Growth and Development of Sourgrass Based on Days or Thermal Units[1]

Crescimento e Desenvolvimento do Capim-Amargoso com Base em Dias ou Unidades Térmicas

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ABSTRACT - This work was carried out with the objective of evaluating growth and development of sourgrass (*Digitaris insularis*) based on days or thermal units (growing degree days - GDD). Two independent trials were developed aiming to quantify the species' phenological development and total dry matter accumulation in increasing or decreasing photoperiod conditions. Plants were grown in 4 L plastic pots, filled with commercial substrate, adequately fertilized. In each trial, nine growth evaluations were carried out, with three replicates. Phenological development of sourgrass was correctly fit to time scale in days or GDD, through linear equation of first degree. Sourgrass has slow initial growth, followed by exponential dry matter accumulation, in increasing photoperiod condition. Maximum total dry matter was 75 and 6 g per plant for increasing and decreasing photoperiod conditions, respectively. Thus, phenological development of sourgrass may be predicted by mathematical models based on days or GDD; however, it should be noted that other environmental variables interfere on the species' growth (mass accumulation), especially photoperiod.

Keyword: *Digitaria insularis*, growing degree days, phenology, dry matter, biology.

*RESUMO - Objetivou-se neste trabalho avaliar o crescimento e o desenvolvimento do capim-amargoso (**Digitaria insularis**) com base em dias ou unidades térmicas acumuladas (graus-dia - GD). Para isso, dois experimentos independentes foram realizados visando quantificar o desenvolvimento fenológico e o acúmulo de matéria seca total da espécie, em condição de fotoperíodo crescente ou decrescente. As plantas foram cultivadas em vasos plásticos de 4 L, preenchidos com substrato comercial, devidamente fertilizado. Em cada experimento, foram realizadas nove avaliações de crescimento, com três repetições. Houve adequado ajuste do desenvolvimento fenológico do capim-amargoso à contagem de tempo em dias ou unidades térmicas acumuladas (GD), por meio da equação linear de primeiro grau. A espécie possui crescimento inicial lento, com posterior acúmulo exponencial de matéria seca, na condição de fotoperíodo crescente. Registrou-se matéria seca total máxima de 75 e 6 g por planta para condição de fotoperíodo crescente e decrescente, respectivamente. Conclui-se que o desenvolvimento fenológico do capim-amargoso pode ser previsto por meio de modelos matemáticos com base em dias ou unidades térmicas acumuladas; contudo, ressalta-se que outras variáveis ambientais interferem no crescimento da espécie (acúmulo de matéria seca), com destaque para o fotoperíodo.*

Palavras-chave: *Digitaria insularis*, graus-dia, fenologia, matéria seca, biologia.

INTRODUCTION

Among weed infestations commonly found in Brazilian farming areas is sourgrass (*Digitaria insularis*). It is a perennial, herbaceous, clustered, rhizomatous species, with erect and striated culm, 50-100 cm high (Kissmann & Groth, 1997). This species often requires the application of glyphosate rates higher than those recommended for an

[1] Recebido para publicação em 21.11.2013 e aprovado em 20.3.2014.
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appropriate control of other species of the family Poaceae. Timossi et al. (2006) observed that an application of 1,440 g ha^{-1} of glyphosate resulted in a satisfactory control of the infesting community but it did not prevent sourgrass re-shooting.

In field observations of areas where glyphosate is used continuously, it has been found that the areas with young plants grown from seeds are controlled by the herbicide; however, when they grow and form rhizomes control is ineffective (Machado et al., 2006). Machado et al. (2008) commented that the greatest difficulty in controlling sourgrass plants grown from rhizomes might be related to the greater thickness of the adaxial and abaxial epidermis and of the leaf blade, when compared to plants originated from seeds. Also, they observed a great amount of starch in the rhizomes, which can hinder glyphosate translocation and allow quick re-growth of the shoots. Correia et al. (2010) found different susceptibility to glyphosate herbicide among sourgrass populations. Currently, reported resistance of sourgrass to glyphosate is also found in the literature (Melo, 2011).

