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Buttonweed emergence as affected by seed burial depth and straw on the soil surface

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ABSTRACT: Knowledge of the effects of seed burial depth and the presence of straw on the soil surface on weed seedling emergence provides useful information for the development of weed management tactics. Buttonweed (*Borreria densiflora* DC.) is a troublesome weed that occurs in large infestations in soybean and sugarcane crops from north-central Brazil. This study investigated buttonweed emergence at different seed burial depths and straw amounts present on the soil surface. The experiment was conducted in greenhouse conditions, under a factorial design between four seed burial depths and four amounts of surface straw. Percent seedling emergence and fresh biomass (g) were evaluated at twenty-five days after installation (DAI). Greater buttonweed emergence occurred in seeds that were placed on the soil surface either without surface straw or with up to 1,000 kg ha^{-1} of straw on the soil surface. With 4,000 kg ha^{-1} of surface straw, buttonweed emergence was prevented when seeds were placed at a depth of 0.5 cm or deeper in the soil. These data indicated emergence of this weed species was greater at depths near the soil surface and in soils with the least amounts of surface straw. Information generated in this study provides a starting point for the development of knowledge for understanding the biology of buttonweed emergence and its population dynamics. Such information may be directly transmitted to growers and lays the groundwork for an integrated management approach for this weed species.

Keywords: vassourinha-de-botão, weed seedbank, no-tillage, weed culture control

Introduction

Buttonweed (*Borreria densiflora* DC.), known in Brazil as vassourinha-de-botão, is a management issue in soybean and sugarcane areas from north-central Brazil. High buttonweed infestations have been reported in soybean areas under no-tillage and in cultivated sugarcane (Martins et al., 2009). This weed is considered a difficult-to-control species, which colonizes cultivated and fallow areas. Knowledge of features related to the maximum depth that enables weed emergence is fundamental to the appropriate adoption of management practices, such as applying mechanical methods, with or without chemical methods (Zimdahl, 2013).

The presence of weed seeds at variable depths in the soil profile influences not only seedling recruitment from the seedbank, but also the vigor of established seedlings (Cousens and Moss, 1990). This, in turn, has the potential to influence competitive interactions between crop and weed. Straw kept on the soil surface promotes changes in the microenvironment, including changes in temperature, light interception and water content in the soil, affecting several stages in the plant life cycle (Fernández-Quintanilla, 1988). Cultural management of weeds includes several techniques, such as tillage, crop rotation, planting date, row spacing and planting species that promote straw formation for suppressing weed seedling emergence (Ross and Lembi, 1999). Such cultural management methods are important because they can enhance crop competitiveness with weeds (Chauhan et al., 2006).

In this current period of water-scarcity, ecological weed management tactics, such as the dispersal of straw on the soil surface, represent alternatives not only for reducing weed seed banks but also for increasing water use efficiency of plants (Bergamaschi and Dalmago, 2014). In no-tillage systems, there is a greater concentration of weed seeds near the soil surface compared to areas under conventional tillage (Chauhan and Johnson, 2010).

Thus far, there is no information on the biology of buttonweed emergence because the importance of this weed species in cropping areas is relatively recent. Data on buttonweed emergence under variable seed depths and crop straw on the soil surface can help growers to optimize current control practices, potentially improving the management of this weed species.

Materials and Methods

Buttonweed mature glomerules were collected from an infested soybean production field from North Tocantins State (08°58′03″ S, 48°10′29″ N). Buttonweed glomerules are formed by fruits (Martins et al., 2009). At maturity, when the glomerules are dry, the seeds come out of the fruits easily. Buttonweed seeds, free from attachment to any plant material, were used in this study.

The experiment was conducted under greenhouse conditions, in a randomized block design and four replications. The experimental units were 3 L plastic pots, filled with clay soil (47 % of clay, 15 % of silt and 39 % of sand). The pots were marked at the standard surface using a white permanent pen and a ruler. This mark indicated a depth of 0 cm. For the greater depth treatments, a second white mark was made in the pots, according to each specific depth, below the 0 cm white mark. Soil was added in the pots until reaching each predetermined depth. For the 0 cm burial depth treatment, thirty buttonweed seeds were distributed on the soil surface. For the greater depths, thirty buttonweed seeds were sown at the soil surface of each depth and soil was added up to the pot's standard surface, at the first white mark. Equal amounts of water were provided to every pot of the experiment on a daily basis, via manual irrigation. The straw used was from sugarcane, collected from a production field close to harvest in Piracicaba, in the state of São Paulo (-22°69′7.931″ S, -47°67′5.933″ N). The straw was air-dried at 60 °C for 72 hours and stored in dry conditions until the initiation of the experiment. To determine sugarcane straw amounts suitably proportional to kg ha^{-1} distributed on the soil surface of the pots, diameter, ratio and area of the experimental units were all considered. All straw amounts were uniformly distributed on the soil surface for every seed depth. When the lengths of straw pieces were greater than the the diameter of the pots, they were cut to fit in the pots.

