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Yield and growth characteristics of sunflower sown from August to February in Santa Maria, RS

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ABSTRACT
Sunflower (*Helianthus annuus* L.) is an oilseed crop that can be grown in different regions and sowing dates, but not all regions and sowing dates are appropriate for the crop development. The aim of this study was to determine yield and growth characteristics of sunflower on seven sowing dates, in Santa Maria, from 2007 to 2012. Five experiments were carried out in a completely randomized factorial design with four replications. The factor "A" was monthly sowing dates from the beginning of August to February and the factor "D" was two sunflower hybrids. Capitulum diameter, maximum leaf area index, maximum height of plants, weight of thousand achenes and yield were determined. In normal or La Niña years the highest yield is reached in September sowing dates, while in El Niño years, the crop growth and yield in early sowings are affected negatively, due to heavy rainfall, soil water excess and plant diseases.

Palavras-chave:
Helianthus annuus L.
épocas de semeadura
condições meteorológicas

Características produtivas e de crescimento do girassol semeado de agosto a fevereiro em Santa Maria, RS

RESUMO
O girassol (*Helianthus annuus* L.) é uma cultura oleaginosa que pode ser cultivada em diferentes regiões e épocas de semeadura, porém nem todas as regiões e épocas de semeadura são apropriadas para o desenvolvimento da cultura. O objetivo deste trabalho foi determinar as características de crescimento e produtividade do girassol em sete datas de semeadura, em Santa Maria, de 2007 até 2012. Cinco experimentos foram conduzidos em um delineamento fatorial inteiramente casualizado com quatro repetições. O fator "A" foram datas de semeadura mensais do início de agosto até fevereiro e o fator "D" foram dois híbridos de girassol. Diâmetro de capítulo, índice de área foliar máximo, altura máxima de plantas, massa de mil aquênios, e produtividade foram determinados. Em anos normais ou de La Niña a maior produtividade é obtida nas semeaduras de setembro, enquanto que em anos de El Niño, o crescimento e a produtividade da cultura em semeaduras precoces são afetadas negativamente, devido à elevada precipitação pluvial, excesso hídrico no solo e doenças.

Introduction

The sunflower (*Helianthus annuus* L.) is a crop having a high phenotypic adaptability that can be cultivated in all continents for production of grains and also for crop rotation (Zaidi et al., 2012). Water availability during the crop growing period and fungal diseases are the main yield limiting factors in Brazil (Cellier et al., 1998; Barros et al., 2004; Leite et al., 2006). Nevertheless, it has been reported by Balalić et al. (2012) that this crop shows adaptability to different regions and sowing dates, due to its high genotype x ambient interactions.

Crop growth variables as solar radiation, air temperature and rainfall are affected by sowing dates (Aguirrezábal et al., 2003; Izquierdo et al., 2009). Both low water availability (Cellier et al., 1998; Göksoy et al., 2004) and excessive rainfall (Grassini et al., 2007) can limit growth and yield.

Fungal diseases occur with greater intensity in later sowing dates, in most years (Loose et al., 2012). However, in El Niño years the occurrence of Alternaria and Septoria can be high on early sowing dates. This occurs because rainy periods with high relative humidity and temperature are favorable for these fungi development (Leite et al., 2006).

The sunflower development is determined by the thermal time above the base temperature (Aiken, 2005), while the solar global radiation affects growth and yield (Izquierdo et al., 2009). Rainy periods with higher cloudiness for several days also reduce yield. According to Alkio et al. (2003), the shading

during the floral initiation tends to reduce yield due to lower leaf area growth and number of achenes.

The better sowing dates for the sunflower crop in southern Brazil have to be determined considering the meteorological conditions for plant growth and development and also water availability. The aim of this research was to determine the growth and yield of sunflower at seven sowing dates in Santa Maria.

Material and Methods

Experiments were carried out in Santa Maria, located at the Central Depression of Rio Grande do Sul (latitude: 29° 43' 23" S, longitude: 53° 43' 15" W and elevation: 95 m). According to the Köppen classification, the regional climate is Cfa type, humid subtropical without dry season (Moreno, 1961). The soil is classified as Alfisol.