Thus, an analysis of the plants behavior in view of ecological factors, as well as the plant' impacts on the environment, especially with regard to their interference with other plants, contributes to the development of weeds integrated management systems (Lucchesi, 1984; Bianco et al., 1995). The ability to predict phenological stages such as flowering, seeds development and dispersal, may help develop management practices (Ghersa & Holt, 1995). Still, the growth characteristics of a given species provide an indicator of its competitive ability (Holt & Orkutt, 1991).

In view of events that may occur during the plant development, there is a need to employ numeric scales to establish levels for this period. Traditionally, days counting has been used to determine the cycle time but it is a variable very much affected by environmental interferences, which are also indirectly expressed in the phenology. Thus, weather temperature has been considered the most important climate element to predict physiological events on condition that no water deficit occurs (Russelle et al., 1984; Gadioli et al., 2000).

The degree-days method is based on the assumption that plants require a certain amount of energy – represented by the sum of thermal degrees necessary to complete a given phenological stage or even the total cycle (Gadioli et al., 2000). In addition, it may assume a linear relation between temperature increase and the plant development (Gadioli et al., 2000). Thus, the use of mathematical models and simulation routines that employ the concept of accumulated growing degree-days becomes possible (Medeiros et al., 2000).

This concept is not different for weeds, but few studies evaluated the development of these species based on accumulated growing degree-days. Prediction of different phenological aspects of cultures, weeds and other plagues with simple thermal equations tends to be an excellent tool to provide practical solutions for farming problems (Ghersa & Holt, 1995). Thus, this work was carried out with the objective of evaluating growth and development of sourgrass (*Digitaris insularis*) based on days or thermal units (growing degree days - GDD).

MATERIAL AND METHODS

Two independent experiments were carried out in the experimental greenhouse of the Instituto Federal do Sul de Minas Gerais, campus of Machado, Machado-MG (21° 40' S; 45° 55' W; 850 m altitude). Sourgrass (*Digitaria insularis*) growth and development were assessed in each experiment. The first experiment was conducted from August to December 2012 (increasing photoperiod), and the second was carried out between March and July 2013 (decreasing photoperiod). *D. insularis* propagules were collected in farming and non-farming areas in the municipality of Machado-MG. Subsequently, the seeds were kept in paper bags in a dry place at room temperature until the beginning of the work.

Sowing was done in 4-liter plastic pots filled with commercial substrate (*Pinus* bark+ peat + vermiculite). Later on, at the plant' stage of two definitive leaves, the seedlings were transplanted to the experimental plots, also consisting of 4-liter plastic pots. Firstly, three seedlings were transplanted per pot. When the seedlings rooted, the plants density was thinned out to a final average density of two plants per pot. The containers were filled with commercial substrate and vermiculite (at a ratio of 3:1; v:v), and added with complete commercial fertilizer, which provided (g pot^{-1}): N at 600; P_2O_5 at 600; K_2O at 800; S at 100; Mg at 20; Zn at 4; B at 0.8; Fe at 8; Cu at 2; Mn at 4; and Mo at 0.8. Additionally, two coverage fertilizations were performed with 630 mg of N and 720 mg of S when full shooting of the plants was identified (six tillers) and in pre-flowering. In both experiments, the pots were irrigated whenever necessary, assuring no water deficit.

At an average interval of three days, the phenology of all population was evaluated. It was used the scale proposed by Hess et al. (1997). The phenological stage was defined when a given characteristic of development was found in 50% + 1 of the total remaining plants. For dry mass accumulation, in both experiments, it was used the randomized blocks experimental design with nine growth evaluations and three replicates. For each evaluation of dry matter, three portions (replicates) were randomly sampled by the destructive method and the plants were washed under running water to remove the remaining substrate found in the roots; then, the material was oven-dried at 70 °C for 72 hours. After drying, the plants' total dry matter was determined (g per plant).

