Initial Growth and Development of Southern Sandbur Based on Thermal Units[1]

Crescimento e Desenvolvimento Inicial do Capim-Carrapicho com Base em Unidades Térmicas

MACHADO, E.C.R.[2], LIMA, R.S.O.[2], SILVA, A.P.P.[2], MARQUES, B.S.[2], GONÇALVES, M.F.[2], and CARVALHO, S.J.P.[2]

ABSTRACT - Availability of basic information on weed biology is an essential tool for designing integrated management programs for agricultural systems. Thus, this study was carried out in order to calculate the base temperature (Tb) of southern sandbur (*Cenchrus echinatus*), as well as fit the initial growth and development of the species to accumulated thermal units (growing degree days - GDD). For that purpose, experimental populations were sown six times in summer/autumn conditions (decreasing photoperiod) and six times in winter/spring condition (increasing photoperiod). Southern sandbur phenological evaluations were carried out, on alternate days, and total dry matter was measured when plants reached the flowering stage. All the growth and development fits were performed based on thermal units by assessing five base temperatures, as well as the absence of it. Southern sandbur development was best fit with Tb = 12 °C, with equation $y = 0{,}0993x$, where y is the scale of phenological stage and x is the GDD. On average, flowering was reached at 518 GDD. Southern sandbur phenology may be predicted by using mathematical models based on accumulated thermal units, adopting Tb = 12 °C. However, other environmental variables may also interfere with species development, particularly photoperiod.

Keywords: *Cenchrus echinatus*, weed, biology, growing degree days, modeling.

*RESUMO - A disponibilidade de informações básicas sobre a biologia de plantas daninhas é uma ferramenta essencial para a elaboração de programas de manejo integrado em sistemas agrícolas. Nesse sentido, este trabalho foi desenvolvido com o objetivo de calcular a temperatura basal (Tb) do capim-carrapicho (**Cenchrus echinatus**), bem como ajustar o crescimento e o desenvolvimento inicial da espécie às unidades térmicas acumuladas (graus-dia). Para isso, foram realizadas seis semeaduras de populações experimentais em condição de verão/outono (fotoperíodo decrescente) e seis semeaduras em inverno/primavera (fotoperíodo crescente). Foi realizado o acompanhamento da fenologia do capim-carrapicho, em dias alternados, bem como se mensurou a matéria seca total no momento do florescimento das plantas. Todos os ajustes de crescimento e desenvolvimento foram realizados com base em unidades térmicas, avaliando-se cinco temperaturas basais, além da ausência desta. O melhor ajuste para desenvolvimento do capim-carrapicho foi obtido com Tb = 12 °C, com equação $y = 0{,}0993x$, em que y diz respeito ao estádio da escala fenológica e x aos graus-dia acumulados. Em média, obteve-se florescimento da espécie com 518 graus-dia. Conclui-se que a fenologia do capim-carrapicho pode ser prevista por meio de modelos matemáticos que utilizem unidades térmicas acumuladas, adotando-se temperatura basal de 12 °C, contudo ressalta-se que outras variáveis ambientais também interferem no desenvolvimento da espécie, com potencial destaque para o fotoperíodo.*

Palavras-chave: *Cenchrus echinatus*, planta daninha, biologia, graus-dia, modelagem.

---

[1] Recebido para publicação em 3.11.2013 e aprovado em 28.1.2014.
[2] Instituto Federal do Sul de Minas Gerais, Campus Machado, Machado - Minas Gerais, Brazil, <edisom_machado@hotmail.com>.

INTRODUCTION

Southern sandbur (*Cenchrus echinatus*) is a weed in the Poaceae family whose occurrence is common in Brazil. It is also known as southern sandspur or burr grass. It has a high competitive potential in crops, but it is much more important for the damage indirectly caused by its spinescent fascicles, i.e., hampering harvesting procedures and/or the quality of the harvested produce (Lorenzi, 2000; Dan et al., 2011), mainly in cotton crops (Salgado et al., 2002).

It is an herbaceous, erect or possibly semiprostrate plant with 20-60 cm in height (Lorenzi, 2000) and it may be totally glabrous or hirsute. According to Kissmann (1997), it can be considered a summer annual species with C4-photosynthetic carbon cycle. In drier regions, its growth is limited and its cycle is shorter. In humid regions, its cycle extends, flowering and fruiting occur for long periods (cycles up to 210 days).

