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Article

Emergence of Razor Grass on the Basis of Origin and Seed Depth in the Soil Profile

Emergência de Capim-Navalha em Função da Origem e da Profundidade da Semente no Solo

MARQUES, A.S.[1]
MARCHI, S.R.[1]*
PINHEIRO, G.H.R.[2]
MARQUES, R.F.[2]
MARTINS, C.C.[3]

ABSTRACT - Razor grass (*Paspalum virgatum* L.) is one weed that has gain importance because of its high seed production capability, mainly when pasture fields need to be renewed. Understanding seedling emergence behavior is crucial to devise strategies to manage this weed. This trial was carried out to evaluate the emergence pattern of razor grass seedlings on the basis of seed depth in the soil profile. The experiment was conducted in a green-house in a completely randomized design, with six replications. The treatments performed in a 11 x 3 factorial arrangement: eleven seeding depths (surface, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0 and 10.0 cm) by three ecotypes (Rondonópolis, Redenção and Cacoal, Brazil). The effect of origin and seed depth was measured by number of emerged seedlings, emergence speed index, relative emergence frequency, mean emergence time and emergence synchrony of seedlings at 35 days after planting. The seeds of ecotype Rondonópolis had higher vigor than those of ecotype Redenção, which had higher vigor that the ones of ecotype Cacoal. The highest seedling emergence percentage, uniformity and speed were found when the seeds were located at the soil surface, regardless of seed origin. There was no seedling emergence when the seeds of ecotypes Rondonópolis and Cacoal were located at a depth equal to or higher than 8.0 cm; and of ecotype Redenção when they were at a depth equal or higher than 7.0 cm.

Keywords: *Paspalum virgatum*, ecotype, weed, pasture, emergence pattern.

RESUMO - O capim-navalha (***Paspalum virgatum*** L.) é *uma planta daninha de pastagens que tem ganhado importância devido à elevada capacidade de multiplicação por sementes, principalmente quando se faz necessária a reforma. O entendimento do comportamento da emergência de plântulas é de fundamental importância para a adoção de estratégias de manejo dessa planta daninha. O objetivo deste trabalho foi avaliar o padrão de emergência de plântulas de capim-navalha em função da profundidade da semente no solo. O experimento foi conduzido em casa de vegetação no delineamento inteiramente casualizado com seis repetições, e os tratamentos, dispostos em esquema fatorial 11 x 3, sendo 11 profundidades de semeadura (superfície; 1,0; 2,0; 3,0; 4,0; 5,0; 6,0; 7,0; 8,0; 9,0; e 10,0 cm) e três ecótipos (Rondonópolis, Redenção e Cacoal). O efeito da origem e da profundidade da semente no solo foi avaliado pela porcentagem de emergência, índice de velocidade de emergência, frequência relativa de emergência, tempo médio de emergência e sincronia de emergência de plântulas obtidas ao longo de 35 dias após a semeadura. As sementes do ecótipo Rondonópolis possuem maior vigor que as do ecótipo Redenção, que por sua vez possuem maior vigor que as do ecótipo Cacoal. As maiores porcentagem, uniformidade e velocidade de emergência de plântulas foram obtidas com as sementes localizadas na superfície*

*** Corresponding author:**
<sidneimarchi.ufmt@gmail.com>

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[1] Universidade Federal de Mato Grosso – Campus Universitário do Araguaia, Barra do Garças, Mato Grosso, Brasil; [2] Universidade Federal de Goiás – Regional Jataí, Jataí, Goiás, Brasil; [3] Universidade Estadual Paulista "Júlio de Mesquita Filho" – FCAV - Campus de Jaboticabal, Jaboticabal, São Paulo, Brasil.

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do solo, independentemente da origem da semente. Não ocorre emergência de plântulas quando as sementes procedentes de Rondonópolis e Cacoal estão em profundidades iguais ou superiores a 8,0 cm, e as de Redenção, em profundidades iguais ou superiores a 7,0 cm.

Palavras-chave: *Paspalum virgatum*, ecótipo, planta daninha, pastagem, padrão emergência.

INTRODUCTION

Razor grass (*Paspalum virgatum* L.) is a grass that invades pasture and has high capacity of multiplication and competition with forage species. In addition, it presents a low nutritional value, and low acceptability by animals, and it can also cause bovine methemoglobinemia (Diaz, 2011; Herrera, 2015).

