academicJournals

Vol. 10(3), pp. 119-124, 15 January, 2015
DOI: 10.5897/AJAR2013.7809
Article Number: 31471A049550
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Growing degree-day sum and crop growth cycle duration for wheat cultivars at different sowing dates

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Received 13 August, 2013; Accepted 17 December, 2014

The wheat *Triticum aestivum* L. is one of the most important foods in the human diet due to its high nutritional value. The grains can be eaten as bread, noodles, pasta, cookies, among others. The cultivation of wheat in Brazil has high production potential; the southern is region responsible for the largest acreage in the country, due to its soil and climate more favorable for crop development. The objective of this study was to determine the growing degree-days sum and the relationship between the period length from sowing to physiological maturity and sowing dates of thirteen wheat cultivars. The data on wheat crop correspond to the harvests of 2007 to 2011. The treatments consisted of 13 wheat cultivars and 3 sowing dates. The data used for the analysis were: Total elapsed days from sowing to silking, to physiological maturity, and of the silking to physiological maturity, along with the growing degree-days sum for these periods, beyond grains yield and hectoliter weight. The results indicate that the average length of sowing to the silking was 71 days. For the period from silking to physiological maturity the average length was 54 days. The increase in length of time from sowing to the silking in cultivars sown in May 25th was due to the decrease in air temperature. The average of growing degree-days sum between the period from sowing to physiological maturity was 1487. The cultivars that stood out presenting a shorter period of silking to physiological maturity and high productivity were the cultivars CD 114, CD 120, CD 121, CD 122, CD 124 and Onix.

Key words: *Triticum aestivum* L., thermal summation, vegetative development.

INTRODUCTION

Between genres of wheat grown, the *Triticum* contains about 30 species; among them the *Triticum aestivum* L., known as common wheat is the species of greatest commercial interest. Besides being part of the human diet, wheat can also be used in the animal feed, with great economic and nutritional importance. The culture is also used as a cover crop in the winter and as succession crops such as soybeans and corn, benefiting soil conservation

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avoiding erosion, and contributing to the family income (Abtrigo, 2006).

In Brazil, according to Conab (2013a), the harvest of 2012/2013 the area cultivated with wheat was approximately 1.90 million hectares, reaching an average yield of 2269 kg ha^{-1}. The yield was lower than the 2011 crop which reached 2672 kg ha^{-1}. The reduction in the productivity of the crop of 2012/2013 was due to the instability of the atmospheric weather, with heavy rainfall after a season of low humidity at the time of sowing (Conab, 2013b).

The instability of the atmospheric weather, as excess or lack of rainfall, marked variations in air temperature, among others, reinforce the needs of the knowledge regarding the development of the wheat crop, combining technology and production planning, seeking greater stability in production, maximizing productivity in areas already cultivated.

Degree-days or heat summation for the growth and development of plants is directly related to average daily temperature of the air. Accumulated during the daily period, the growing degree-days are calculated by the difference between the average daily air temperature and the minimum basal temperature. According to Streck and Alberto (2006) for wheat, basal minimum temperature increase is 5°C. The thermal requirements needed to achieve a particular crop growth stage, allow predicting adaptation to different regions and sowing dates suffering direct influence of environmental conditions (Ferolla et al., 2007).

Therefore the objective of this study was to determine the growing degree-days sum and the relationship between the period length from sowing to physiological maturity and sowing dates of thirteen wheat cultivars in Cascavel State of Paraná Brazil.

MATERIALS AND METHODS

The data on wheat crop were collected by the Cooperativa Central de Pesquisa Agrícola (COODETEC) and correspond to the harvests of 2006 to 2011. The experiment was conducted in the field, in the research center of COODETEC located in Cascavel in the State of Parana, Brazil.

Cascavel is located at 24° 56' 36 "South latitude and 53° 32' 15" west longitude, 700 m altitude. The climate is subtropical (Cfa) according to the Köppen classification, with average annual air temperatures ranging from 20 to 21°C and total rainfall between 1800 to 2000 mm annual (Caviglione et al., 200). The soil is a latosol red typical dystrophic (Embrapa, 2006). The climatological data were obtained from the meteorological station of the Instituto Tecnológico Simepar located in Cascavel, in the period from 2007 to 2011, in the months from April to September.

The experimental design was randomized blocks with plots consisting of 6 rows with 5 m long, spaced 0.20 m between rows. The factorial scheme was 13 × 3, repeated for 5 growing seasons from 2007 to 2011, whose treatments consisted of 13 wheat cultivars and three sowing dates (April 25^{th}, May 15^{th} and 25^{th}).