The experiments were evaluated independently through the application of the Ftest in the analysis of variance at 1% probability level. The sourgrass phenological data were adjusted to time scale in days or in accumulated thermal units, or growing degree-days (GDD), through the linear regression model $y = ax$, where y refers to the sourgrass development according to the phenological stage (Hess et al., 1997); x refers to the scale used; and a is the model parameter. In practice, the parameter a of the equation can be understood as the percentage of environmental energy units effectively converted into plant phenology, allowing estimation of the plants development in a given season or sowing time.

To calculate the daily thermal units (GDD), the Gilmore Jr. & Rogers' equation (1958) was used:

$$GD = \left(\frac{T\max + T\min}{2}\right) - Tb$$

where: *Tmax* is the daily maximum temperature; *Tmin* is the daily minimum temperature; and *Tb* refers to basal temperature, evaluated at 10 or 15 °C. The maximum and minimum daily temperatures were obtained from the meteorological station installed at the campus of Machado-MG and available from the *Instituto Nacional de Pesquisas Espaciais* – INPE (Figure 1).

Total dry matter was analyzed by nonlinear logistic regression also based on days or thermal units (GDD). It was adopted the model proposed by Streibig (1988):

$$y = \frac{a}{\left[1 + \left(\frac{x}{b}\right)^{c}\right]}$$

where: y is the response variable of interest; x is time scale (days or GDD); and a, b and c are estimated parameters of the equation (a is the existing amplitude between the maximum and minimum points of the variable; b corresponds to the number of days or degree-days required for the occurrence of 50% of the response variable; and c estimates the slope of the curve).

RESULTS AND DISCUSSION

There was proper fit of the phenological development of sourgrass to the scales used in days or accumulated thermal units (GDD) by means of the first-degree equation with coefficients of determination always higher than 85% (Table 1). In all scales there was overlap of the confidence intervals of the experiments carried out in 2012 and 2013, in increasing and decreasing photoperiod conditions, respectively. This finding suggests similar plant development (phenology) at different times of the year when adjusted to days or degree-days scales.

So, for the species phenology, a joint analysis of the experiments, considering days, Tb = 10 °C or 15 °C (Figure 2) was performed. Basal temperature (Tb) is the minimum