Different sowing dates were compared in five years. A completely randomized design was used with four replications in a factorial scheme (A x D), the factor "A" being different sowing dates and the factor "D" different sunflower hybrids. Seven sowings were done in 2007/2008, from August to February; five in 2008/2009, from August to November and February; four in 2009/2010, from October to January; two in 2010/2011, in November and December; six in 2011/2012, from September to February.

In the first three experiments the sunflower hybrids Aguará 03 (Ag 03) and Helio 358 (Hl 358) were used. They were replaced by Helio 251 (Hl 251) and Helio 250 (Hl 250) in 2010/2011 and 2011/2012. The four hybrids are precocious and can be sown during different seasons and different regions of the country.

The experimental area was cultivated under conventional tillage. The fertilization was done following recommendations for sunflower crop based on soil chemical analysis (CQFS, 2004). Seeds were treated with the insecticide thiamethoxam and sowing was done at 0.9 m between rows and 0.25 m between plants, resulting in a population of 44,444 plants ha^{-1}. The plot size was 4.5 x 5.0 m.

Weed and pest control were made when necessary, by manual weeding and use of insecticide (lambda-cyhalothrin + thiamethoxam), respectively. It should be noted that no fungicide application and no supplemental irrigation were done. After sowing and when the soil water content was low, a 6 mm irrigation was done.

Eight plants were randomly selected in plots for weekly measurements of plant height and width of leaves. The leaf area index (LAI) was determined using the methodology reported by Maldaner et al. (2009). Harvest was manually done at the physiological maturity (R9 stage) on plants sampled in 2.25 m^2 located at the center of each plot. The diameter of each capitulum was measured, except in the 2008/2009 experiment. Threshing was done manually and the weight of thousand achenes and yield at 13% moisture were determined.

Interaction analysis was performed among sowing dates and hybrids. When interactions were not significant, the average values of both hybrids were unfolded on sowing dates. The variables: yield (kg ha^{-1}), weight of thousand achenes (g), capitulum diameter (cm), maximum LAI (m^2 m^{-2}) and plant height (cm) were subjected to variance analysis by the F test and the difference between averages were compared by the Tukey test ($p < 0.05$).

Using data from the five agricultural years, yield was correlated with weight of thousand achenes, capitulum diameter, maximum LAI and plant height. Furthermore, the mean and standard deviation were obtained for growth variables and sowing dates.

Results and Discussion

The statistical analysis was significant for yield only in 2007/08, for the weight of thousand achenes in 2008/09 and 2009/10, for maximum LAI in 2007/08 and 2011/12 and for the plant height in 2007/08, 2009/10 and 2011/12. There was no significant difference between the two hybrids in most sowing dates. However, differences were recorded in yield and growth variables among sowing dates (Table 1 and 2).

In the agricultural year 2007/08, the highest yield occurred in the first (August) and second (September) sowing dates for both hybrids (Table 1). The lowest yield was found in sowings of December, January and February, which did not differ for both hybrids. Similar differences were found for weight of thousand achenes and capitulum diameter. The growth characteristics as maximum LAI and plant height were significantly lower in February (Table 2).

Lower yields were related with reduced rainfall in October, November, December and January sowing dates (Table 3). High disease severity was also recorded in January and February sowing dates, as was previously reported by Loose et al. (2012). Both high disease severity and low maximum LAI in February, contributed to reduced yield.

In 2008/09, higher yield was also recorded on sowings made in August and September, while the lowest was in October and November (Table 1). In this growing period, plants were damaged by heavy precipitation of hail in January 2009. Plants sown in October were damaged by hail at the R6 stage and those sown in November at the R1 stage, affecting negatively the weight of thousand achenes of the two hibrids. The LAI and the maximum height of plants were reduced in both hybrids (Table 2). According to Muro et al. (2001) and Karadogan & Akgün (2009), yield is strongly reduced by foliar injury due to the LAI reduction and greater predisposition to diseases.