For the experiment we used the direct seeding over straw, performed mechanically. The seeding density used was 360 viable seeds per square meter for all cultivars. For all harvests dates of sowing were transformed into Julian Days (JD), which are obtained by counting the days of the year in sequence (Table 1).

Table 1. Dates of sowing in Julian days in the harvests from 2007 to 2011 in Cascavel, Brazil.

City	Harvests	Dates	Julian days
Cascavel	2007 to 2011	April / 25	115
		May / 15	135
		May / 25	145

Fertilization, control of pests, diseases and weeds were made according to technical recommendations (Coodetec, 2010). For this study we used data from cycle cultivars early CD 105, CD 114, CD 117 and CD 118, ranging from 115 to 120 days from emergence to physiological maturity and average cycle, CD 113, CD 115, CD 119, CD 120 , CD 121, CD 122, CD 123, CD 124 and Onix, ranging 120 to 141 days from emergence to physiological maturity.

The data used for the analysis were: Total elapsed days from sowing to the silking and to physiological maturity, and of the silking to physiological maturity, along with the growing degree-days sum for these periods, beyond grains yield and hectoliter weight (HW). The analysis of HW was determined according to the Rules for Testing Seeds (Brasil, 1992) and the results expressed in kg hL^{-1}.

The growing degree-days sum (GD) in each development stage of wheat crop were obtained by the following equation used by Oliveira et al. (2011). The equation uses the number of days in the period considered, the average air temperature in the same period and the minimum temperature basal crop growth.

$$GD = \sum_{i=1}^{n}(Ti - Tb)$$

Where: Ti = Average daily temperature (°C); Tb = Base temperature 5°C (Streck and Alberto, 2006), n = Number of days in the period considered.

The data collected were subjected to analysis of variance, occurring significant interaction cultivars x sowing dates, proceeded up the developments needed for the parameter evaluated. Means were compared by grouping averages of Scott and Knott (1974) for evaluation of the effects of cultivars, and regression analysis to verify the behavior of the parameters, according to the sowing dates for each cultivar, 5% probability.

The analysis of the data was performed since the ratio between the largest and smallest mean square residual was not more than seven (Pimentel-Gomes, 2009). Was too performed analyzed of correlation between parameters. Data processing and statistical analysis were performed using the SISVAR statistical software (Ferreira, 2011).

RESULTS AND DISCUSSION

The Figure 1a and b shows the variation average monthly of air temperatures (average, minimum and maximum), and average total rainfall in Cascavel. As shown in Figure 1a, the average minimum air temperature (14.2°C) occurred