It is known that changes or physiological events that occur during plant development can be defined by numerical scales (Medeiros et al., 2000; Shirtliffe et al., 2000; Gadioli et al., 2000). These scales, most often, are defined as a function of time (days). However, this variable is very subject to environmental interference that is also indirectly expressed in phenology. Thus, temperature is the most important climatic element for predicting physiological events, as long as there is no water deficit (Russelle et al., 1984; Gadioli et al., 2000).

Rates for a wide range of biological processes are markedly altered by temperature. The growth and development of an organism respond to changes in temperature as a result of the integrated effect of many individual physiological processes (Russelle et al., 1984). The concept of thermal time allows accurate estimates of plant phenological development in varied environments (Shirtliffe et al., 2000).

The method of degree days is based on the premise that a plant needs a certain amount of energy, represented by the amount of thermal degrees required to complete any given phenological phase or even the entire cycle. In addition, it enables a linear relationship between temperature increase and plant development (Gadioli et al., 2000; Gramig & Stoltenberg, 2007). Thus, mathematical models and simulation routines based on the concept of degree days can be used (Medeiros et al., 2000).

This concept is no different for weeds, but few studies have assessed the development of these species based on accumulated degree days. According to Ghersa & Holt (1995), the ability to predict different phenological aspects of crops, weeds and other pests with simple thermal equations tends to be an excellent tool to provide practical solutions to crop-related problems.

Accordingly, studies on weed growth and development provide information about the different phenological stages and patterns of plant growth. These results allow the analysis of how plants behave towards ecological factors, as well as their effect on the environment, especially regarding their interference on other plants, which may contribute to the development of integrated weed management systems (Lucchesi, 1984; Bianco et al., 1995).

This study was developed with the aim of calculating the base temperature (Bt) of southern sandburn (*Cenchrus echinatus*) and fitting the initial growth and development of the species to the accumulated thermal units (degree days).

MATERIAL AND METHODS

The whole work was carried out in an experimental nursery. The experiment was divided into two sowing periods, during the year 2012. In each period, initial growth and development of southern sandburn (*Cenchrus echinatus*) were assessed under the following conditions: summer/fall (first period) and winter/spring (second period). The first period of the experiment took place between February and May 2012 (decreasing photoperiod), and the second, between August and November of the same year (increasing photoperiod).

The fascicles of southern sandbur were collected in agricultural and non-agricultural areas of the municipality of Machado - MG. Later, they were packed in paper bags and kept in a dry place at room temperature for later use in the experiment. The experimental design was completely randomized as there was no direct interest in the comparison of sowing periods. The observations of 12 sowing dates (treatments) and five replications were discussed. Plots consisted of 4 L plastic pots filled with commercial substrate (Carolina II ®), 3,0 g of NPK 04:14:08 (N, P_2O_5, K_2O) and 1,2 g of ammonium sulfate were added in each plot. The pots were irrigated whenever necessary, avoiding water deficiency.

At each stage of the experiment, six sowings of southern sandbur were performed. In the first phase (decreasing photoperiod), sowings were made on 02/16, 02/23, 03/01, 03/08, 03/15 and 22/03; and in the second, on 08/03, 08/10, 08/17, 08/24, 08/31 and 09/07. On each date, 80 fascicles were distributed directly along the experimental plots. After emergence, the pots were successively thinned while keeping final density of four plants per plot.

In each plot, at the time of seedling emergence, phenological assessments began to be made every other day, using the scale proposed by Hess et al. (1997). For each plot, a certain phenological stage was considered as such when it was recognized in three out of the four plants on the plot. Phenological assessments were performed up to the date of harvesting the plots. For each sowing date, the whole plant material present in the pots was harvested separately when early flowering plants were detected (stage 60), while considering that stage in at least three out of the five replications.

At harvest, for each sowing date, each of the five plots (replications) was washed individually in running water to remove the remaining substrate from the roots. Then, the material sampled was oven-dried at 70 °C for 72 hours. After drying, total dry matter was measured for each plot. Data on mass were analyzed by applying the F-test for analysis of variance followed by the Scott-Knott test (1974), both at 5% significance level.

