

## Factors influencing the germination and emergence of tall windmill grass (*Chloris polydactyla*) and swollen fingergrass (*Chloris barbata*)

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### Abstract

This study characterized the germination of seeds of *Chloris polydactyla* (synonymy *Chloris elata*) and *Chloris barbata* at varying temperature, luminosity, soil texture and cover. The first experiment WAS conducted in laboratory to determine the temperature and light effects on germination of these species. The experimental design was a 2x7 factorial, where 2 represents the absence/presence of light and 7 temperatures 15, 20, 25, 30, 35, 40 and 45°C. The second experiment was conducted in greenhouse to determine effect of edaphic factors on seedling emergence, in a 3x6 factorial arrangement, consisting of 3 soil textures (sandy, medium and clayey) and 6 sowing depths (0, 1, 2, 4, 6 and 8 cm). The third experiment was conducted in greenhouse to determine soil cover effects and to evaluate the percentage reduction of dry matter of weeds, where the treatments were mulching with 0, 5, 10, 15 and 20 t ha<sup>-1</sup> sugarcane straw. All experiments were conducted in completely randomized design, analyzed separately for each species. No seed was germinated under absence of light. Both species achieved better germination in medium textured soil. It was observed that the emergence of the species was low even without straw. *Chloris* showed better germination under higher temperatures of 30°C and 35°C, although exhibited a drastic decline in the emergence with the increase in soil depth or mulching with sugarcane straw. Greater germination of these weeds occurs in medium textured soils.

**Keywords:** Biology of weeds; luminosity; poaceae weeds; seeds; soil texture; straw; temperature; weeds.

**Abbreviations:** DAS\_days after sowing; E%\_emergence percentage.

### Introduction

The genus *Chloris* is represented by annual or perennial plants with C4 photosynthesis cycle, belonging to the family Poaceae, well-developed Kranz anatomy and with high adaptive capacity to different habitats (Kissmann and Growth, 2007).

In Brazil, the weed tall windmill grass [*Chloris barbata* Sw.] has the highest incidence in the Northeast region and the weed swollen fingergrass [*Chloris polydactyla* (L.) Sw. (synonymy *Chloris elata* Desv.)] is found in the North, Central-West regions of the country. However, the occurrence of these weeds has expanded in the last few years to the south of Brazil, especially in roadsides, vacant lands, pastures, orchards, and with greater economic importance, in crops such as sugarcane and soybean (Kissmann and Growth, 2007). Hence, these weeds are present in different environments and crops in Brazil.

In the sugarcane crop, one of the greatest losses in yield is caused by weeds. It is estimated that for each 26.5 grams of dry matter accumulated by the weed plants per square meter, the final yield of the crop is reduced by 1 ton per

hectare according to the local phytosociology (Kuva et al., 2003).

In the raw sugarcane system, an important weed control factor is the deposition of straw on the soil, which can inhibit the germination and the growth of weeds. This inhibition can be physical or chemical, and in this system, a drastic reduction in the incidence of grasses is observed (Yamauti et al., 2011). In addition to the negative influence on the sugarcane crop, these species are already beginning to be found in the edges of soybean crops (Rasool et al., 2017).

The increase in the frequency and number of individuals of the genus *Chloris* in Brazil might be due to emergence of populations with resistance to glyphosate, which are being selected for the incorrect application of this herbicide (Barroso et al., 2014; Brunharo et al., 2016).

This genus is already a major problem in Australia, whereas two populations of *Chloris truncata* R. Br. and three populations of the *Chloris virgata* Swartz species are considered resistant to the group of inhibitors of the EPSPs

(Heap, 2019). This genus began to be more economically important when the species *C. truncata* and *C. virgata* acquired resistance to the herbicide glyphosate (Watt, 2016). The no-tillage system in Australia also favoured its dispersal due to non-tillage practices and fallow periods. Thus, they are among the main grass weed species in this country (Daniel, 2016; Ferguson et al., 2019).