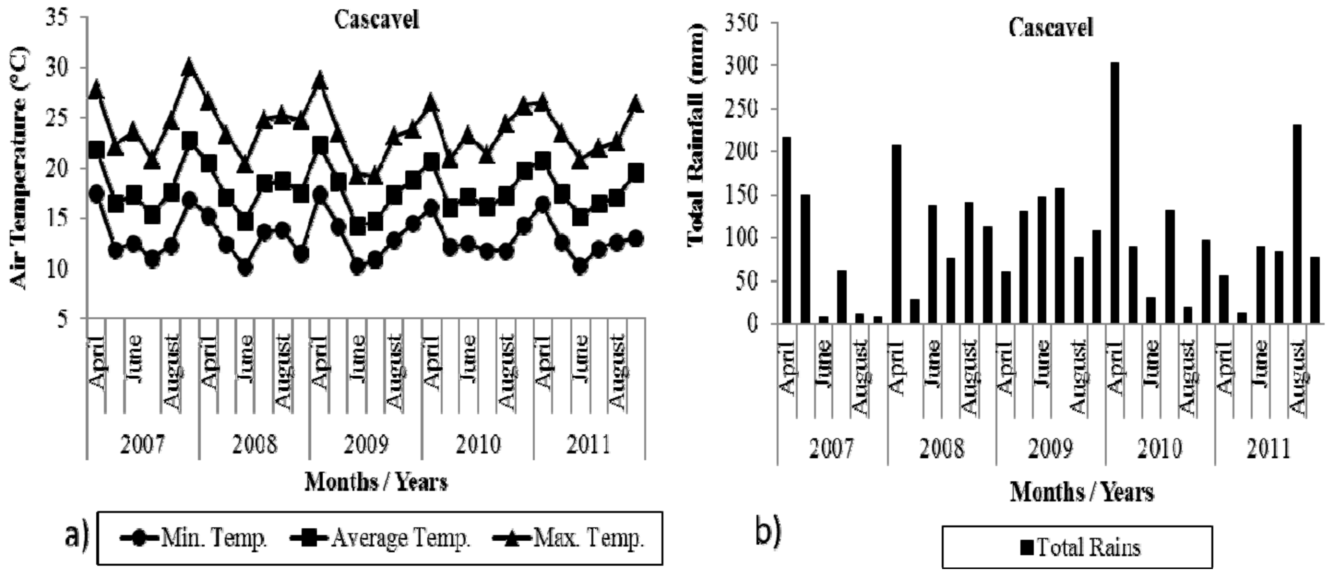

Figure 1. (a) Mean monthly minimum temperatures, maximum and average air (°C) in the months of April to September, between 2007 to 2011 (b) Total rainfall (mm) in the months of April to September from 2007 to 2011.

in June 2009, while September had the highest average air temperature (22.7°C) for the year 2007.

The total rainfall ranged from 8.4 mm for the months of June and September in 2007 and 302.8 mm in April 2010 (Figure 1b). The interaction of cultivars x sowing dates verified by analysis of the data was significant ($P<0.05$) only for the period from sowing to the silking, indicating different responses of cultivars in different sowing dates, in the harvests of 2007 to 2011.

The unfolding of the interaction of cultivars within each planting date was presented in Table 2.

The average number of days to cultivars reach silking in the three sowing dates was 71 days (Table 2). For the period of days between sowing and silking, there was an increase from 69 to 72 days between the cultivars sown in JD 115 and 145, respectively. The cultivar CD 124 had the highest number of days from sowing to the silking for the three sowing dates (April 25th, May 15th and 25th), whose values were 74, 77 and 82 days, respectively. For cultivars sown in JD 145 (May 25th), the average number of days from sowing to silking was 72 days.

The increase in the average number of days from sowing to silking (Table 2) for the seeded cultivars especially in the last sowing date DJ 145 (May 25th), were possibly genetic characteristic of each cultivar, responding differently to environmental conditions especially related to low air temperature (Viganó et al., 2011). Since in this period according to the water balance performed to Rattlesnake in the years 2007 to 2011, by method of Thornthwaite and Mather (1955), water deficit was 5.7 mm in June 2007, down from 12.21 found mm by Oviedo et al. (2001) that causes damage to the wheat crop. Regression analysis of the data for the unfolding of

Table 2. Average duration of the period from sowing to silking (days) of thirteen wheat cultivars at three sowing dates, in the harvests from 2007 to 2011 in Cascavel, Brazil.

Cultivars	**Sowing dates (Julian Days)**			**Average**
	115	**135**	**145**	
CD 105	65^{C}	68^{B}	68^{D}	67
CD 113	62^{D}	66^{C}	68^{D}	65
CD 114	69^{B}	70^{A}	71^{C}	70
CD 115	71^{A}	72^{A}	74^{B}	72
CD 117	66^{C}	70^{A}	77^{B}	71
CD 118	71^{A}	72^{A}	72^{C}	72
CD 119	69^{B}	73^{A}	74^{B}	72
CD 120	67^{B}	71^{A}	72^{C}	70
CD 121	73^{A}	73^{A}	72^{C}	73
CD 122	73^{A}	72^{A}	71^{C}	72
CD 123	62^{D}	64^{C}	64^{D}	63
CD 124	74^{A}	77^{A}	82^{A}	78
ONIX	68^{B}	73^{A}	74^{B}	72
Average	69^{c}	71^{b}	72^{a}	
Average		71		
CV(%)		3.91		

Means followed by the same capital letter in the column and lowercase letter on the line belong to the same group, according to the grouping criteria of Scott and Knott (1974) at 5% probability. CV(%) = Coefficient of variation.