The mature plant is cespitose, rhizomatous, and forms clumps that reach 1.5 m in height. Its leaves are upright and measure between 50 and 75 cm in length and 1.0 to 2.0 cm width, with jagged and sharp margins. Each plant produces up to ten inflorescences (panicles), containing between 5 and 16 brown racemes, with 5 to 12 cm in length. Each panicle contains between 800 and 1,500 seeds, which are considered to be small, because one kilogram contains approximately 785 thousand units (Sistachs and León, 1987; Cruz et al., 1996).

This species can be found in all the states of the North and Midwest regions of Brazil, in addition to Maranhão, Pernambuco, São Paulo and Paraná, where it is called different names in Portuguese, such as "navalhão", "capim-cabeçudo" and "capim-capivara" (Oliveira & Valls, 2015; Silva et al., 2017).

Razor grass has become the main weed in pasture fields only in the past 15 years, because it has been associated with the death syndrome of *Urochloa brizantha* (A.Rich.) R.D.Webster cv. Marandu, a progressive disease that causes plant death, and in clumps of forage grasses, thereby making room for colonization of weeds and leading to pasture degradation. Attempts at reform of pastures highly infested by razor-grass, using conventional methods, e.g., harrowing and planting new forage varieties, have been frustrated in the majority of cases as a result of reinfestation of the area because new plants have emerged from seeds present in the soil (Herrera, 2015).

Some authors have stated that ecotypes of a certain species may be originated from variations in the environment where they survive, resulting in phenotypic changes that ensure evolutionary and ecological success to specimens and, consequently, higher capacity to invade and establish in an area (Gemelli et al., 2012; Melo et al., 2012). In this way, the site of origin can change the formation of seeds and, thus, affect their germination and vigor (Bognounou et al., 2010; Mendonça et al., 2014) and, consequently, facilitate their ability to reinfest a certain environment.

Currently, because of great weed competition, several studies have been developed to provide further insights into the behavior of these ecotypes and, consequently, manage them efficiently (Marchi et al., 2017). Studying the mode of propagation, dispersion and emergence of species that are expected to be controlled is important because, without compliance with these characteristics, the attempts to control can result in uncoordinated, costly and ineffective activities.

Knowledge of seedling emergence ability of seeds located at different soil depths may assist in the management of species through the adoption of methods that reduce or prevent their occurrence. An example is cultural control using equipment to prepare soil to incorporate seeds at unfavorable depths to depths that are ideal for seedling emergence (Voll et al., 2001; Maciel, 2014). Conversely, there are several studies in the literature pointing to the effect of sowing depth and initial development of pasture; it is indisputable that a sowing depth between 1.0 and 2.0 cm is the most appropriate for the whole of the forage grasses (Pacheco et al., 2010; Zuffo et al., 2014; Santos et al., 2015). Thus, by locating razor grass seeds at greater soil depths and seeds of forage grasses in the topsoil, it would be possible to facilitate germination, emergence and development of the forage species at the expense of weeds, and stimulate pasture establishment.

The only study found in the scientific literature about the dynamics of seed germination and emergence of razor grass was conducted a long time ago and reported that only 26% of seedlings emerged from the ground when the seeds were buried at 7.0 cm depth, and there was no emergence at depths greater than 12.5 cm (Sistachs and Leon, 1987).

In view of the data reported above, and based on the lack of information in the literature, this study was developed to study the seedling emergence pattern of razor grass on the basis of seed origin and depth along the soil profile.

MATERIAL AND METHODS

The experimental phase of this research was represented by a study conducted from May 20 to June 23 2016, in a greenhouse whose geographic coordinates are 15°52'25" S and 52°18'51" W GR.

Panicles of *P. virgatum* containing physiologically mature spikelets were handpicked in several pasture fields located in the towns of Rondonópolis-MT, Redenção-PA and Cacoal-RO (Table 1), forming three lots named according to the origin: ecotype Rondonópolis, ecotype Redenção and ecotype Cacoal. The point of physiological maturity was determined as the moment when the spikelets started to naturally fall from the inflorescences (Lopes and Franke, 2011a, b). Table 2 shows the climate conditions of the places of origin.