One factor that Brazil should be aware of is that the species of the genus *Chloris* are among the 10 weeds most frequently in Argentina. Although there is no record of resistant plants in this country, authorities have reported a major problem for control outside the recommended stage or perennial plants (Metzler et al., 2014). Studies of weed biology, especially herbicide-resistant plants, provide a better understanding of their vital and adaptive characteristics, so that they can be used to adjust practices to the integrated management. The characterization of germination is of great value to reduce or inhibit the emergence of weeds present in the seed bank of a crop (Wu and Owen, 2015). In this context, the study of germination of *C. polydactyla* and *C. barbata* is of paramount importance to avoid the spread of resistance of these plants, as well as to propose specific management for each case, given that both have high potential for seed production and dispersal (Carvalho et al., 2005b). The aim of this study was to characterize the germination of *C. polydactyla* and *C. barbata* seeds in different environments, by varying temperature, presence or absence of light and edaphic characteristics and soil cover.

## Results

### **Effect of temperature and light on germination**

*C. barbata* presented better germination in the range of 25 - 35°C, with its germination peak near 30°C. For *C. polydactyla*, this range was kept but the germination peak was close to 35°C (Fig. 1). Comparing the species, we observed a significant difference in the ideal temperature range, where *C. polydactyla* reached germination 50% higher than *C. barbata*.

### **Effect of light on germination**

All seeds under absence of light did not germinate, regardless of the temperature, to which they were subjected. So, these species can be classified as positive photoblastic.

### **Edaphic effects on germination**

The regression analysis of germination data in *C. barbata* showed no fit to the model for the medium soil texture at different depths.

The studied species achieved better germination in medium textured soil. This soil texture provided 20% and 10% more emergence for *C. polydactyla* and *C. barbata*, respectively, compared to the other textures. The depth at which the seed was sown in the soil showed a decisive effect on the emergence of these species, so that the increase in depth caused a linear reduction in the emergence of *C. polydactyla* and *C. barbata* for all the studied textures.

For *C. polydactyla*, the germination in the medium texture was superior in all the depths and the sandy and clay

textures. Seeds of *C. barbata* exhibited a similar response, however, the clay texture caused a greater decline in the germination at shallow depths, compared to the sandy texture. In its best conditions, sandy soil of surface, this species germinated 50% less than *C. polydactyla*, even under ideal conditions (Fig. 2).

### **Effect of soil cover on emergence**

We observed that the emergence of the species was low even without straw, whereas. Only 14% of the total seeds of *C. barbata* (3.5 seeds) and 53% (13 seeds) of *C. polydactyla* were emerged. With deposition of only 5 t ha<sup>-1</sup> of cane straw, there was a decrease in the germination of both species, where 12% of *C. barbata* and 16% *C. polydactyla* were emerged. At 10 t ha<sup>-1</sup> of straw deposition, the emergence of both species was less than 8% (Fig. 3). In response to the initial amounts of sugarcane straw, *C. barbata* germination was reduced by 80% of dry mass by deposition of 5 t ha<sup>-1</sup> of mulch, whereas *C. polydactyla* showed a reduction of 91% of dry mass using 5 t ha<sup>-1</sup> of mulch as cover. With the increase of sugarcane straw to 10 t ha<sup>-1</sup>, the reduction of two species reached around 95%. From this amount of cover, the reduction in the dry mass is continuous until reaching a reduction of 100% in the dry mass of these weeds (Fig. 4).