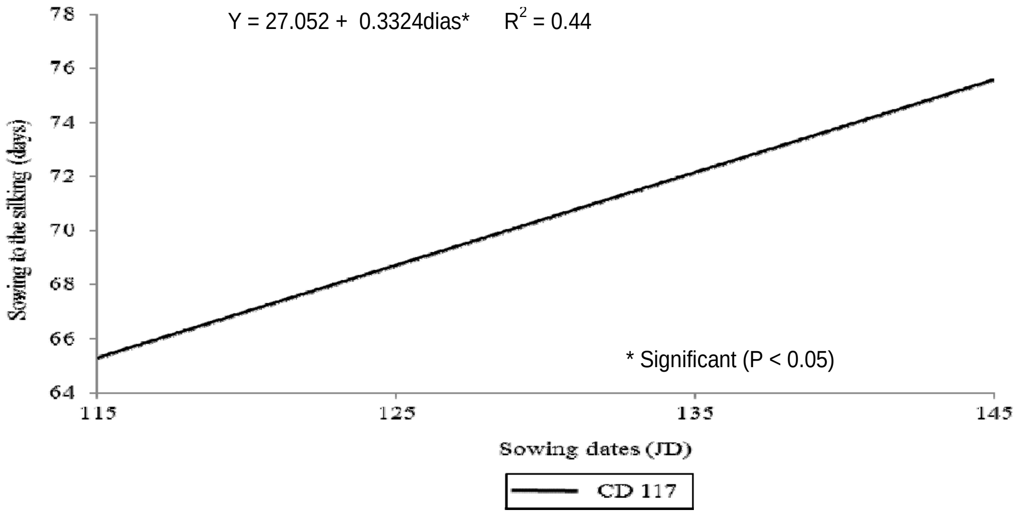

Figure 2. Average the period length of time from sowing to silking (days) for the cultivar CD 117 in three sowing dates, in the harvests from 2007 to 2011.

the interaction of cultivars x sowing dates, revealed a significant effect (P<0.05) only for the cultivar CD 117 in the period of days between sowing and the silking according to dates seeding increased linearly (R^2 = 0.44), as shown in Figure 2.

According to Figure 2 the regression analysis was significant only for the cultivar CD 117. Therefore, for this cultivar, sowing later result greater period of time between sowing and silking, in consequence of lower air temperatures was observed from May 25th (Figure 1a).

For variables, average period length of days from sowing to physiological maturity, silking to physiological maturity, growing degree-days sum to silking and to physiological maturity, growing degree-days sum degree-days from silking to physiological maturity, grain yield and hectoliter weight, no significant interaction (P <0.05) cultivar x sowing dates, carrying the analysis of the data with the average of the three sowing dates (Table 3).

The average duration from sowing to physiological maturity was 124 days, ranging from 120 (CD 123) and 127 days (CD117 and CD124). The growing degree-days sum average from seeding to physiological maturity was 1487 as can be seen in Table 3.

For cultivars CD 121, CD 122 and CD 124 the period between the SI-FM was 50 days, which resulted in growing degree-days sum for the period of 667, 663 and 696, respectively. This period was 57 days for cultivars CD 105, CD 117 and CD 123 resulting in growing degree-days sum of 749, 758 and 725, respectively (Table 3).

Table 3 reveals the reduction in the period from silking to physiological maturity for cultivars sown on May 25th, as well as period in which the cultivars were in the grain filling between the months of August to September. The average air temperature for five years in September was 19.7°C. One of the factors that may influence the length of grain filling is the increase in air temperature, which will increase the rate of grain filling and substantially reduce the length of time between silking and physiological maturity (Nedel et al., 1999).

The cultivars sowing on May 25th in Cascavel needed an average of 52 days between the SI-FM. The average growing degree-days sum from sowing to silking was 776. Among the evaluated cultivars, CD 124 had the highest accumulation of 834 degree-days (Table 3).

For grain yield there was no statistical difference between cultivars or sowing dates. The average yield was 3550 kg ha^{-1}. The hectoliter weight of the cultivars evaluated ranged from 73 kg hL^{-1} (CD 124) to 78 kg hL^{-1} (CD 122) (Table 3). The overall average was 76 kg hL^{-1}.

The Table 4 presented the correlation coefficients between the parameters evaluated using the average of the three sowing dates. The periods of the S-SI and SI-FM were the variables that showed a strong negative correlation (-0.60). A strong positive correlation was observed between the periods of S-FM and growing degree-days sum in this period (0.77) as shown in Table 4.

Grain yield showed significant positive correlation with the period of the SI-FM (0.29). For variable HW there is a significant negative correlation (-0.49) with the period of the S-SI. According to Table 4, increase in the number of days of the S-SI will decrease the period between the SI-FM and confirmed by significant negative correlation coefficient between periods, without altering the total number of days in the cycle, as can be seen in Tables 2 and 3.

The strong positive correlation between the periods of

Table 3. Average period of length sowing to physiological maturity (S-FM) and silking to physiological maturity (SI-FM), growing degree-days sum from sowing to silking (S-SI) and growing degree-days sum from sowing to physiological maturity (S-FM) and growing degree-days sum from silking to physiological maturity (SI-FM), grain yield (YIELD) and hectoliter weight (HW) of thirteen wheat cultivars, in the harvests from 2007 to 2011 in Cascavel, Brazil.