Table 1 **-** Geographic coordinates of seed collection sites of *P. virgatum*

Location	County	Coordinates	
		South latitude	West longitude
Pasture 1	Rondonópolis / MT	16°27'22.5"	54°10'16.7"
Pasture 2	Rondonópolis / MT	16°44'53.5"	54°28'19.3"
Pasture 3	Rondonópolis / MT	16°44'52.7"	54°16'35.5"
Pasture 4	Redenção/PA	8°18'16.9"	50°40'21.0"
Pasture 5	Redenção/PA	7°47'23.5"	49°15'18.7"
Pasture 6	Redenção/PA	8°43'25.1"	49°49'13.4"
Pasture 7	Cacoal / RO	11°23'43.6"	61°04'41.0"
Pasture 8	Cacoal / RO	11°05'53.8"	61°26'05.1"
Pasture 9	Cacoal / RO	11°27'19.9"	61°36'05.7"

Table 2 - Climate data(1) of the places of origin of *P. virgatum* seeds

Origin	Climate(2)	Average annual temperature (ºC)			Solar radiation(3)	Annual rainfall (mm)
		Minimum	Average	Maximum		
Rondonópolis	AW	20.4	26.8	33.2	16.49	1313
Redenção	AW	21.5	27.4	33.7	17.65	1165
Cacoal	AW	22.4	27.6	32.9	18.92	1982

(1) Average of the last 10 years. (2) Köppen classification. (3) Solar radiation in W m^{-2} day^{-1}. Source: Agritempo: Agrometeorological Monitoring System.

The three seed lots were first cleaned using a set of juxtaposed sieves, followed by handpicking of impurities that had remained trapped together with the spikelets in the 1.7 mm sieve, in order to obtain only the dispersal units of this species. For each lot of clean seeds, empty seeds and other fragments were separated from full seeds using an air blower with a uniform air flow; the full seeds were considered to be pure seeds (Brasil, 2009). Then, viability of pure seeds was assessed in an aqueous solution containing 2,3,5-triphenyltetrazolium chloride at 0.75% (Brasil, 2009). Also, thousand seed weight (TSW) of full seeds was determined by the mean weight of eight subsamples of 100 seeds multiplied by 10. For each ecotype, 50 razor grass seeds were sown with replication in soil inside 1.0 L pots. Sowing was performed at 11 depths from the surface of the substrate, namely: 0 (surface); 1.0; 2.0; 3.0; 4.0; 5.0; 6.0; 7.0; 8.0; 9.0; and 10.0 cm. Then, the seeds were covered with the substrate until the pot was completely filled, except for the seeds that had remained on the surface.

The substrate was collected in the topsoil soil of a sandy loam Dystrophic Red Latosol, dried and sieved to remove plant debris. The chemical and physical characteristics of the substrate were: pH in $CaCl_2$ = 4.8; 22.0 g dm^{-3} organic matter; 4.0 mg dm^{-3} resin P; V = 44.6%; contents of K, Ca, Mg and H+Al of 3.1, 6.0, 18.0 and 34.0 $mmol_c\ dm^{-3}$, respectively; 706 g kg^{-1} sand; 85 g kg^{-1} silt; 209 g kg^{-1} clay. There was no amendment for fertility and acidity. The pots were irrigated when necessary during the experimental period.

Daily counts were made of number of emerged seedlings until the date when there was no variation between the assessments for a minimum period of five consecutive days. This fact was observed at 35 days after sowing. The seedling was considered as emerged when the cotyledonary leaf was fully expanded and the development of the first true leaf was found to have started. Figure 1 shows the daily minimum and maximum temperatures inside the greenhouse during the experiment.