The equation by Gilmore Jr. & Rogers (1958) was used to calculate growing degree days (*GDD*):

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

where: *Tmax* is the maximum daily temperature, *Tmin* is the daily minimum temperature, and *Bt* is the base temperature of southern sandbur. Daily minimum and maximum temperatures during the period of development of the experiment were collected from the meteorological station installed on campus, provided by INPE - National Institute for Space Research (Figure 1).

Considering the lack of specific information in the literature, a statistical procedure was used to estimate the base temperature (Bt) of southern sandbur for further use in the calculation of GDD. In this estimation, five temperatures (5, 8, 10, 12 and 15 °C) were used, as well as the absence of temperature. The following were used as estimators for defining Bt: data variance, standard deviation and range between sowing dates. After this fit, the phenological data on southern sandbur were fitted to accumulated thermal units through the linear regression model $y = ax$, where y is the development of southern sandbur according to the phenological scale (Hess et al., 1997), x refers to the accumulated thermal units, and a is the model parameter. In practice, the parameter a of this equation can be understood as the percentage of GDD effectively converted into units of plant phenology, allowing the estimation of the speed of plant development in a particular season or time of sowing.

RESULTS AND DISCUSSION

During flowering of southern sandbur, differences were detected in total dry matter accumulation between sowing dates (Figure 2). Accordingly, a choice was made to present data graphically, as the parabola formed can be better viewed. Plants that had been sown in early February and in September 2012 accumulated more dry matter than all others, with values greater than 60 g plot^{-1} . In the first half of 2012 (decreasing photoperiod), the longer the intervals between sowings after 02/16, the lower the final biomass production. Conversely, in the second half of 2012, the longer the intervals between