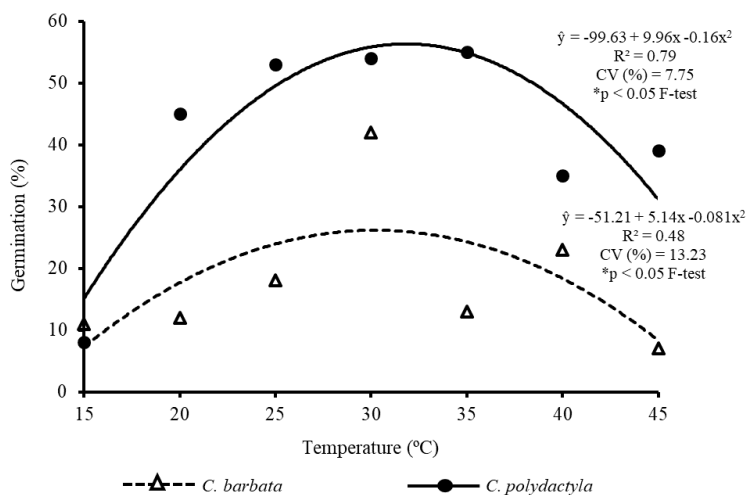
## Discussion

It is known that the temperature influences the water absorption rate of the seeds, interacts with plant hormones altering the endogenous levels and the biochemical reactions that determine the whole process, thus affecting germination (Marcos Filho, 2015). Carvalho et al. (2005a) found that *C. polydactyla*, requires temperature higher than 25°C to achieve good germination, with better performance under alternating temperatures of 20 - 30°C. The weed *C. truncata* R. Br. shows an ideal germination under alternating temperature of 30/20 °C, whereas *C. virgata* Sw. exhibited excellent germination in 15 - 30°C range (Maze et al., 1993; Department of Agriculture and Food Western Australia, 2014). In Australia, an optimal temperature of 28°C with higher fresh matter accumulation was reported for *C. truncata*, within lower and upper limits of 10 and 34°C for development of this plant (Michael et al., 2012). Light is a key factor in the germination of seeds of many weeds, such as *Conyza* spp. (Nandula et al., 2006), but not essential for many species including *Ipomoea triloba* L., which germinates without light (Chauhan and Aguglio, 2012). Light is responsible for activating seed phytochrome, initiating the germination process (Cardoso et al., 2012). Carvalho et al. (2005a) reported that seeds of *C. polydactyla* cannot germinate without light even at the ideal temperature. Invasive species *C. truncata* and *C. virgata* also required light to germinate (Maze et al., 1993; Department of Agriculture and Food Western Australia, 2014).

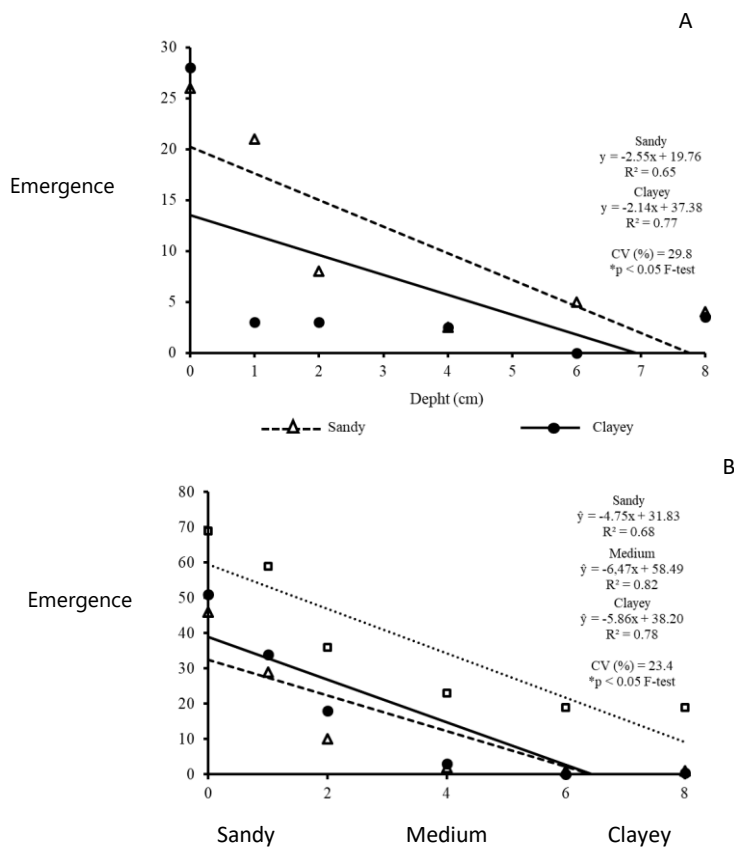
According to Silva et al. (2009), the use of potassium nitrate stimulated germination of *C. barbata* and triggered germination even without light. It is known that nitrate has beneficial action on positive photoblastic seeds, because it reduced the light energy requirements acting as a support for phytochrome,

**Table 1.** Granulometric classification of soils used for different experimental textures in the seeding of genus *Chloris* species under different depths.