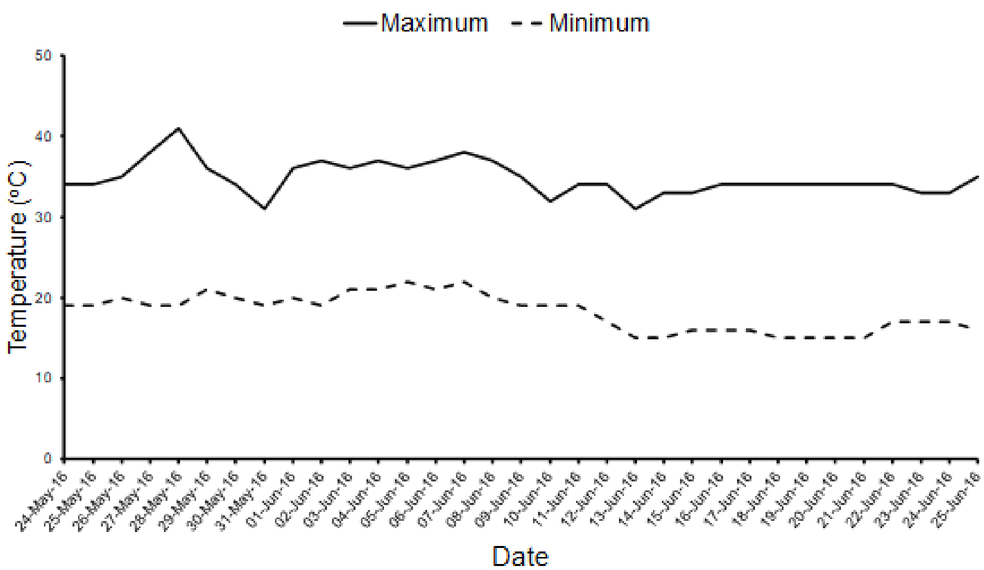


Figure 1 **-** Minimum and maximum temperatures inside the greenhouse during the experimental period.

The effect of treatments was evaluated on the basis of emergence percentage, emergence speed index, relative emergence frequency, mean emergence time and seedling emergence synchrony. Emergence percentage was calculated using the equation established by Labouriau and Valadares (1976):

$$EP\,(\%) = (N/A * 100)$$

where EP = seedling emergence percentage, N = total number of emerged plants and A = total number of seeds put to germinate. Emergence speed index (ESI) was calculated with the formula described by Maguire (1962), mean time (Tm), synchrony (Z) and relative emergence frequency (Fr) were determined using the formulas described by Santana and Ranal (2004).

The experiment used a completely randomized design, with treatments distributed in a factorial 11 x 3 arrangement (11 sowing depths x 3 seed origins) and six replications. Variation in relative emergence frequency was assessed by observing unimodality or polimodality of graphic polygons obtained on the basis of different seed depths on the substrate over time. The results of seedling emergence (%), ESI, mean time and synchrony of seedling emergence were adjusted to the polynomial or exponential regression models with the software program Origin 8.5.1 SR1. The choice of the regression model was based on the highest value of the coefficient of determination (R^2) $p \leq 0.05$, in accordance with the F test, while respecting the biological response.

RESULTS AND DISCUSSION

Ecotype Cacoal had the highest value for thousand seed weight of full seeds: 1,640 g. Ecotype Redenção presented intermediate TSW value of 1.484 while ecotype Rondonópolis had the lightest seeds, with TSW of 0.834 g, approximately 50% lower than that of ecotype Cacoal (Table 3).

Carmona et al. (1999) found variation of up to 44% in the TSW of species of the genus *Paspalum* collected in two separate years; the authors attribute the difference between the lots to the proportion between full and empty seeds. Importantly, the TSW values found in the ecotypes Cacoal and Redenção are similar to the values reported by Lopes and Franke (2011b) for the species *P. notatum*, ecotypes André da Rocha and Bagual, with mean TSW values of 1,640 g and 2,290 g, respectively.

Table 3 - Thousand seed weight (TSW) and full seed viability (%) of Rondonópolis, Redenção and Cacoal ecotypes

Ecotype	TSW (g)	Viability (%)
Rondonópolis	0.834 c	69.3 a
Redenção	1.484 b	44.0 b
Cacoal	1.640 a	40.6 b
Ecotype F	1260.00**	5.11*
CV (%)	2.58	12.36

** Significant at 1% probability; * Significant at 5% probability. Means followed by the same letter do not differ statistically by the Scott-Knott test ($p<0.05$).

The differences in the TSW of seeds can be attributed to genetic variability among populations and climatic conditions that occur during seed formation (Barros et al., 2017). The higher TSW value found in the ecotype Cacoal is probably due to the climatic conditions of the region, especially the association between greater water availability, occurrence of higher minimum and medium temperatures and higher incidence of solar radiation, when compared to the other two regions (Table 2). Such environmental conditions favor the process of photosynthesis, plant metabolism and, consequently, the synthesis of reserve substances accumulated during seed formation (Carvalho and Nakagawa, 2012; Lamarca et al., 2013).