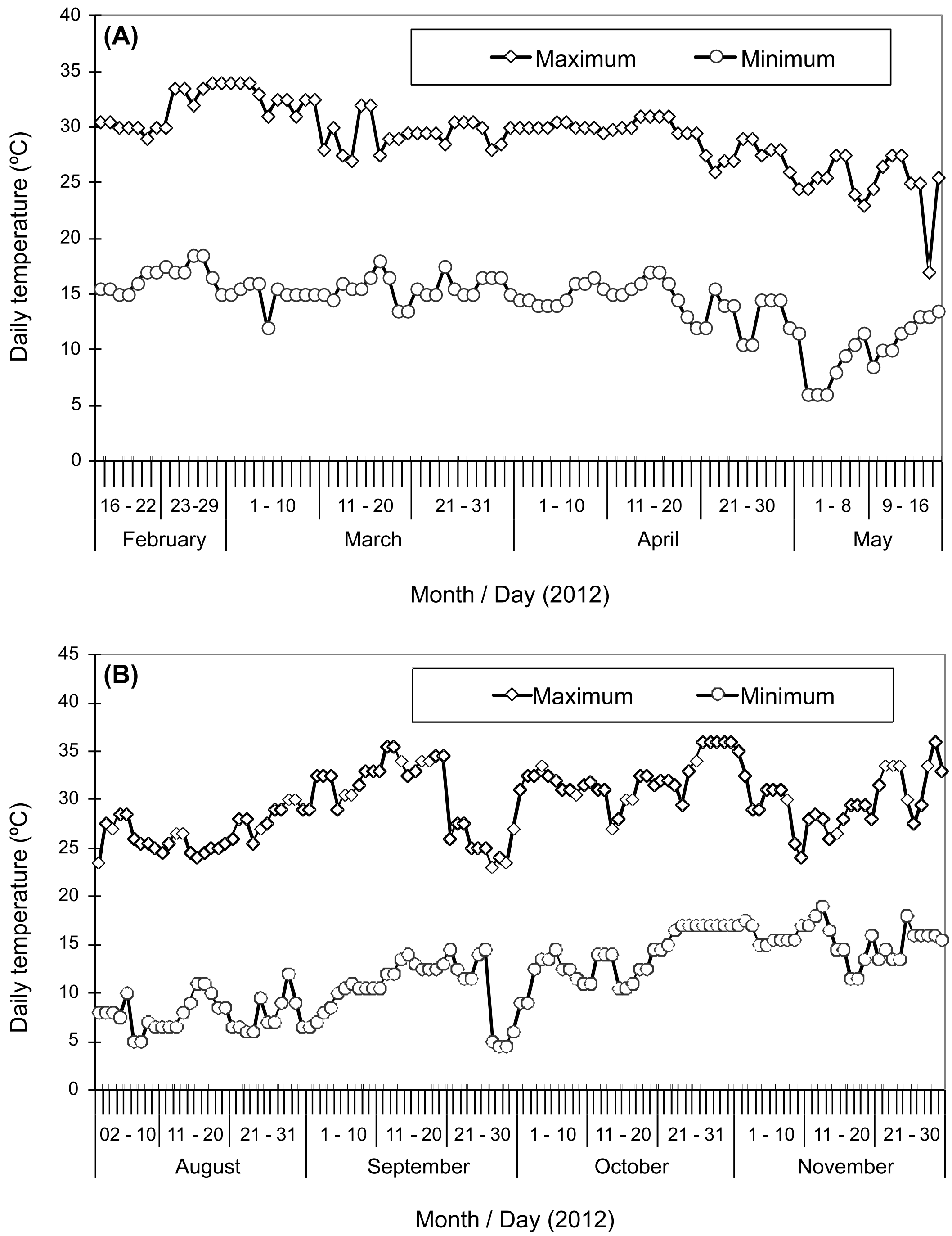

Figure 1 - Daily maximum and minimum temperatures for the period and development site of the experiment. A - first half of 2012, B - second half of 2012. Machado - MG, 2012.

sowings after 08/03, the greater the biomass production (Figure 2). Based on these data, it is suggested that there is a significant influence of temperature, and possibly of photoperiod as well, on dry matter accumulation by southern sandbur plants.

Likewise, the number of days required for flowering of southern sandbur was also variable between sowing dates (Table 1). The earliest flowering (46 days after sowing - DAS) occurred for sowing performed on 02/23 and 03/01, while later flowering, recorded at

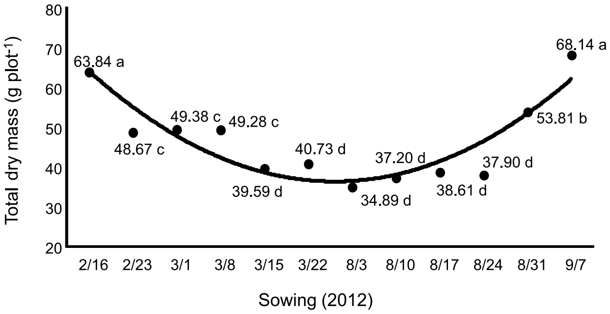

Figure 2 - Total dry matter of southern sandbur (*Cenchrus echinatus*) after flowering, when developed at 12 sowing dates. Machado - MG, 2012.

67 DAS, was identified for sowing in winter (08/03), with full maximum range of 21 days. The simultaneous analysis of Figure 2 and Table 1 shows that southern sandbur has a preference for summer (longer days), when a great deal of biomass was produced, with early flowering (48 DAS).

Pacheco & De Marinis (1984), when studying different sown populations of *C. echinatus*, observed flowering ranges between 60 and 150 DAS. These values are different from those found in the present study. It is noteworthy that, among ecological factors, the effect of temperature is prominent and can influence the growth and yield of different plant species (McLanchlan et al, 1993; Guo & Al-Khatib, 2003). However, the effect of photoperiod can be crucial to stimulate or deter plant flowering.

Table 1 shows the degree days accumulated up to flowering, calculated for all sowing dates, considering different base temperatures (Bt). Between sowing dates, the lowest value of variance, standard deviation and range were obtained when Bt = 12 °C was used. Additionally, second-degree polynomial regression was performed between data dispersion measurements and the different Bts (Table 2). The equations were used to calculate the minimum point of the parabolas by equating the first derivative of the equation to zero and, on average, 12 °C was confirmed as the ideal Bt for southern sandbur.