The variables evaluated were buttonweed seedling emergence (%) and aboveground fresh biomass (g) per experimental unit, at twenty-five days after installation (DAI) of the experiment. Seed burial depths and straw amounts were evaluated in a factorial design with three levels of seed burial 0 (soil surface), 0.5, 1 and 2 cm and four amounts of straw 0; 1,000; 2,000 and 4,000 kg ha^{-1}.

For determining fresh biomass, buttonweed seedlings were cut aboveground and stored in paper bags properly marked. Immediately after, the samples were weighed using an electronic 0.01 g precision scale.

Because treatments were from a continuous range of values, the approximation of the response function (Response Surface Methodology) was chosen to explore the relationships between the explanatory variables, seed burial depth and straw amount on the soil surface, and the response variables, buttonweed seedling emergence and fresh biomass.

To calculate the expected values of both buttonweed emergence and fresh biomass, a quadratic response-surface model was used:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + \beta_4 x_1^2 + \beta_5 x_2^2 + \varepsilon$$

where: y is the predicted buttonweed emergence or fresh biomass, β_0 is the intercept, β_1 through β_5 are coefficients, x_1 is the seed burial depth factor, x_2 is the straw amount on the soil surface factor, and ε the error associated with the data. The resulting values for β_1 through β_5 represent partial regression coefficients in which the effect of x_1 on buttonweed emergence or fresh biomass is altered by the inclusion of x_2.

Response-surface and canonical analyses provided a method for characterizing the interaction visually, by producing contour plots, and allowing for the examination of the characteristics of the contour plots with the second order of quantitative predictors. The PROC RSREG (SAS® v. 9.3, SAS Institute, Cary, NC) procedure was used in these analyses to perform model fitting, lack-of-fit test, and canonical analysis (Bowley, 1999). The RIDGE statement was used to compute the ridge of optimum response. The SAS® GCONTOUR procedure was used to graph the relationships between the three numeric variables from this study in two dimensions. The explanatory variables were for x and y axes, and each response variable (z) was for contour levels. The contour levels were plotted as lines, and the area between the lines were color coded to indicate interpolated values.

Results and Discussion

The regression that best fitted the data was a second-order linear equation, which explained 75% and 80 % of the data variability for buttonweed emergence and fresh biomass, respectively. In addition, the lack-of-fit tests indicated that the second-order models were adequate for both emergence and fresh biomass data (p-value > 0.05). Most of the predictor variables had a significant linear relationship with buttonweed emergence and fresh biomass (Table 1). The estimated parameter values for the fitted models are shown in Table 1.

Table 1 – Parameter estimates from raw and coded emergence and fresh biomass data for the second order linear regression models.

	Parameter	DF	Estimate	Parameter estimate from coded data	p-value
Emergence	Intercept	1	45.1958	-0.551701	< 0001
	Seed Burial Depth	1	-54.838	-13.048075	< 0001
	Straw Amount on the Soil Surface	1	-8.1963	-7.216636	0.0051
	Seed Burial Depth*Seed Burial Depth	1	15.5492	15.549242	< 0001
	Straw Amount*Seed Burial Depth	1	5.34558	10.691156	< 0001
	Straw Amount*Straw Amount	1	-0.1894	-0.757576	0.7613
Fresh Biomass	Intercept	1	0.46743	-0.016664	< 0001
	Seed Burial Depth	1	-0.6534	-0.157913	< 0001
	Straw Amount on the Soil Surface	1	-0.0498	-0.057299	0.1356
	Seed Burial Depth*Seed Burial Depth	1	0.20352	0.203523	< 0001
	Straw Amount*Seed Burial Depth	1	0.04421	0.088424	0.0004
	Straw Amount*Straw Amount	1	-0.0058	-0.023068	0.4294

For buttonweed emergence, canonical analysis indicated that the predicted response-surface was shaped like a saddle. The largest eigenvalue (17.145361) corresponded to the eigenvector {0.958198, 0.286105}, the largest component of which (0.958198) was associated with seed burial depth (Table 2). Similarly, for fresh biomass data, the largest eigenvalue (0.211844) corresponded to the eigenvector {0.982746, 0.18496}, the largest component of which (0.982746) was associated with seed burial depth. For emergence and fresh biomass, the hill orientation of the saddle was more curved than the valley orientation. The coefficients of the associated eigenvectors showed that the hill was more aligned with the seed burial depth factor and the valley with the straw amount on the soil surface factor (Table 2). Thus, for both buttonweed emergence and fresh biomass, the response-surface was relatively more sensitive to changes in seed burial depth (Figures 1 and 2).