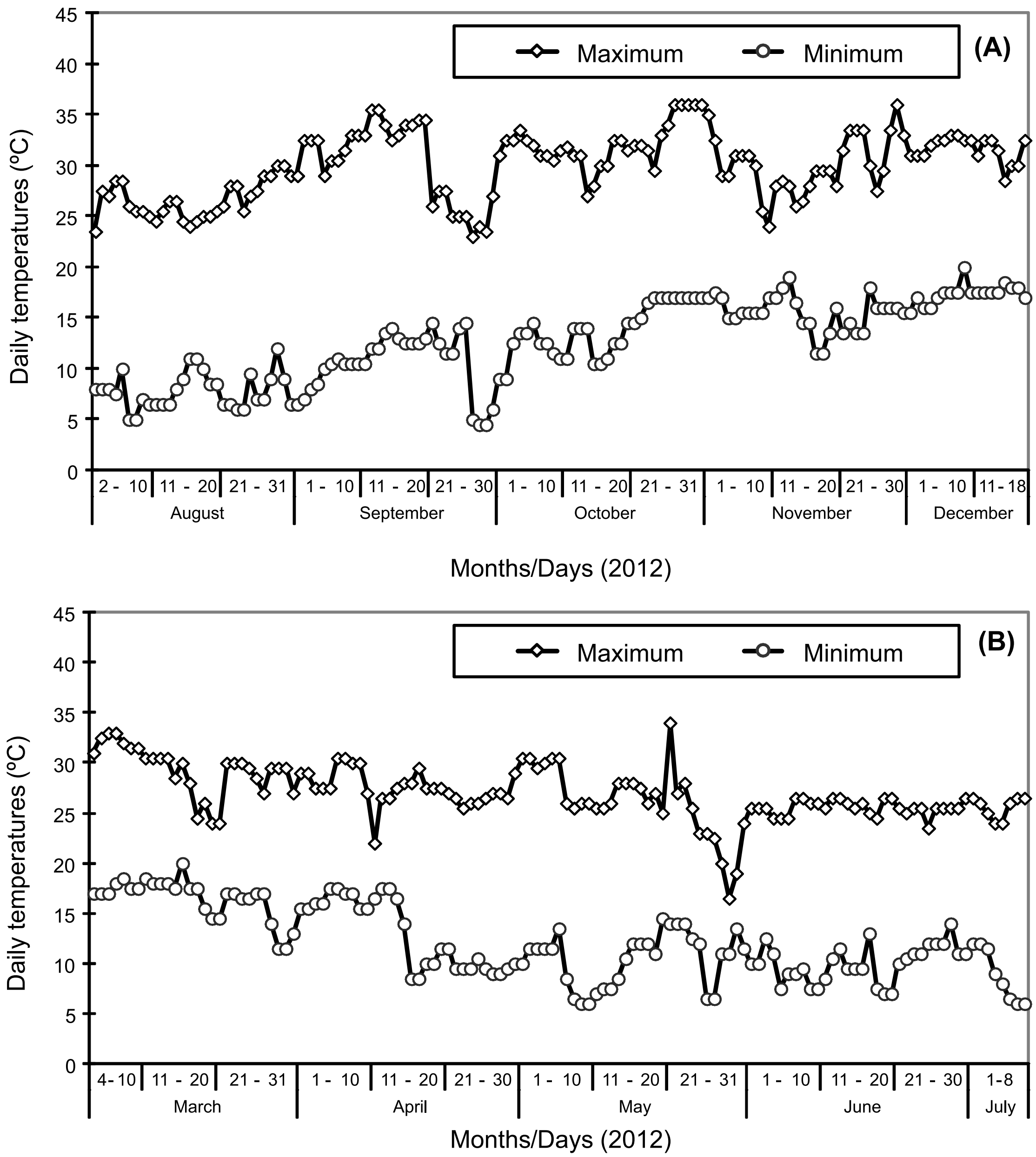

Figure 1 - Maximum and minimum daily temperatures in the period and location of the experiment. (A) second semester 2012; (B) first semester 2013. Machado - MG, 2012/13.

temperature required for the plant's growth, under which growth stops or is drastically reduced. In literature, Tb values = 0 ºC are usually considered for weeds and temperate climate crops, such as barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) (Cao & Moss, 1989; Kirkby, 1995). As for sunflower (*Helianthus annuus*), Granier & Tardieu (1998) found basal temperatures around 4.8 ºC. For redroot pigweed (*Amaranthus retroflexus*), a species with type C_4 photosynthesis, Gramig & Stoltenberg (2007) reported Tb = 8.5. Basal temperatures of about 10 ºC have been reported for beans (Medeiros et al., 2000), corn (Gadioli et al., 2000), *Leonurus sibiricus* (Silva et al., 2014) and forage *Panicum virgatum* (Sanderson & Wolf, 1995). For southern sandbur (*Cenchrus echinatus*), Machado et al. (2014) reported Tb = 12°C. Villa Nova et al. (1999) used Tb = 15°C for elephant grass

Table 1 **-** Adopted scale, residual mean square[1/] (QMres), F-test, coefficient of determination (R^2), parameter *a* of the equation and confidence interval (CI) at 5% significance level, for the adjustment of the phenological development of *Digitaria insularis* to the accumulated degree-days under all experimental conditions. Machado-MG, 2012/13