Unlikely of 2007/8 and 2008/9, in 2009/10 the highest yield occurred at the late sowing date, January, while the lower was in October and November (Table 1). Similar differences were recorded for the capitulum diameter, confirming the relationship with yield reported by Alkio et al. (2003). The weight of thousand achenes was higher in the November and December sowing dates for both hybrids, without relationship with yield.

Maximum values of LAI and height of plants were ovserved for the hybrid Hl 358 in December and January sowing dates,

Table 1. Yield, weight of thousand achenes and capitulum diameter of sunflower plants at different sowing dates in 2007/08, 2008/09, 2009/10, 2010/11 and 2011/12

Harvest	2007/08		2008/09		2009/10		2010/11		2011/12	
Hybrid	Ag03	HI358	Ag03	HI358	Ag03	HI358	Ag03	HI251	Ag03	HI250
					Yield (kg ha^{-1})					
August	3109.0 a**	2455.0 ab	2600.6 a		-		-		-	
September	2738.8 a*	2967.9 a	2412.9 ab		-		-		3756.6 a	
October	1972.5 b	1675.4 cd	1511.8 cd		1314.5 c		-		3064.5 bc	
November	2729.1 a	2106.8 bc	1146.8 d		1593.8 bc		3704.1 a		1732.8 d	
December	1462.3 bc	1020.6 e	-		1981.9 b		2665.2 b		2788.4 c	
January	1406.0 c	1197.4 de	-		2529.1 a		-		3460.9 ab	
February	1511.8 bc	1088.3 e	1944.9 bc		-		-		2831.8 c	
CV (%)	12.05		16.88		16.19		14.27		12.96	
					Weight of Thousand achenes (g)					
August	58.66 a*		71.83 a**	71.16 ab	-	-	-		-	
September	56.66 ab		56.87 bc	61.85 bc	-	-	-		79.96 a	
October	49.25 b		62.78 ab	75.69 a	40.46 b**	45.51 b	-		62.39 b	
November	55.73 ab		50.38 bc	71.83 ab	69.45 a	81.85 a	63.74 a		58.05 b	
December	35.28 c		-	-	67.01 a	87.96 a	50.29 b		61.18 b	
January	39.09 c		-	-	48.83 b	52.86 b	-		63.98 b	
February	48.86 b		47.70 c	51.73 c	-	-	-		60.68 b	
CV (%)	8.27		9.79		9.32		6.57		9.69	
					Capitulum diameter (cm)					
August	15.76 ab*		-		-		-		-	
September	16.87 a		-		-		-		16.27 bc	
October	14.40 bc		-		12.14 c		-		15.66 c	
November	16.55 a		-		13.04 bc		18.34 a		13.04 d	
December	12.32 d		-		14.42 ab		17.07 b		15.50 c	
January	12.50 d		-		15.71 a		-		18.16 a	
February	13.26 cd		-		-		-		17.55 ab	
CV (%)	6.39		-		7.79		6.22		6.44	

CV - Coefficient of variation. *Means followed by the same letter in the column do not differ by Tukey test ($p > 0.05$). **Interaction analysis of factor A (sowing dates) and D (hybrid) significant by Tukey test ($p < 0.05$) and "A" unfolded in "D"

Table 2. Maximum leaf area index and plant height of sunflower plants at different sowing dates in 2007/08, 2008/09, 2009/10, 2010/11 and 2011/12