In the literature, Bt values = 0 °C are usually considered for weeds and crops in temperate climate, such as barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) (Cao & Moss, 1989; Kirkby, 1995; Shirtliffe et al., 2000; Ball et al., 2004), while for sunflower (*Helianthus annuus*), Granier & Tardieu (1998)

Table 1 - Days and accumulated thermal units (growing degree days - GDD) between sowing and flowering for southern sandbur (*Cenchrus echinatus*), at 12 sowing dates, considering five base temperatures (Bt) or the absence of temperature. Machado - MG, 2012

Photoperiod	Sowing	No. day	Accumulated degree days (GDD)					
			Tb 0 °C	Tb 5 °C	Tb 8 °C	Tb 10 °C	Tb 12 °C	Tb 15 °C
Decreasing	16/02/2012	48	1134.8	889.8	742.8	644.8	546.8	399.8
	23/02/2012	46	1088.3	853.3	712.3	618.3	524.3	383.3
	01/03/2012	46	1074.7	839.7	698.7	604.7	510.7	369.7
	08/03/2012	49	1095.4	850.4	703.4	605.4	507.4	360.4
	15/03/2012	50	1105.2	850.2	697.2	595.2	493.2	340.2
	22/03/2012	55	1162.2	882.2	714.2	602.2	490.2	322.2
Increasing	03/08/2012	67	1289.8	954.8	753.8	619.8	485.8	284.8
	10/08/2012	64	1256.4	936.4	744.4	616.4	488.4	296.4
	17/08/2012	60	1203.4	903.4	723.4	603.4	483.4	303.4
	24/08/2012	60	1239.4	939.4	759.4	639.4	519.4	339.4
	31/08/2012	60	1287.9	987.9	807.9	687.9	567.9	387.9
	07/09/2012	60	1323.9	1023.9	843.9	723.9	603.9	423.9
Variance		54.1	8010.6	3558.6	2051.7	1532.3	1401.0	1931.7
Standard deviation		7.4	89.5	59.7	45.3	39.1	37.4	44.0
Range		21	249.3	184.3	146.8	128.8	120.5	139.2

Tabela 2 **-** Variance, standard deviation and range fitted as a function of different base temperatures used for calculating thermal units, coefficient of determination and minimum point of the parabola. Machado - MG, 2012

Parameter	Polynomial regression	R^2	Minimum point[1/]
Variance	$y = 48.51x^2 - 1133x + 8010.6$	> 0.9999	11.6768
Standard deviation	$y = 0.3525x^2 - 8.4979 + 90.529$	0.9909	12.0538
Range	$y = 0.7757x^2 - 19.651x + 253.08$	0.9780	12.6666
		Mean	12.1324

[1/] Minimum point obtained by equating the first derivative of the equation to zero.

found base temperatures of 4.8 °C. For redroot pigweed (*Amaranthus retroflexus*), a species with C4-photosynthetic pathway, Gramig & Stoltenberg (2007) recorded Bt = 8.5. Base temperatures of 10 °C have been recorded for bean plants (Kish & Ogle, 1980; Medeiros et al,. 2000), for corn crops (Gadioli et al., 2000), and for forage *Panicum virgatum* (Sanderson & Wolf, 1995). Finally, Villa Nova et al. (1999) used Bt = 15 °C for elephant grass cv. Napier (*Pennisetum purpureum*) and Vasconcelos et al. (2012) obtained Bt = 15 °C for sourgrass (*Digitaria insularis*), especially plants of the Poaceae family in tropical climate. Thus, considering the size and hardiness of southern sandbur, its C4-photosynthetic pathway and its classification as a summer annual weed, establishing Bt = 12 °C seems appropriate.

The ability to predict phenological stages, such as flowering and development and dispersal of weed seeds, may aid the development of management practices (Ghersa & Holt, 1995). Moreover, the growth characteristics of a particular species are indicative of competitive ability (Holt & Orkutt, 1991). Therefore, the total phenological development of southern sandbur (Hess et al., 1997) was fitted to the accumulated thermal units, while taking into account the sum of sowings, with Tb = 12 °C (Figure 3). Equation $y = 0.0993\,x$ was yielded with a coefficient of determination greater than 90%, and on average, flowering occurred with 518 degree days. Based on these data, it can be concluded that for every 100 degree days, there is average phenological advance of 10 units on the BBCH scale (Hess et al., 1997).