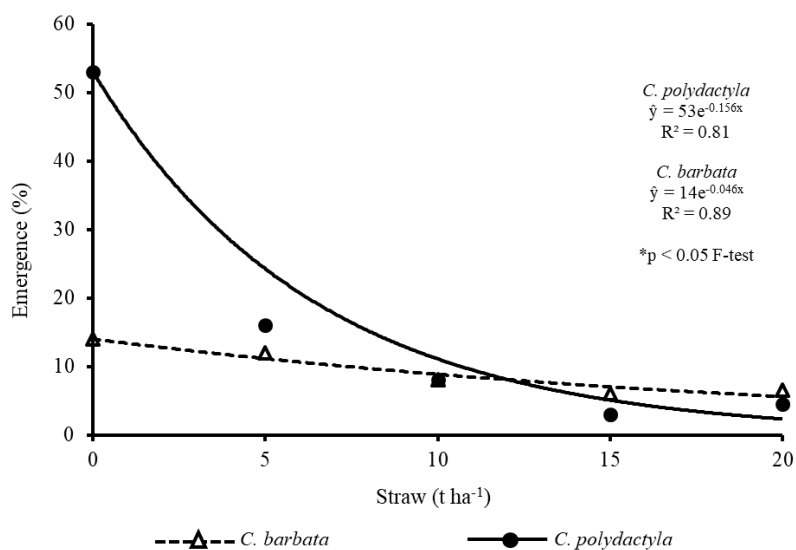
Soil contents (g Kg <sup>-1</sup> )	Classification of soil		
	Clayey	Medium	Sandy
Sand	339	595	740
Silt	134	92	21
Clay	528	314	239



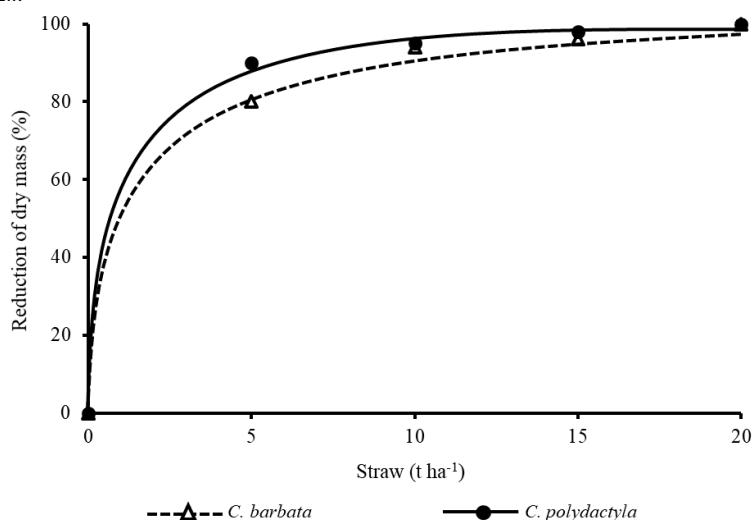
**Fig 1.** Average germination of the seeds of *C. barbata* and *C. polydactyla* submitted to different temperatures in 12-hour photoperiod of light, Piracicaba, São Paulo, Brazil.



**Fig 2.** Mean values of the emergence of *C. barbata* (A) and *C. polydactyla* (B) seedlings, in function of soil sowing depth and soil texture, Piracicaba, São Paulo, Brazil.



**Fig 3.** Mean values for the seedlings emergence (%) of *C. barbata* and *C. polydactyla* due to increased coverage of sugarcane straw, Piracicaba, São Paulo, Brazil.



**Fig 4.** Mean values for the reduction of dry matter (%) of *C. barbata* and *C. polydactyla* due to increased coverage of sugarcane straw, Piracicaba, São Paulo, Brazil.

However, interaction between nitrate and light is necessary, since it is verified that the efficacy of this depends on the presence of Fvd (Marcos Filho, 2015). For *Chloris gayana* Kunth., the optimal germination occurs with day/night temperature alternation of 20/30 °C or 20/35 °C, with minimum photoperiod of 8 hours of light per day (Brazil, 2009).

The weed *C. truncata* has caused major problems in areas of Australia. It showed better germination in lighter textured soils and only 5% of its seeds germinate out of the 0 - 2 cm depth range (Maze et al., 1993; Department of Agriculture and Food Western Australia, 2014). These data corroborate with Brighenti et al. (2007), reporting that seeds of *C. polydactyla* germinated by 60% on the surface of the soil. This germination was decreased to 44, 28, 12 and 0% with increase in depth of 1, 2, 3 and 4 cm, respectively. There is decisive influence of depth on plant establishment. According to Davis and Renner (2007), many species in the

seed bank do not emerge because of greater depth caused by some crop practices. Seeds with little reserves cannot develop seedlings to reach the soil surface and to initiate the photosynthetic processes. Moreover, those that emerge from great depths are chlorotic and consequently more susceptible to different weed management methods.