Harvest	2007/08		2008/09		2009/10		2010/11		2011/12	
Hybrid	Ag03	HI358	Ag03	HI358	Ag03	HI358	Ag03	HI251	Ag03	HI250
					Maximum leaf área index (m^2 m^{-2})					
August	2.96 ab*	2.95 a	2.97 a		-		-		-	-
September	3.26 a**	2.94 a	2.78 ab		-		-		2.44 ab**	1.99 ab
October	2.96 ab	3.20 a	3.20 a		1.25 c		-		2.48 ab	1.99 ab
November	2.79 ab	2.57 ab	2.27 b		2.02 bc		3.29 a		1.37 b	0.78 c
December	3.57 a	2.98 a	-		2.18 ab		2.22 b		3.57 a	2.45 ab
January	2.96 ab	2.24 ab	-		2.98 a		-		3.03 a	2.67 ab
February	2.19 b	1.63 b	3.29 a		-		-		2.99 a	2.98 a
CV (%)	16.72		17.26		28.44		26.38		24.06	
					Height of plants (cm)					
August	157.8 ab*	142.8 a	142.3 d		-	-	-		-	-
September	148.3 ab	141.5 a	172.8 a		-	-	-		161.8 ab	175.3 a
October	175.0 a**	14.0 a	155.5 bc		166.3 a	106.5 c	189.8 a		135.3 b	129.8 b
November	179.8 a	160.8 a	150.6 cd		166.3 a	106.5 c	189.8 a		135.3 b	129.8 b
December	185.0 a	157.0 a	-		168.5 a	154.0 ab	170.3 b		177.3 ab	160.1 ab
January	156.0 ab	132.5 a	-		180.8 a	166.0 a	-		182.8 a**	161.3 ab
February	125.0 b	133.5 a	167.4 ab		-	-	-		162.0 ab	169.8 ab
CV (%)	12.75		5.21		9.76		6.50		12.67	

CV: coefficient of variation. * Means followed by the same letter in the column do not differ by Tukey test ($p > 0.05$). ** Interaction analysis of factor A (sowing dates) and D (hybrid) significant by Tukey test ($p < 0.05$) and "A" unfolded in "D"

in a similar way of yield (Table 2). In this agricultural year, under influence of El Niño, higher cumulative rainfall occurred mainly in August and September sowing dates (Table 3). As a consequence, plant emergence was reduced by water excess in the soil. In October and November sowing dates, yield was also reduced due to soil water excess (Grassini et al., 2007), low levels of solar radiation (Table 3) (Alkio et al., 2003) and the high severity of fungal diseases (Leite et al., 2006; Vrandecic et al., 2012).

In 2010/11, yield, weight of thousand achenes, capitulum diameter, maximum LAI and plant height were higher in the November sowing date (Tables 1 and 2). Environmental growing

Table 3. Cumulative rainfall and cumulative global solar radiation during the growing period of sunflower plants at different sowing dates in 2007/08, 2008/09, 2009/10, 2010/11 and 2011/12

Harvest	2007/08	2008/09	2009/10	2010/11	2011/12	2007/08	2008/09	2009/10	2010/11	2011/12
	Cumulative rainfall (mm)					Cumulative solar radiation (MJ m²)				
August	448.2*	455.2	-	-	-	1749.0	2075.0	-	-	-
September	395.2	334.2	-	-	309.2	2112.6	2259.2	-	-	2578.8
October	198.0	413.0	1183.6	-	236.6	2079.7	2031.6	1865.7	-	2532.0
November	57.2	194.0	1099.2	426.4	334.8	2242.0	2008.6	1771.1	2409.6	2701.1
December	100.0	-	744.6	263.6	368.8	1546.4	-	1864.6	2305.2	2106.3
January	273.8	-	442.6	-	422.2	1699.3	-	1749.3	-	1908.1
February	361.0	296.4	-	-	319.4	1488.4	1352.3	-	-	1485.4