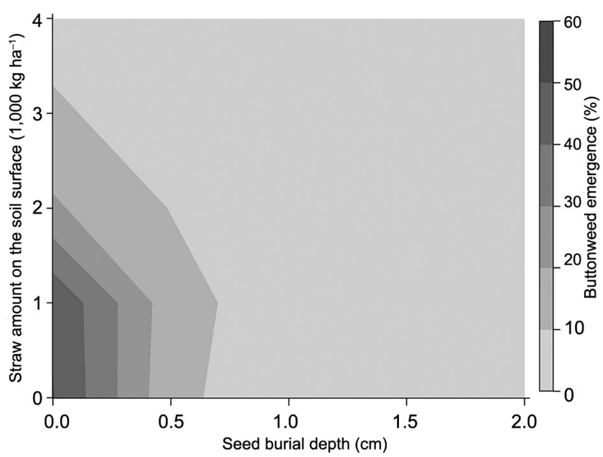

Figure 1 – Variation in buttonweed emergence (%) in response to variation in buttonweed seed burial depth (cm) and straw amount on the soil surface (1,000 kg ha^{-1}).

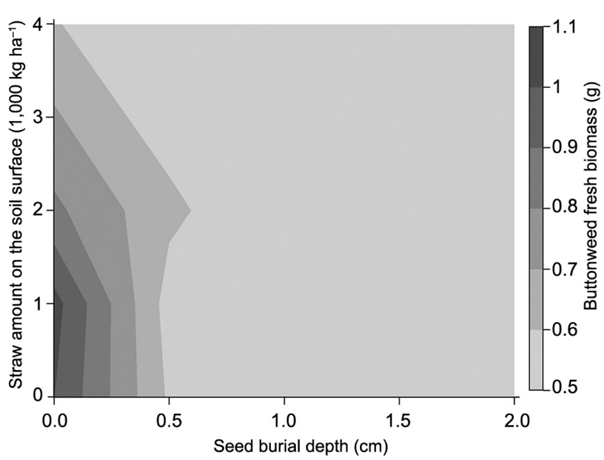

Figure 2 – Variation in buttonweed fresh biomass (g) in response to variation in buttonweed seed burial depth (cm) and straw amount on the soil surface (1,000 kg ha^{-1}).

Table 2 – Eigenvectors from canonical analysis for buttonweed emergence and fresh biomass.

	Eigenvalues	Eigenvectors	
		Seed burial depth	Straw amount on the soil surface
Emergence	17.145361	0.958198	0.286105
	-2.353694	-0.286105	0.958198
Fresh biomass	0.211844	0.982746	0.18496
	-0.031389	-0.18496	0.982746

The contour plots in Figures 1 and 2 indicate that buttonweed seedling emergence and fresh biomass declined as seed burial depth and the straw amount on the soil surface increased. At a depth of 0 cm, buttonweed emergence was observed in all straw amounts tested.

Figures 1 and 2 indicate that buttonweed emergence and fresh biomass achieved maximum reduction from 1 cm to greater seed burial depths. In this case, buttonweed establishment would be reduced. If the straw amount on the soil surface is at the highest end of its range, buttonweed emergence and fresh biomass will be reduced only from 0.5 cm onwards of seed burial depth. However, when seeds were placed on the soil surface (0 cm), the straw amount of 4,000 kg ha^{-1} reduced seedling emergence by 94 % and seedling fresh biomass by 80 % compared to the absence of straw on the soil surface.

At the 0.5 cm depth, buttonweed seedling emergence was also affected by the presence of straw on the soil surface (Figure 1) and some buttonweed seedlings were able to emerge with the presence of straw amounts of 2,000 kg ha^{-1}; however, seedlings were far less robust than seedlings that emerged at 0 cm with the same straw amounts (Figure 2).

Canonical analyses of the response-surfaces indicated that the stationary points for buttonweed emergence and fresh biomass data sets were saddle points; i.e., there was no unique maximum or minimum point within the range of factors used, given the presence of positive and negative eigenvalues (Table 2). This is a realistic situation, where there is not a predominate optimum. However, since the stationary points for emergence and fresh biomass were out of the range of the experiment, ridge analysis was carried out.