The influence of straw on the emergence of these weeds is associated with the need for abundant light for their germination, highlighted by the first experiment of this work. The straw represents a physical barrier to the entry of the light lengths required for activation of phytochrome and the consequent onset of germination (Carvalho et al., 2005a; Silva et al., 2009; Yamauti et al., 2011).

Another possible justification for this reduction is the slow initial growth of the species (Carvalho et al., 2005b), which along with their low energy reserve in the diaspore, can cause germinated seedlings not to grow beyond the straw layer and to start production of energy from photosynthesis

(Pitelli and Durigan, 2001). In the second experiment, the same was occurred for the soil barrier that hindered germination of both species.

These sugarcane residues also decreased the soil temperature and its oscillations (Galdos et al., 2009; Cerri et al., 2011), which for the species studied would be detrimental since they show a better germination with temperatures above 25°C. Based on these results, it can be concluded that management actions such as soil cover with plant material are indicated when these species are present. It is observed that the requirement of light is essential for establishment of seeds and seedlings, which corroborates other studies (Carvalho et al., 2005a; Brazil, 2009; Department of Agriculture and Food Western Australia, 2014). Therefore, the use of suitable cultivars to accelerate canopy closure is essential for management of weeds.

Due to the biological characteristics of this genus, management techniques such as soil inversion aiming to bury seeds more than 5 cm deep, or preferably 10 cm, are effective in reducing the viability of the seed bank by 60 - 70%. Therefore, association of these practices with herbicides with residual effect has been an ideal management for areas with high infestation (Department of Agriculture and Food Western Australia, 2014).

Finally, morphological characteristics of the seeds are presented to facilitate the identification of the species studied, where *C. barbata* has 3 awned lemma, with the lower lemma ciliate on the margins and carena, second and third lemmas reduced to glabrous scales, and *C. polycatyla* has two awned lemma, with the lower lemma ciliate on the margins and carena, the second glabrous lemma, and the third reduced to scales (without awn) (Kissmann and Growth, 2007).

## Materials and methods

### Location and plant material

The experiments were set up and conducted at the Crop Science Department of USP/ESALQ (University of São Paulo / "Luiz de Queiroz" College of Agriculture), in Piracicaba, state of São Paulo, Brazil (22°42'30.9"S 47°37'42.9"W). Seeds of *C. polycatyla* and *C. barbata* were collected from plants in the region and correctly identified in the botanical area of the same university.

### Temperature and light effects on germination

The germination test was carried out in transparent plastic box for light treatments and opaque for dark treatments. In each box, 50 seeds were sown on paper towels moistened with an amount of water equivalent to 2.5 mass of the paper. For the treatment with light presence, the plates were subjected to a 12:12 light-dark photoperiod, in BOD (MA415, Marconi Equipamentos para Laboratórios Ltda, Piracicaba, SP, Brazil) germination chamber.

The temperatures of 15, 20, 25, 30, 35, 40 and 45°C were used for each species and light condition in a completely randomized design, in a 2x7 factorial arrangement, where 2 represents the absence (12 hours without light) and presence (12 hours with light) of light and 7, the temperatures tested, with 4 replications per treatment.

The germination was evaluated by daily counting of seedlings with a radicle longer than 0.2 mm, until 15 days after sowing (DAS), evaluating the treatments of darkness under green light (Krzyanowski et al., 1999).

Data were analyzed separately for each specie, and tested by analysis of variance and F-test ( $p < 0.05$ ), comparing the different depths through regression analysis ( $p < 0.05$ ). For this purpose, the Sisvar 5.6 software was used (Ferreira, 2011). To choose the best regression model, the following adjustment criteria were followed: biological explanation, significant regression, non-significant regression deviations and coefficient of determination.

### Edaphic effects on germination

The second experiment was conducted in a greenhouse, with an average temperature of 26 °C, relative humidity of 60% and daily irrigation of 5mm day<sup>-1</sup>, for *C. polydactyla* and *C. barbata*, using 3 L pots filled with different classes of soil and 25 seeds of each species sown at different depths.

The experimental design was completely randomized with a 3x6 factorial arrangement, with 3 soil textures (sandy, medium and clayey) and 6 sowing depths 0, 1, 2, 4, 6 and 8 cm, with 4 replications per treatment. The soils used in the experiment were classified according to FAO (2009) as clayey, medium and sandy, because they contain the following amounts of textural components (Table 1).