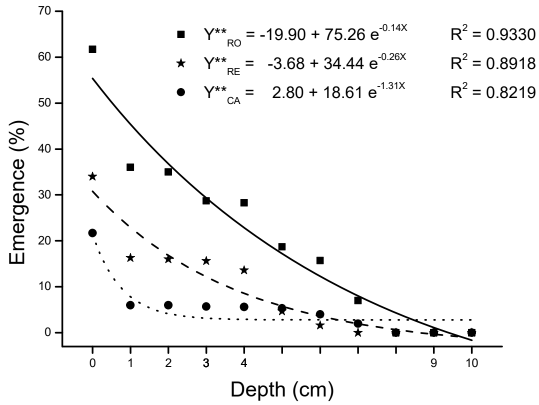
The tetrazolium test showed that the full seeds of ecotype Rondonópolis showed viability of 69.3%, higher than the seeds of ecotypes Redenção and Cacoal, whose values were 44.0% and 40.6% (Table 3), respectively. These levels of germination are in agreement with those reported by Silva et al. (2017), who found values between 30% and 73% of germination of *P. virgatum* seeds under different dormancy breaking methods.

Viability of the seeds, as observed in the three ecotypes, can be considered to be low, and the values corroborate those found in other studies, which reported that several species of the genus *Paspalum* have low production capacity of viable seeds, especially because of the lack of phytosanitary practices during seed production (Lopes and Franke, 2011a). In addition, lower viability values may also be due to the occurrence of dormancy that is typical of the species *P. virgatum* (Silva et al., 2017).

The differences in the viability of seeds found in the ecotypes Rondonópolis, Redenção and Cacoal may be due to the occurrence of pathogens; however, they were not evaluated in this study. Mallmann et al. (2013) claimed that environmental conditions are favorable not only for seed formation but also for development of certain pathogenic organisms responsible for a decrease in seed viability. In addition, Aguiar et al. (2013) reported that low germination of *P. notatum* seeds is usually associated with the presence of pathogenic fungi; the genera most commonly found are *Fusarium*, *Aspergillus*, *Curvularia* and *Geniculosporium*.

Seedling emergence decreased exponentially with increased sowing depth of razor grass. When analyzing only the origin factor, the highest percentages were found in the ecotype Rondonópolis, followed by ecotypes Redenção and Cacoal (Figure 2), because the constants that multiply the variable of the exponent were, respectively, 0.14, 0.26 and 1.31 (Figure 2). It should be noted that, in the exponential function, the values of Y approach zero as the values of X increase, and the negative sign indicates that the function is descending (Rezende et al., 2012).

Considering only the depth factor, seedling emergence percentage decreases proportionally with increased depth, even when the seed is located just 1.0 cm below the surface of the ground, regardless of seed origin. Another relevant finding is that the percentage values of seedling emergence were numerically similar, and they virtually did not change at depths between 1.0



** Significant ($p \leq 0.01$).

Figure 2 - Seedling emergence (%) of Rondonópolis (RO), Redenção (RE) and Cacoal (CA) ecotypes, determined on the basis of different seed origins and depths in the substrate.

and 4.0 cm. It was zero at depths greater than or equal to 7.0 cm for the seeds of ecotype Redenção and greater than or equal to 8.0 cm for the seeds of ecotypes Rondonópolis and Cacoal (Figure 2).

The results of seedling emergence found with ecotypes Rondonópolis, Redenção and Cacoal corroborate the findings of the only article found in the literature, a study conducted in Cuba by Sistachs and León (1987), which showed that only 26% of razor grass seeds buried at 7.5 cm depth emerged from the soil, but there was no emergence at depths greater than 8.0 cm.

In addition, the difference in emergence percentages found at different depths can be due to the characteristics of *P. virgatum* seeds and how these characteristics are influenced by field situations in the dispersal environment of the species. Silva et al. (2017) stressed that razor grass seeds are dispersed and fall on the ground, straw or other surface prone to solar radiation and high temperature conditions, especially in the North and Midwest regions of Brazil.