Photoperiod	Year	Scale	QMres	F	R²	*a*	C.I. (5%)	
							Minimum	Maximum
Increasing	2012	Days	63.876	551.928**	0.9128	0.4571*	0.4162	0.4980
		Bt 10 °C	41.941	849.998**	0.9237	0.0430*	0.0399	0.0461
		Bt 15 °C	38.964	916.321**	0.9252	0.0804*	0.0749	0.0860
Decreasing	2013	Days	35.093	679.572**	0.9186	0.4235*	0.3894	0.4577
		Bt 10 °C	49.462	476.918**	0.9080	0.0413*	0.0373	0.0453
		Bt 15 °C	74.030	312.674**	0.8900	0.0799*	0.0705	0.0895
General		Days	49.086	1202.359**	0.9430	0.4423*	0.4165	0.4681
		Bt 10 °C	43.898	1348.96**	0.9463	0.0423*	0.0399	0.0446
		Bt 15 °C	53.535	1099.28**	0.9402	0.0803*	0.0753	0.0851

[1/] Phenology = a.(degree-days); Tb = basal temperature; * Significant by F- Test at 5% probability level.

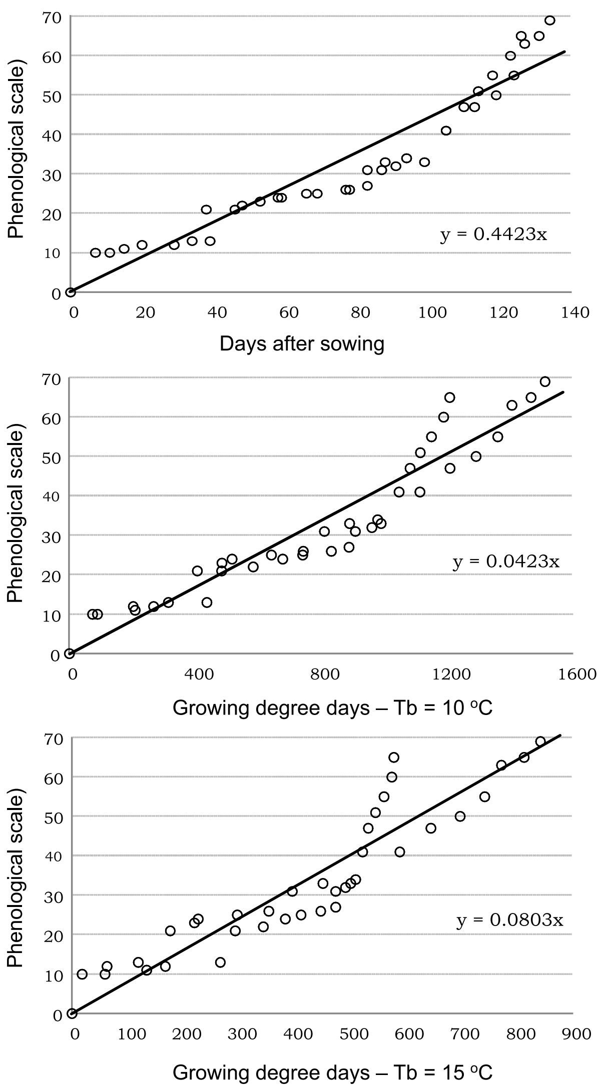

Figure 2 **-** Adjustment of sourgrass phenological development to different scales, considering days and growing degree days, calculated with basal temperature of 10 or 15 °C. Machado-MG, 2013.

(*Pennisetum purpureum*), a tropical plant of the family Poaceae.

Vasconcelos et al. (2012) reported basal temperature of 15 °C for sourgrass in an experiment conducted in decreasing photoperiod (January - July/2011). Thus, considering the size of the sourgrass plant, C_4 photosynthesis and classification as a perennial weed, basal temperatures of 10 °C or 15° as used for the analysis of dry matter can be considered suitable.

Machado et al. (2006), in an experiment carried out between April and August 2004, considered sourgrass as a species with slow initial growth, flourishing between 63 and 70 days after emergence (DAE). Bianco et al. (2012), when cultivating sourgrass between November 2010 and April 2011 also found a slow initial growth of this species, flowering at 63 DAE and maximum accumulation of dry matter at 143 DAE. In the conditions of Machado-MG, on average, the emergence of the species occurred seven days after sowing (DAS) and flowering at 120 DAS or 113 DAE (Table 2).