Seedling emergence was evaluated at 5, 10, and 20 days after sowing (DAS), and the total emergence at the end of the period (E%) was inferred. The count was completed at 20 days after sowing, when no new emergencies were observed for more than 3 consecutive evaluations.

Data were analyzed separately for each specie and tested by analysis of variance and F-test ( $p < 0.05$ ), comparing the different depths through regression analysis ( $p < 0.05$ ). For this purpose, the Sisvar 5.6 software was used (Ferreira, 2011). To choose the best regression model, the following adjustment criteria were followed: biological explanation, significant regression, non-significant regression deviations and coefficient of determination.

### Effects of soil cover on emergence

The third experiment was conducted under greenhouse conditions. The same conditions mentioned previously were applied in which 25 seeds of *C. polydactyla* and *C. barbata* were germinated in 3 L pots, 0.5 cm deep. Five amounts of sugarcane straw were used for each biotype (0, 5, 10, 15 and 20 t ha<sup>-1</sup>), which were deposited on the seeds and soil once dried.

This was a completely randomized experimental design with four replicates per treatment. Straws were collected from a sugarcane field nearby, with the sugarcane variety RB 867515.

Seedling emergence was evaluated by counting from seven days to twenty-eight days after sowing, at which the plants were cut close to the soil, storing their shoots in Kraft paper bags. This material was oven-dried at 60°C for 72 hours, which after dry, was weighed on a scale accurate to 2 decimal places.

With these values, we calculated the percentage reduction of the dry mass with increasing amounts of straw in relation to the control. Data were analyzed separately for each

species and tested by analysis of variance and F-test ( $p < 0.05$ ). Once the analysis of variance for the data obtained was significant, they were subjected to regression analysis. For this purpose, the Sisvar 5.6 software was used (Ferreira, 2011). To choose the best regression model, the following adjustment criteria were followed: biological explanation, significant regression, non-significant regression deviations and coefficient of determination.

## Conclusion

The *Chloris* species analyzed here showed better germination and germination speed index under higher temperatures, close to 30°C and 35°C. Furthermore, these also presented a drastic decline in the emergence with the increase of the depth in the soil or mulching with sugarcane straw. The greater germination of the species analyzed occurs in medium textured soils.

