize straw and without straw.

Therefore, the soil cover with straw have significantly contributed to decrease the weed infestation and, despite it allowed many plants to emerge, they were suppressed and presented hindered development and low biomass accumulation (Figure 4). Thus, weed density not always means a high or low infestation, and evaluating the plant biomass is required to accurately determine the effect of soil cover on the suppression of weeds. It can be decisive factor in decision making for post-emergence herbicide application, since the plant size is the main factor to define the correct application time.

Moreover, the emergence flow of each weed species is important to define the correct application time of herbicides, mainly post-emergence ones. Applications based on only the presence of weeds minimize the control effect of the herbicide, since other weed emergence flows will not be controlled by the product applied, and a new application may be needed, which increases the production costs. The use of pre-emergence herbicides is an alternative because of their residual effect to control these emergence flows over time. However, the soil cover with straw changes the dynamics and transport of part of the herbicide to the soil, which should be taken into consideration for the application planning of these products.

Monocotyledon species were, in general, more sensitive to the effect of soil cover with maize straw, except eudicotyledonous species of the genus Conyza (Figures 2 and 3). The results showed the important effect of soil cover with straw on the crop system, with decreases in infestation of weed species from 57.91% for *A. hybridus* to 100% for *Conyza* spp. (Figure 2). In addition, the suppression of weeds by the soil cover potentially reduces the use of herbicides and improves weed control by enabling applications on plants at low developmental stages and debilitated due to the energy spent to overcome the physical barrier generated by the straw. The soil cover with straw also potentially contributes to the management of resistance by decreasing the infestation of plants, and consequently their dispersion.

This effect is important because of the low number of available herbicide molecules that are effective on these plants. Moreover, all target species evaluated have resistance to some herbicide. *D. insularis* has multiple resistance to glyphosate (EPSPS), haloxyfop and fenoxaprop (ACCase), *Conyza* spp. present populations with multiple resistance to diuron (PSII), paraquat (PSI), glyphosate, 2.4-D (auxin), and saflufenacil (PPO), *B. pilosa* has multiple resistance to imazethapyr (ALS) and atrazine (PSII), *A. hybridus* has multiple resistance to glyphosate (EPSPS) and chlorimuron (ALS), *E. heterophylla* has multiple resistance to several protox and ALS inhibitor herbicides, and populations with resistance to glyphosate, and *E. indica* has multiple resistance to glyphosate, haloxyfop, and fenoxaprop and some populations resistant to ACCase inhibitors of the DIM group (sethoxydim) (Heap, 2021).

4. Conclusions

The use of soil cover with 5 Mg ha^{-1} of maize straw significantly decreases infestations of *Digitaria insularis*, *Conyza* spp., *Bidens pilosa*, *Amaranthus hybridus*, and *Eleusine indica* plants, contributing to integrated weed managements.

The correlations between the studied variables allows a more holistic view of the populational dynamics of weeds as a function of soil cover with maize straw in crop systems and may assist in decision making.

Authors' contributions

TG, CAC, and EDV: conceptualization, formal analysis, investigation, methodology, project administration, writing - review & editing. TG: writing - original draft. CAC and EDV: funding acquisition.

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