This information has valuable practical application because is ensures that, after seeds germination there is an interval of at least 60 days available to use the management practices before flowering occurs. Pacheco & De Marinis (1984), when studying southern sandbur (*Cenchrus echinatus*), also observed flowering intervals of the species varying from 60 to 150 DAS. It is worth noting that among the ecological factors, temperature has an unmistakable effect on the growth and productivity of different plant species (McLanchlan et al., 1993; Guo & Al-Khatib, 2003); however, the effect of the photoperiod can be crucial to stimulate or delay the plants' flowering.

Considering Tb = 10 °C, sourgrass flowering was identified after 1,380 and 1,190 accumulated degree-days (GDD), for the increasing and decreasing photoperiod, respectively (Table 2). Similarly, for Tb = 15 °C, flowering of the species was found after 760 and 575 accumulated GDD, for the increasing and decreasing photoperiod, respectively. Although no difference has been identified in the number of days until the species flourished, a lower accumulation of thermal units in the decreasing photoperiod was found.

A slow initial growth occurred in this species with further exponential accumulation of dry matter in the condition of increasing photoperiod (Figure 3). This finding is in agreement with Machado et al. (2006), who reported slow growth at the initial stage until 45 days after transplanting. The maximum values of dry matter were found in the increasing photoperiod condition: around 75 g per plant. In the decreasing photoperiod conditions, the minimum values of accumulated dry matter were observed at the end of the experiment, on average about 6 g per plant. In this aspect, Bianco et al. (2012) reported a theoretical maximum accumulation of dry matter of 12.41 g, while Machado et al. (2006) reported 30.66 g per plant. Melo (2011), when studying two sourgrass biotypes found different growth between them, with total dry matter varying from 30 and 45 g per plant. All parameters of the logistic models adjusted to accumulated thermal units are presented in Table 2.

An overall analysis of the data allows assuming that time scale in days as well as in thermal units, or degree-days (GDD), can be used as an estimator of sourgrass phenology but they do not estimate properly the species' growth with different behaviors under photoperiod conditions (Figure 3). It is clear that other variables also have influence on the accumulation of dry matter and can potentially complement the mathematical model. The flow rate and duration of photosynthetically active radiation, the availability of nutrients and water, the loss of photosynthetic tissue and, surely, the photoperiod, can also impact the plant's growth and development (Russelle et al., 1984; Gramig & Stoltenberg, 2007).

At this point it is worth emphasizing that growing is different from developing. While growing can be understood as an irreversible increase of mass and volume, developing refers to the alternation of successive physiological stages, with expression on the plant's phenology. So, at least theoretically, a plant can grow and not necessarily develop, and vice versa. A global analysis of the environmental variables (Figure 1), phenological development (Table 1; Figure 2), time or temperature required for flowering (Table 2), and accumulation of dry matter (Figure 3), indicates clearly a distinct behavior of the plants regarding the growth-development relationship when they recognize a certain time of the year.

In the increasing photoperiod condition, the phenological development occurs more slowly (760 GDD for flowering; Tb = 15 °C) while

Table 2 - Adopted scale, recorded flowering time, coefficient of determination (R^2) of the model[1/] and parameters *a*, *b* and *c* of the logistic equation used for adjustment of the total dry matter of sourgrass (*Digitaria insularis*), under all experimental conditions. Machado-MG, 2012/13

Year	Photoperiod	Scale	Observed flowering	Parameters of the model			R^2
				a	*b*	*c*	
2012	Increasing	Days	125	132.593	131.264	-6.417	0.982
		Bt 10 °C	1380	121.753	1418.571	-5.335	0.985
		Bt 15 °C	760	118.754	770.334	-4.602	0.986
2013	Decreasing	Days	123	6.971	98.908	-5.805	0.956
		Bt 10 °C	1190	6.825	1002.686	-8.242	0.953
		Bt 15 °C	575	6.393	502.344	-13.816	0.957

[1/] $y = a/(1+(x/b)^c)$; Tb = Basal temperature.