Also using the linear model, the parameter a was calculated separately for each sowing date (Figure 4). In this case, data are also shown graphically to facilitate visualization of the parabola formed, whereby larger values for a were obtained in the period closer to winter (short days). Lower values for a were identified at the beginning of February and for sowing

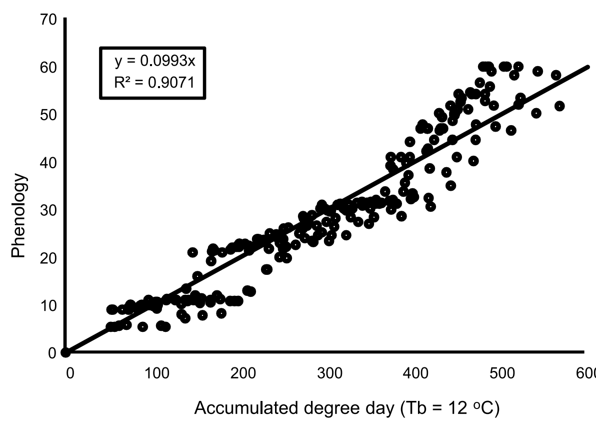

Figure 3 - Phenological development of southern sandbur (*Cenchrus echinatus*) fitted to growing degree days, with base temperature of 12 °C. Machado - MG, 2012.

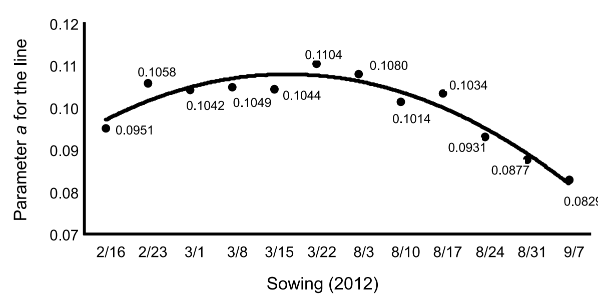

Figure 4 - Parameter a of the linear model ($y = ax$) to fit the phenological development of southern sandbur (*Cenchrus echinatus*) to the accumulated thermal units (Bt = 12 °C), with 12 sowing dates. Machado - MG, 2012

performed in September. All equations had coefficients of determination above 90%; however, among the 12 sowing dates, only eight were similar to the general model (Table 3). In this case, the models were compared by analyzing the overlap of the confidence interval (Carvalho & Christoffoleti, 2007).

The overall analysis of the data allows the assumption that temperature, through the accumulated degree days (Tb = 12 °C), can be used to estimate the phenology of southern sandbur. However, it is clear that other environmental variables also influence the development of the species and can potentially complement the mathematical model. The flow and duration of photosynthetically active radiation, the availability of nutrients and water, loss of photosynthetic tissue and, undoubtedly, photoperiod can also alter plant growth and development (Russelle et al., 1984; Gramig & Stoltenberg, 2007).

At this point, it is worth noting that growth is different from development. While growth can be understood as an irreversible increase in mass and volume, development is the alternation between successive physiological stages that are expressed on plant phenology. Thus, at least in theory, a plant is able to grow without necessarily develop, and vice versa. The conformation of opposing parabolas recorded in Figures 2 and 4 clarifies the distinct behavior of plants for the binomial growth-development when they recognize a certain time of the year.

For example, for sowing performed on 09/07, the highest dry matter was obtained (68.14 g plot^{-1}; Figure 2) and, in contrast, the smallest parameter a (Figure 4). Thus, the species clearly has the ability to recognize and be influenced by environmental conditions of its habitat. Sowing was performed close to the spring, so there was greater radiation available, increasing photoperiod and heat for successive days. In this situation, phenological development occurs more slowly (lower a), while the plant allows higher caloric yield to be directed to mass accumulation and establishment in the environment (higher growth) and, only after that, it starts flowering (60 days; Table 1) and seed production. In summary, it can be assumed that plants made more effort into growing and lesser effort into developing.