Although the experiment has been conducted in a protected environment and incidence of solar radiation has not been evaluated, the reduction in seedling emergence percentage found in the present study is probably due to indirect incidence of solar radiation on seeds that were located at greater depths, which, according to Silva et al. (2017), may not induce germination. Lack of seedling emergence at depths greater than or equal to 7.0 or 8.0 cm is due to the fact that the quantities of seed reserves (carbohydrates and proteins) are insufficient to break the physical barrier imposed by the soil (Pacheco et al., 2010; Zuffo et al., 2014; Santos et al., 2015).

The assessment of emergence frequency showed that the greatest uniformity was found when the seeds of ecotype Rondonópolis were located on the surface and at 1.0 cm, while those of ecotypes Redenção and Cacoal were located only on the surface of the substrate. Relative frequency polygons for emergence tended to unimodality, with peaks of emergence between the seventh and the ninth day after sowing (Figure 3A, B), and a peak of seedling emergence between the seventh and the eleventh day.

On the contrary, there was polimodality in relative frequency polygons of emergence of those seeds located at depths between 2.0 and 7.0 cm, characterized by several peaks of emergence found mainly on the 10^{th} day and later, indicating less homogeneity in the seed emergence behavior of the three ecotypes (Figure 3C, D, E, F, G and H).

A study conducted by Bortolin (2016) showed that the peak frequency of germination of *Paspalum regnellii* seeds occurred during the first five days of the experiment, and seeds collected in different years showed different germination frequency behavior.

As mentioned above, the different peaks of seedling emergence frequency are possibly due to the amount of solar radiation incidence on seeds and the energy available to break the higher layers of soil that covered the seeds.

For mean emergence time (T_m), the three ecotypes showed virtually the same AT (8.5 days) when the seeds were located on the surface of the substrate. Ecotype Rondonópolis showed values ranging between 8.55 and 13.06 days, and AT increased linearly with increased sowing depth on the substrate (Figure 4).

The seeds of ecotype Cacoal presented initial mean emergence time of 8.12 days and quadratic and ascending behavior with an increase of depth up to 6.0 cm; after that, AT tended to be inversely proportional to increases in sowing depth (Figure 4).