## References

- Barroso AAM, Albrecht AJP, Reis FC, Placido HF, Toledo REB, Albrecht LP, Victoria Filho, R (2014) Different glyphosate susceptibility in *Chloris polydactyla* accessions. *Weed Technol.* 28(4): 587-291.
- Brazil (2009) Regras para análise de sementes. Ministério da Agricultura Pecuária e Abastecimento, Brasília.
- Brighenti A, Voll E, Gazziero DLP (2007) *Chloris polydactyla* (L.) Sw., a perennial Poaceae weed: Emergence, seed production, and its management in Brazil. *Weed Biol Manag.* 7(2): 84-88.
- Brunharo CACG, Patterson EL, Carrijo DR, Melo MS, Nicolai M, Gaines TA ... Christoffoleti PJ (2016) Confirmation and mechanism of glyphosate resistance in tall windmill grass (*Chloris elata*) from Brazil. *Pest Manag Sci.* 72(9): 1627-1802
- Cardoso VJM (2012) Germination. In: Kerbauy GB (ed) Plant physiology. Guanabara Koogan, Rio de Janeiro.
- Carvalho SJP, Nicolai M, López-Ovejero RF, Christoffoleti PJ (2005a) Influência da luz, temperatura e profundidade da semente no solo sobre a germinação e emergência do capim-branco (*Chloris polydactyla*). *Bol Inf – SBPCD.* 11: 11-15.
- Carvalho SJP, Nicolai M, López-Ovejero RF, Christoffoleti PJ (2005b) Growth, development and seed production of *Chloris polydactyla*. *Planta Daninha.* 23(4): 603-609.
- Cerri CC, Galdos MV, Maia SMF, Bernoux M, Feigl BJ, Powlson D, Cerri CEP (2011) Effect of sugarcane harvesting systems on soil carbon stocks in Brazil: an examination of existing data. *Eur J Soil Sci.* 62: 23-28.
- Chauhan BS, Abugho SB (2012) Threelobe morningglory (*Ipomoea triloba*) germination and response to herbicides. *Weed Sci.* 60(2): 199-204.
- Daniel R (2016) Fallow management of grass weeds. <https://grdc.com.au/Research-and-Development/GRDCUpdatePapers/2016/06/Fallow-Management-of-Grass-Weeds> [accessed 06 August 2017]
- Davis AS, Renner KA (2007) Influence of seed depth and pathogens on fatal germination on velvetleaf (*Abutilon theophrasti*) and giant foxtail (*Setaria faberi*). *Weed Sci.* 55(1): 30-35.
- Department of Agriculture and Food Western Australia (2014) Integrated weed management of feathertop rhodes grass. <http://grdc.com.au/Resources/Publications/2014/11/Integrated-Weed-Management-of-Feathertop-Rhodes-Grass-2014> [accessed 06 August 2017]
- Ferguson JC, Chauhan BS, Chechetto RG, Hewitt AJ, Adkins SW, Kruger GR, O'Donnell CC (2019) Droplet-size effects on control of *Chloris* spp. with six POST herbicides. *Weed Technol.* 33(1): 153-158.
- Ferreira DF (2011) Sisvar: a computer statistical analysis system. *Cienc Agrotecnol.* 35: 1039-1042.
- Food and Agriculture Organization of The United Nations [FAO] (2009) Guide for the description of soils [online]. Website <http://www.fao.org/3/a-a0541s.pdf> [accessed 08 August 2017]
- Galdos MV, Cerri CC, Cerri CEP (2009) Soil carbon stocks under burned and unburned sugarcane in Brazil. *Geoderma.* 153: 347-352.
- Heap I (2019) International survey of herbicide resistant. <http://www.weedscience.org> [accessed 01 March 2019]
- Kissmann KG, Groth, D (2007) Plantas infestantes e nocivas, 3th ed. BASF, São Paulo.
- Krzyanowski FC, Vieira RD, França Neto JB (1999) Vigor de sementes: conceitos e testes. Abrates, Londrina.
- Kuva MA, Gravena R, Pitelli RA, Christoffoleti PJ, Alves PLCA (2003) Interference periods of weeds in the sugarcane crop. III – *Brachiaria decumbens* and *Panicum maximum*. *Planta Daninha.* 21(1): 37-44.
- Marcos Filho J (2015) Fisiologia de sementes de plantas cultivadas. Abrates, Londrina.
- Maze KM, Koen TB, Watt LA (1993) Factors influencing the germination of six perennial grasses of central New South Wales. *Aust J Bot.* 41(1): 79–90.
- Metzler M, Papa JC, Tiesca D (2014) *Chloris* spp. un problema en franca expansión. INTA – EEAP, Oro Verde Entre Ríos.
- Michael PJ, Yeoh PB, Scott JK (2012) Potential distribution of the Australian native *Chloris truncata* based on modelling both the successful and failed global introductions. *PLoS one.* 7(7): e42140.
- Nandula VK, Eubank TW, Poston DH (2006) Factors affecting germination of horseweed (*Conyza canadensis*). *Weed Sci.* 54(5): 898-902.
- Pitelli RA, Durigan JC (2001) Ecologia das plantas daninhas no sistema de plantio direto. In: Rossello RD (ed) Siembra directa en Cono Sur. PROCISUR, Montevideo.
- Rasool G, Mahajan G, Yadav R, Hanif Z, Chauhan BS (2017) Row spacing is more important than seeding rate for increasing Rhodes grass (*Chloris gayana*) control and grain yield in soybean (*Glycine max*). *Crop Pasture Sci.* 68: 620-624.
- Silva JL, Guimarães SC, Yamashita OM (2009) Germinação de sementes de *Chloris barbata* (L.) Sw. em função da luz. *Rev Cie Agro-Amb.* 7: 23-34
- Watt S (2016) Feathertop rhodes grass is on the move and is glyphosate resistant. <https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Feathertop-Rhodes-grass-is-on-the-move-and-is-glyphosate-resistant>. [accessed 01 October 2018]

Wu C, Owen MDK (2015) When is the best time to emerge— II: seed mass, maturation, and afterripening of common waterhemp (*Amaranthus tuberculatus*) natural cohorts. Weed Sci. 63(4): 846-854.

Yamauti MS, Barroso AAM, Giancotti PRF, Squassoni VL, Revolti LTM, Alves PDC (2011) Weed emergence as a function of seed position and quantity of sugarcane straw. Sci Agraria. 12: 75-80.