Table 3 - Coefficient of determination (R^2), F-test applied to the model ($y = ax$) and confidence interval of parameter a related to fitting the phenological development of southern sandbur (*Cenchrus echinatus*) to the accumulated thermal units (Bt = 12 °C), considering the general cumulative and 12 sowing dates. Machado - MG, 2012

Sowing	R^2	F	Confidence interval of a (5%)	
			Minimum point	Maximum point
General	0.9071	11162.120**	0.0974	0.1011
16/02	0.9434	1491.282**	0.0899	0.1003
23/02	0.9639	1892.102**	0.1007	0.1109
01/03	0.9516	1356.574**	0.0982	0.1102
08/03	0.9601	1792.835**	0.0997	0.1101
15/03	0.9518	1566.445**	0.0989	0.1099
22/03	0.9597	2292.963**	0.1056	0.1152
03/08	0.9620	2109.550**	0.1031	0.1129
10/08	0.9397	1310.740**	0.0955	0.1072
17/08	0.9345	1247.466**	0.0973	0.1095
24/08	0.9288	1143.068**	0.0873	0.0988
31/08	0.9433	1278.697**	0.0826	0.0928
07/09	0.9310	962.941**	0.0773	0.0885

** Significant F-test at 1% probability.

In contrast, when considering sowings performed on 03/22 or 08/03, an opposite behavior was observed for the species. In these cases, higher a (Figure 4) and low dry matter production (Figure 2) were obtained. The plants possibly recognized the coldest days (Figure 1), or the unfavorable photoperiod (short days), as environmental adversity and, thus, directed most of the heat sum towards phenological development. Under this condition, it is assumed that the species is more interested in developing and producing seeds and less interested in growing. It is common knowledge, in the field of plant physiology, that environmental stresses stimulate flowering.

This discussion may be confirmed by considering the degree days required for flowering to occur (Tb = 12 °C) in each planting date (Table 1), also in parabola conformation, in accordance with the data on dry mass (Figure 1). In more favorable environmental conditions (sowings on 02/16 and 09/07), the plants require more degree days for flowering, whereas a higher percentage of energy is expended on growth and dry matter accumulation. Potentially, there is a physiological binomial growth-development, which is sometimes balanced. However, increased investment in one event deters the progress of another and vice versa. The same data distribution is not recognized for the counting of days, because this variable is less appropriate for estimation of plant development. Ghersa and Holt (1995) emphasize that weeds and crops have a high degree of phenotypic plasticity, so that plants with the same genotype at the same stage of growth may have different morphology depending on the environmental history of each specimen during growth.

In conclusion, the phenology of southern sandbur can be predicted by mathematical models based on accumulated thermal units while adopting a base temperature of 12 °C. However, it should be noted that other environmental variables also affect the development of the species, particularly photoperiod.

ACKNOWLEDGEMENTS

The authors would like to thank the Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais (IFSULDEMINAS), Campus Machado, for awarding a research grant, especially the research apprentice scholarship awarded to the first and second authors.

LITERATURE CITED

BALL, D. A.; FROST, S. M.; GITELMAN, A. I. Predicting timing of downy brome (*Bromus tectorum*) seed production using growing degree days. **Weed Sci.**, v. 52, n. 4, p. 518-524, 2004.

BIANCO, S. et al. Estimativa da área foliar de plantas daninhas. XIII – *Amaranthus retroflexus* L. **Ecossistema**, v. 20, n. 1, p. 5-9, 1995.

CAO, W.; MOSS, D. N. Temperature and daylength interaction on phyllochron in wheat and barley. **Crop Sci.**, v. 29, n. 4, p. 1046-1048, 1989.

CARVALHO, S. J. P.; CHRISTOFFOLETI, P. J. Estimativa da área foliar de cinco espécies do gênero *Amaranthus* usando dimensões lineares do limbo foliar. **Planta Daninha**, v. 25, n. 2, p. 317-324, 2007.

DAN, H. A. et al. Influência do estádio de desenvolvimento de *Cenchrus echinatus* na supressão imposta por atrazine. **Planta Daninha**, v. 29, n. 1, p. 179-184, 2011.

GADIOLI, J. L. et al. Temperatura do ar, rendimento de grãos de milho e caracterização fenológica associada à soma calórica. **Sci. Agric.**, v. 57, n. 3, p. 377-383, 2000.

GHERSA, C. M.; HOLT, J. S. Using phenology prediction in weed management: a review. **Weed Res.**, v. 35, n. 6, p. 461-470, 1995.

GILMORE JR., E. C.; ROGERS, J. S. Heat units as a method of measuring maturity in corn. **Agron. J.**, v. 50, n. 10, p. 611-615, 1958.