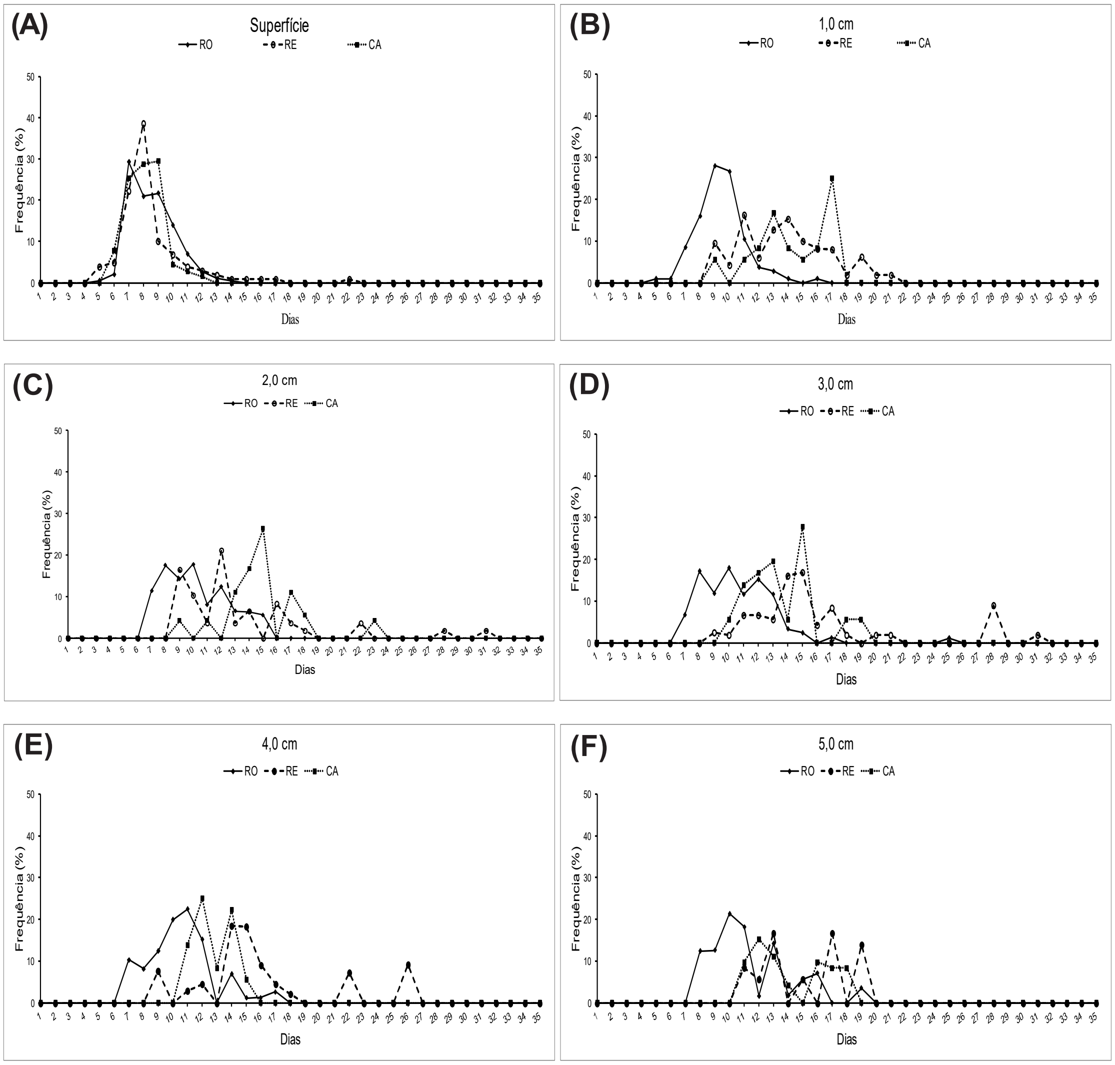
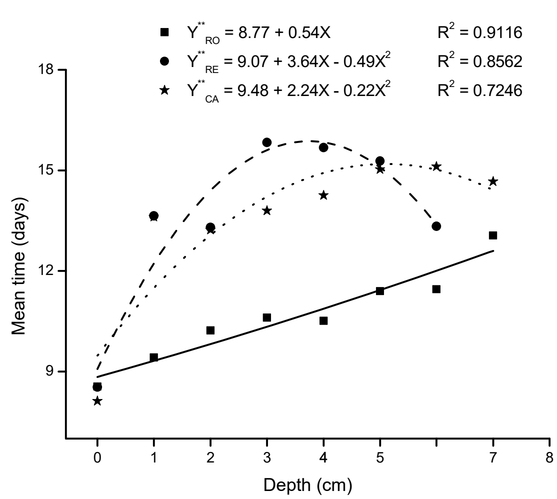


Figure 3 - Relative frequency polygons of seedling emergence of Rondonópolis (RO), Redenção (RE) and Cacoal (CA) ecotypes, determined on the basis of seed locations in the substrate.



** Significant at 1% probability.

Figure 4 - Mean seedling emergence time of Rondonópolis (RO), Redenção (RE) and Cacoal (CA) ecotypes, determined on the basis of different seed locations in the substrate.

The same effect produced on AT by the depth of seeds in the substrate was found in the seeds of ecotype Redenção, but the inversion of the AT values occurred at a depth of 3.0 cm, which is relatively lower when compared with the AT of the seeds of ecotype Cacoal (Figure 4).

The results for mean emergence time of razor-grass seedlings in the present study show that there may be genotypic differences between populations, possibly causing highly competitive capacity. Such genotypic characteristics may be the result of conditions of the environment where the species is dispersed. Such conditions change the pattern of seed germination and seedling emergence in order to recruit the environmental resources even in scarcity conditions (Vivian et al., 2008). Furthermore, early occupation of space in the environment restricts resources and consequently stops the growth of neighboring plants, which allows the species to dominate the community more easily (Radosevich et al., 1997; Rigoli et al., 2009).

Regression analysis showed that seedling emergence synchrony is linear and inversely proportional to increased depth of seeds in the soil. Comparatively, the highest synchrony values were found with the seeds of ecotypes Redenção and Cacoal (0.32 and 0.33, respectively), followed by ecotype Rondonópolis (0.23), when the seeds were located at topsoil depth (Figure 5).