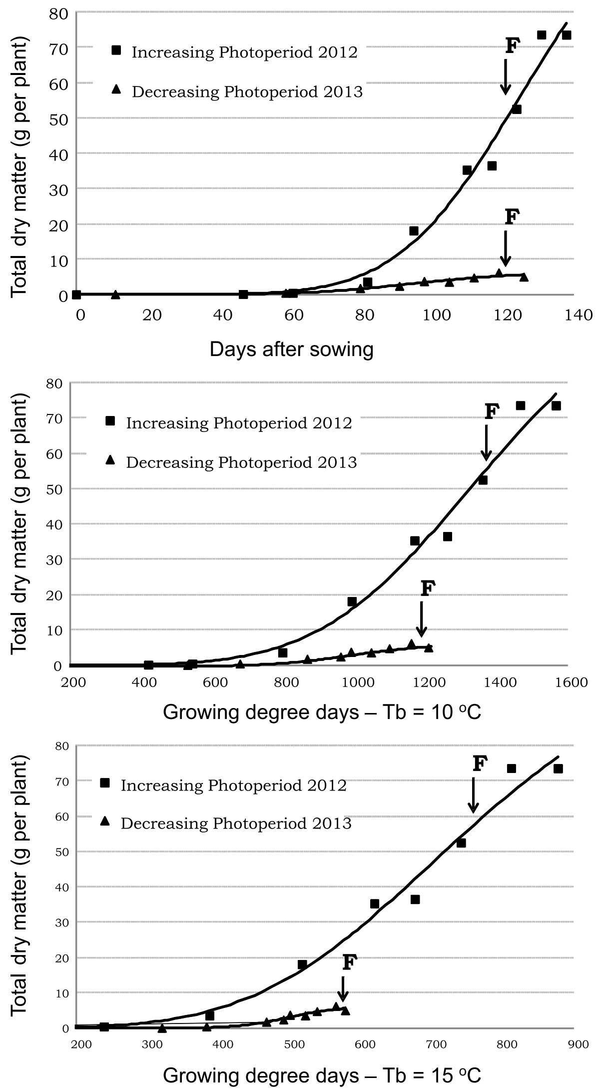

Figure 3 **-** Total accumulated mass of dry matter per sourgrass (*Digitaria insularis*) plant under two distinct growth conditions, adjusted to different scales, considering days and accumulated degree-days, calculated with basal temperature of 10 or 15 °C. F = Flowering phenological stage. Machado-MG, 2013.

the plant allows that a higher calorie yield is directed to the accumulation of dry matter and the establishment in the environment (higher growth rate; Figure 3) and then begin to flourish and produce seeds. In short, it can be assumed that there was a greater investment of the plant in growing and a lower investment in developing.

Conversely, under the decreasing photoperiod condition the situation is reversed, with 575 GDD until flowering and a smaller mass of dry matter. It is possible that the plants recognized the coldest days (Figure 1) or the unfavorable photoperiod (short days) as environmental adversities and started to move a larger portion of the calories to the phenological development. In this condition, it is assumed a greater interest of the species in developing and producing seeds than in growing. There was not a remarkable difference in the number of days until flowering (120), since the thermal accumulation was different in the different seasons.

Potentially, there is a physiological growth-development relationship, which sometimes is balanced, but a higher investment on an event hinders the progress of the other, and vice versa. In short, it can be concluded that mathematical models that use days or accumulated thermal units as a scale for time counting can estimate the phenological development of sourgrass. However, it should be emphasized that other environmental variables also interfere with the species' growth (mass accumulation), especially the photoperiod.

ACKNOWLEDGEMENTS

The authors wish to thank the Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais – IFSULDEMINAS (Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais), campus of Machado, and FAPEMIG, for the support to this research, especially for the scientific initiation scholarship granted to the first author.

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