GRAMIG, G. G.; STOLTENBERG, D. E. Leaf appearance base temperature and phyllochron for common grass and broadleaf weed species. **Weed Technol.**, v. 21, n. 1, p. 249-254, 2007.

GRANIER, C.; TARDIEU, F. Is thermal time adequate for expressing the effects of temperature on sunflower leaf development? **Plant, Cell Environ.**, v. 21, n. 7, p. 695-703, 1998.

GUO, P.; AL-KHATIB, K. Temperature effects on germination and growth of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*A. palmerii*), and common waterhemp (*A .rudis*). **Weed Sci.**, v. 51, n. 6, p. 869-875, 2003.

HESS, M. et al. Use of the extended BBCH scale - general for descriptions of the growth stages of mono-and dicotyledonous weed species. **Weed Res.**, v. 37, n. 6, p. 433-441, 1997.

HOLT, J. S.; ORKUTT, D. R. Functional relationships of growth and competitiveness in perennial weeds and cotton (*Gossypium hirsutum*). **Weed Sci.**, v. 39, n. 4, p. 575-584, 1991.

KIRKBY, E. J. M. Factors affecting rate of leaf emergence in barley and wheat. **Crop Sci.**, v. 35, n. 1, p. 11-19, 1995.

KISH, A. L.; OGLE, W. L. Improving the heat unit system in predicting maturity date of snap beans. **HortScience**, v. 15, n. 2, p. 140-141, 1980.

KISSMANN, K. G. **Plantas infestantes e nocivas**. 2.ed. São Paulo: BASF, 1997. Tomo 1. 825 p.

LORENZI, H. **Plantas daninhas do Brasil:** terrestres, aquáticas, parasitas e tóxicas. 3.ed. Nova Odessa: Plantarum, 2000. 608 p.

LUCCHESI, A. A. Utilização prática de análise de crescimento vegetal. **Anais ESALQ**, v. 41, n. 1, p. 181-202, 1984.

McLANCHLAN, S. M. et al. Effect of corn induced shading and temperature on rate of leaf appearance in redroot pigweed (*Amaranthus retroflexus* L.). **Weed Sci.**, v. 41, n. 4, p. 590-593, 1993.

MEDEIROS, G. A. et al. Crescimento vegetativo e coeficiente de cultura do feijoeiro relacionados a graus-dia acumulados. **Pesq. Agropec. Bras.**, v. 35, n. 9, p. 1733-1742, 2000.

PACHECO, R. P. B.; DE MARINIS, G. Ciclo de vida, estruturas reprodutivas e dispersão de populações experimentais de capim-carrapicho (*Cenchrus echinatus* L.). **Planta Daninha**, v. 7, n. 1, p. 13-21, 1984.

RUSSELLE, M. P. et al. Growth analysis based on degree days. **Crop Sci.**, v. 24, n. 1, p. 28-32, 1984.

SALGADO, T. P. et al. Períodos de interferência das plantas daninhas na cultura do algodoeiro (*Gossypium hirsutum*). **Planta Daninha**, v. 20, n. 3, p. 373-379, 2002.

SANDERSON, M. A.; WOLF, D. D. Morphological development of switchgrass in diverse environments. **Agron. J.**, v. 87, n. 5, p. 908-914, 1995.

SCOTT, A. J.; KNOTT, M. A. Cluster analysis method for grouping means in the analysis of variance. **Biometrics**, v. 30, n. 2, p. 507-512, 1974.

SHIRTLIFFE, S. J.; ENTZ, M. H.; van ACKER, R. C. *Avena fatua* development and seed shatter as related to thermal time. **Weed Sci.**, v. 48, n. 5, p. 555-560, 2000.

VASCONCELOS, G. M. P. V. et al. Determinação da temperatura base (Tb) para estudo da exigência térmica de *Digitaria insularis*. In: CONGRESSO BRASILEIRO DA CIÊNCIA DAS PLANTAS DANINHAS, 28., 2012, Campo Grande. **Resumos Expandidos...** Campo Grande: SBCPD, 2012. p. 776-780.

VILLA NOVA, N. A. et al. Modelo para previsão da produtividade do capim elefante em função de temperatura do ar, fotoperíodo e frequência de desfolha. **R. Bras. Agrometeorol.**, v. 7, n. 1, p. 75-79, 1999.