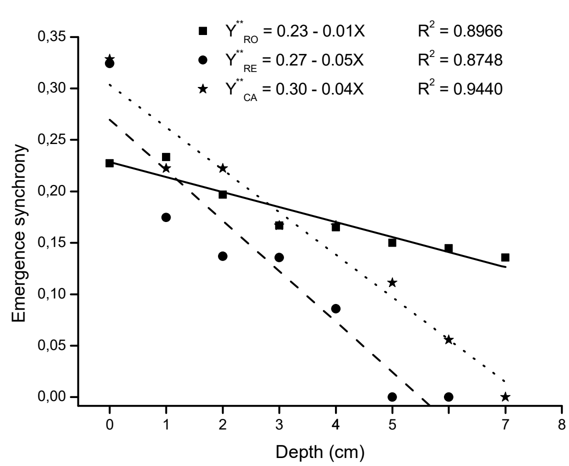
Importantly, although the ecotypes Redenção and Cacoal had higher emergence synchrony for seeds located on the surface, these ecotypes are more influenced by sowing depth when compared with ecotype Rondonópolis, because of the higher slope of the straight line resulting from higher angular coefficients of equations. It should also be noted that seedling emergence synchrony is almost equal when seeds are located at 3.0 cm depth, and ecotype Rondonópolis presents higher emergence synchrony at depths greater than or equal to 4.0 cm (Figure 5).

This fact deserves special attention, because the flow of seed germination of weeds, i.e., germination synchrony, is an important factor for characterization of patterns of infestation of a particular species over time; it is crucial to classify weeds based on their model of emergence to assist control programs, especially integrated ones. In such programs, the chemical and mechanical method is complemented, and both can generally influence the dynamics of weed emergence (Parreira et al., 2009). In addition, the pattern of germination synchrony is a very effective parameter to establish how the species that colonize the same physical space can explore different opportunities by distributing their germination over time differentially (Conserva et al., 2013).

As regards emergence synchrony, ecotypes Redenção and Cacoal can be said to be more effective than ecotype Rondonópolis in establishing in an area where their seeds are located at depths between 0 (zero) and 3.0 cm in the soil, while at greater depths, ecotype Rondonópolis is the one with the greatest advantages.

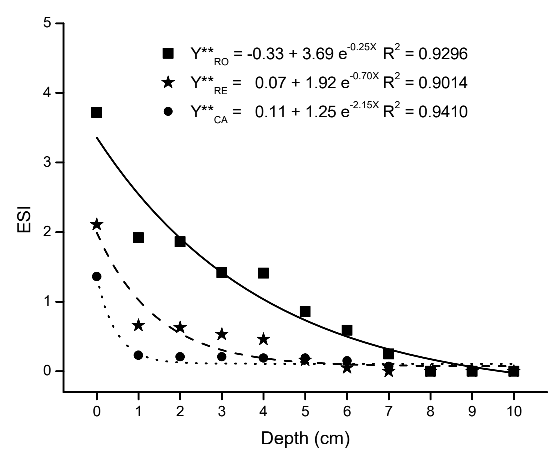
ESI followed the same pattern of exponential response found for seedling emergence percentage; the greater the depth, the lower the ESI values. Again, ecotype Rondonópolis presented the highest ESI values in comparison with the other ecotypes, justified by the smaller value of the constant that multiplies the variable X (Figure 6).

The highest ESI values were found at 0 (zero) cm depth, irrespective of seed origin. ESI also remained virtually unchanged when the seeds were located at depths between 1.0 and 4.0 cm. The lowest ESI values are represented by the depths of 5.0 and 6.0 cm and were null when the seeds were located at depths greater than or equal to 7.0 cm for ecotype Redenção and 8.0 cm for ecotypes Rondonópolis and Cacoal (Figure 6).



** Significant (p≤0.01).

Figure 5 - Seedling emergence synchrony of Rondonópolis (RO), Redenção (RE) and Cacoal (CA) ecotypes, determined on the basis of different seed locations in the substrate.



** Significant (p≤0.01).

Figure 6 - Emergency Speed Index of Rondonópolis (RO), Redenção (RE) and Cacoal (CA) ecotypes, determined on the basis of different origins and seed depths in the substrate.

Thus, it can be concluded that razor grass seeds from Rondonópolis/MT, Redenção/PA and Cacoal/RO can establish better in pasture areas when located on the soil surface, because maximum percentage, greater uniformity and maximum speed for seedling emergence were found in this condition.

Conversely, emergence and establishment of the species are impaired as seed depth increases in the soil profile, and establishment may be null when seeds are located at depths equal to or greater than 7.0 cm.

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