Cultivars	S-FM	SI-FM	Growing degree-days sum			Yield	HW
	(days)		S-SI	S-FM	SI-FM	(kg ha^{-1})	(kg hL^{-1})
CD105	124^{B}	57^{A}	741^{C}	1490^{A}	749^{A}	4005	76^{A}
CD113	121^{B}	56^{A}	718^{D}	1436^{B}	718^{A}	3742	76^{A}
CD114	122^{B}	52^{B}	774^{B}	1456^{B}	681^{B}	3765	77^{A}
CD115	126^{A}	54^{A}	804^{A}	1523^{A}	719^{A}	3074	74^{B}
CD117	127^{A}	57^{A}	777^{B}	1535^{A}	758^{A}	3545	76^{A}
CD118	126^{A}	54^{A}	796^{A}	1515^{A}	720^{A}	3341	76^{A}
CD119	126^{A}	55^{A}	796^{A}	1519^{A}	723^{A}	3507	77^{A}
CD120	123^{B}	53^{B}	773^{B}	1472^{B}	698^{B}	3488	77^{A}
CD121	123^{B}	50^{B}	807^{A}	1474^{B}	667^{B}	3577	76^{A}
CD122	122^{B}	50^{B}	800^{A}	1464^{B}	663^{B}	3575	78^{A}
CD123	120^{B}	57^{A}	700^{D}	1426^{B}	725^{A}	3422	76^{A}
CD124	127^{A}	50^{B}	834^{A}	1531^{A}	696^{B}	3560	73^{B}
ONIX	125^{A}	53^{B}	794^{A}	1494^{A}	700^{B}	3653	76^{A}
Date (JD)							
115	125^{A}	57^{A}	783^{A}	1487	704	3539	77^{A}
135	123^{B}	53^{B}	782^{A}	1489	707	3611	75^{B}
145	123^{B}	52^{C}	763^{B}	1484	721	3501	76^{A}
Average	124	54	776	1487	711	3550	76
CV (%)	2.87	9.20	5.14	3.41	8.59	17.15	3.19

Means followed by the same capital letter in the column and lowercase letter on the line belong to the same group, according to the grouping criteria of Scott and Knott (1974) at 5% probability. CV (%) = Coefficient of variation.

Table 4. Correlation coefficient of the length of periods (days), growing degree-day sum, grain yield (YIELD) and hectoliter weight (HW), in harvests from 2007 to 2011 in Cascavel.

Parameters		Length (days)		Growing degree-days sum			Yield	HW
		S-FM	SI-FM	S-SI	S-FM	SI-FM	(kg ha^{-1})	(kg hL^{-1})
Length (days)	S-SI	0.39**	-0.60**	0.71**	0.27*	-0.35**	-0.39**	-0.49**
	S-FM		0.50**	0.40**	0.77**	0.37**	-0.09^{ns}	-0.13^{ns}
	SI-FM			-0.32**	0.41**	0.66**	0.29*	0.35**
Growing degree-days sum	S-SI				0.38**	-0.50**	-0.16*	-0.45**
	S-FM					0.61**	-0.15*	0.02^{ns}
	SI-FM						-0.10^{ns}	0.40^{ns}
Yield								0.18*

^{ns} Not significant; * Significant at the 5% probability; ** Significant at 1% probability; (S-SI) period from sowing to the silking; (S-FM) period from sowing to physiological maturity; (SI-FM) period from sowing to physiological maturity.

S-FM and growing degree-days sum during this period was resulting time that culture remains in the field, growing higher value of degree-days sum if there is a greater number of days between sowing and maturity physiological (Table 4). The significant negative correlation between HW and S-SI suggested that an increase in the number of days of S-SI causes reduction in HW. The increase in the number of days of S-SI causes a reduction in the number of days in the period of the SI-FM, confirmed by the observed significant negative correlation for these variables. This results in reduced HW possibly by the decreasing number of days of the SI-FM, period that corresponds to grain filling as evidenced by the significant positive correlation of the variable HW with the period of the SI-FM (Table 4).

Conclusions

The results indicate that the average length of sowing to silking was 71 days. For the period from silking to physiological maturity the average length was 54 days.

The increase in length of time from sowing to silking in cultivars sown in May 25th (JD 145) was due to the decrease in air temperature.

The average of growing degree-days sum between the period from sowing to physiological maturity was 1487. The cultivars that stood out presenting a shorter period of silking to physiological maturity and high productivity were the cultivars CD 114, CD 120, CD 121, CD 122, CD 124 and Onix.

Conflict of Interest

The authors declared no conflict of interest.

ACKNOWLEDGEMENT

The authors thank the State University of Western Paraná by the support provided.

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