In ridge analysis, the ridge starts at a given point x_0, and the point on the ridge at radius r from x_0 is the collection of factor settings that optimizes the predicted response at this radius (SAS® Institute, 2010). In this study, the default radii at which the ridge was computed were in the range from 0 through 1 (Figures 3A and B). Ridge analysis is a tool used for interpreting an existing response-surface, that is, searching for the region of optimum response, or indicating the direction in which further experimentation should be performed.

Although the estimated surface did not have a unique optimum, the ridge analyses predicted that maximum buttonweed emergence or fresh biomass would result from the shallowest seed burial depths and the

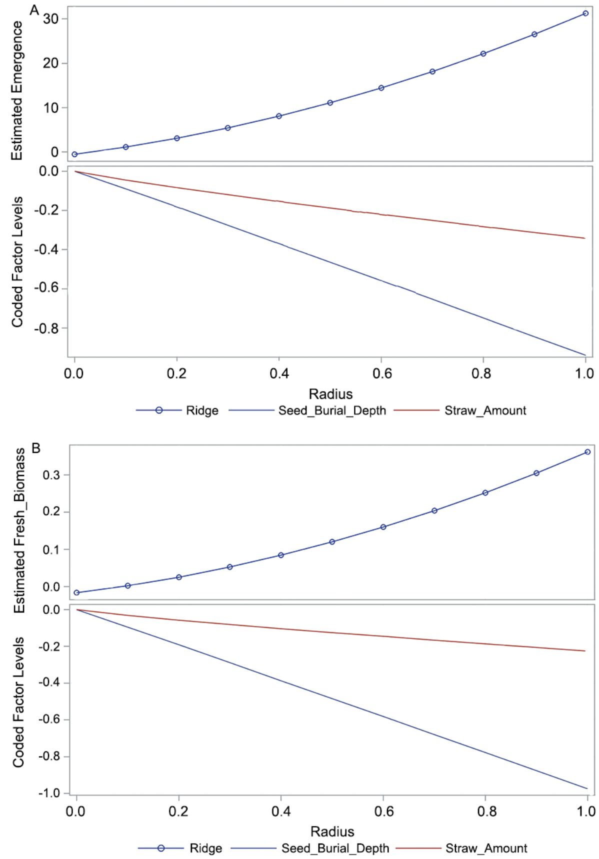

Figure 3 – Ridge plot of predicted response-surface for buttonweed emergence (A) and fresh biomass (B).

lowest straw amounts tested in this study (Table 3, Figures 3A and B). The contour plots of the predicted response-surface, shown in Figures 1 and 2, confirmed this conclusion.

Small seed size was considered to be one of the possible causes for weed emergence reduction when straw was present on the soil surface (Baskin and Baskin, 1998). Buttonweed seed is small, (~1 mm long), and weighs about 0.1 mg. Length and weight of buttonweed seeds were probably associated with emergence reduction as both seed burial depth and straw amount on the soil surface increased.

In one study, the weed *Conyza bonariensis*, whose seeds were small (1.5 mm), emerged predominantly from the soil surface with very few seedlings emerging from depths below 1 cm (Peltzer, 2009). Seed size and weight of the small-seeded species *Inula salicina* L. was about 1.5 cm long and 0.1 mg, respectively. Seed length and weight of this species were similar to those of buttonweed. Maximum depth of emergence for *I. salicina* was 1 cm (Burmeier et al., 2010). In another study, a sharp decline in emergence was found for the small-seeded species *Tripleurospermum inodorum* and *Veronica arvensis* when burial exceeded 1 cm (Grundy et al., 2003).

Table 3 – Estimated ridge of maximum response for buttonweed emergence and fresh biomass.

	Coded Radius	Estimated Response	Standard Error	Uncoded Factor Values: Seed Burial Depth	Uncoded Factor Values: Straw Amount on the Soil Surface
Emergence	0	-0.5517	2.30288	1	2
	0.1	1.10374	2.26139	0.910453	1.910978
	0.2	3.0927	2.20068	0.81837	1.83254
	0.3	5.41929	2.12365	0.724995	1.760231
	0.4	8.08553	2.03662	0.630886	1.69175
	0.5	11.0925	1.95026	0.536324	1.625811
	0.6	14.441	1.8808	0.441465	1.561644
	0.7	18.1313	1.85017	0.346403	1.498758
	0.8	22.1637	1.88355	0.251194	1.436831
	0.9	26.5384	2.00295	0.155878	1.375637
	1	31.2555	2.22012	0.060479	1.315018
Fresh Biomass	0	-0.0167	0.0269	1	2
	0.1	0.0022	0.02643	0.904827	1.938611
	0.2	0.02525	0.02576	0.808288	1.886044
	0.3	0.05249	0.0249	0.711103	1.838279
	0.4	0.08395	0.02396	0.613569	1.793398
	0.5	0.11964	0.02307	0.515828	1.750383
	0.6	0.15955	0.02245	0.417954	1.708643
	0.7	0.2037	0.02235	0.319991	1.667812
	0.8	0.25208	0.02308	0.221965	1.627652
	0.9	0.30469	0.02486	0.123893	1.588
	1	0.36153	0.02778	0.025786	1.548745

Weed seed germination, persistence, and emergence under different environmental factors vary according to different seed sizes (Bekker et al., 1998). For example, even within the same weed species, emergence varied based on different seed sizes (Tanveer et al., 2013). These authors classified *Convolvulus arvensis* seeds as large, medium or small. Larger seeds lead to improved stand establishment compared to small seeds.

Buttonweed seeds are positive photoblastic, that is, light is required for germination. Light interception was impaired by the presence of straw on the soil surface, especially for seeds buried at soil depths of 2 cm or more (Benvenuti, 1995). A reduction in light interception might be another factor associated with the decrease in buttonweed emergence at greater depths and superficial straw amounts. The manipulation of the light environment under field conditions is, therefore, a potential tool for managing the emergence of positive photoblastic seeds (Holt, 1995) - such as buttonweed seeds.

The maximum seedling emergence observed in this study was 50 %, when seeds were placed on the soil surface without superficial straw (Figure 1). In the laboratory under variable conditions of light and temperature, buttonweed maximum cumulative germination was 60 % (Martins et al., 2010). In the present study, some buttonweed seeds might have germinated under greater seed burial depths and straw amounts on the soil surface than 0 cm and 0 kg ha^{-1}, respectively; however, emergence *per se* may not have occurred in 100 % of the germinated seedlings possibly due to fatal germination. It is known that fatal germination plays a role in the decline of seedling emergence (Benvenuti et al., 2001). At the same time, studies have shown that seeds possess a depth-sensing mechanism, which prevents seed germination from depths from which they cannot physically emerge (Grundy et al., 2003).

No-tillage systems concentrate weed seeds near the soil surface, and also maintain after-harvest straw on the ground. Surface crop straw, to effectively prevent weed emergence and consequent establishment, must consistently produce a thick and uniform ground cover. The construction of such straw layer under no-tillage systems is a process built up over time, especially in soybean areas, in which straw production is lower compared to that of sugarcane. In those soybean areas under no-tillage where buttonweed is a difficult-to-control weed, the increase in straw amount on the soil surface has the potential to reduce buttonweed emergence and consequently, its establishment, avoiding subsequent interference with the crop. For instance, a study on rice under no-tillage showed that 5,000 kg ha^{-1} of superficial wheat straw reduced weed density from 22 to 76 % and promoted predation of rice-wheat weeds (Kumar et al., 2013). Other studies have also shown that weed suppression was species-specific and could be achieved with residue from different plant species being present on the soil surface (Campiglia et al., 2012; Mirsky et al., 2013; Anderson, 2014).

The maintenance of after-harvest straw represents a component to be added in the integrated management of buttonweed. In the short term, buttonweed control tactics should include chemical management (Martins and Christoffoleti, 2014), given that its emergence is favored in the absence of, or with low amounts of crop straw on the soil surface.

Modern agricultural sustainability requires continuous optimization of cropping systems. Conservationist systems, such as no-tillage, along with crop rotation, are alternatives that should be encouraged, especially for tropical regions, where weather conditions promote great biological dynamism of the ecosystems (Cruz et al., 2015).

In order to develop ecologically based weed management practices, information on weed ecology and biology is of paramount importance (Chauhan and Gill, 2014). Our results indicated that soils without after-harvest straw on the ground and with buttonweed seeds occurring on the surface, had greater buttonweed seedling emergence and fresh biomass.

This study contributed to the understanding about buttonweed emergence dynamics in the soil. It might be inferred that adopting the practice of straw maintenance on the soil surface, integrated with chemical management, has the potential to reduce buttonweed emergence even in the short term. In the long term, without tilling the soil, seed accumulation near the soil surface might promote a gradual decrease in the seed bank of buttonweed. Results of this study may help growers to identify cultivation practices that best collaborate with the management of buttonweed seedling emergence, in areas where it occurs in large infestations.

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