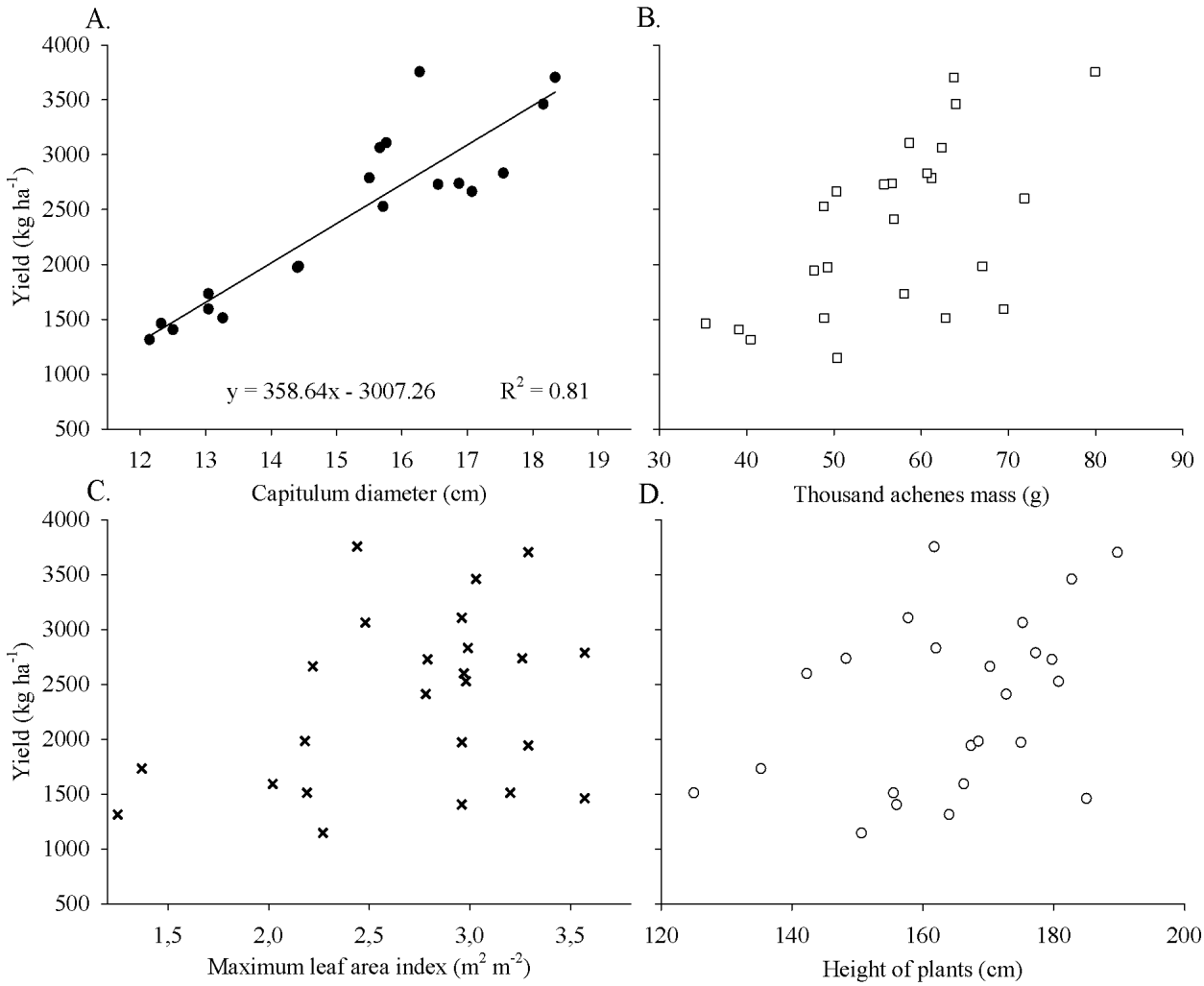
*Summation of the total rainfall and solar radiation over the cycle

conditions of rainfall and solar radiation were better for plants of this sowing date (Table 3) and lower the severity of diseases, which explains this result.

In 2011/12, the higher yields were obtained in the September and January sowing dates, which did not differ significantly, while the lowest yield was in November (Table 1). Moreover, the September sowing date had the highest weight of thousand achenes, while the capitulum diameter was higher in January and February, which resulted in high yield, even with the smaller weight of thousand achenes.

Regarding the growth characteristics, November presented the lower values of plant height and maximum LAI (Table 2). Plants sown in November suffered from water deficit which reduced growth and yield (Karam et al., 2007).

Positive relationships were found among yield and capitulum diameter, weight of thousand achenes, maximum LAI and height of plants, with coefficient of determination (R^2) of 0.82, 0.35, 0.08 and 0.12, respectively (Figure 1). The capitulum diameter presents the highest correlation coefficient, indicating its direct and positive effect on the achenes production, with high genetic



Significance ($p < 0.05$)

Figure 1. Yield as a function of capitulum diameter (A), weight of thousand achenes (B), maximum leaf area index (C) and plant height (D) of sunflower sown from August to February during the years 2007 to 2012

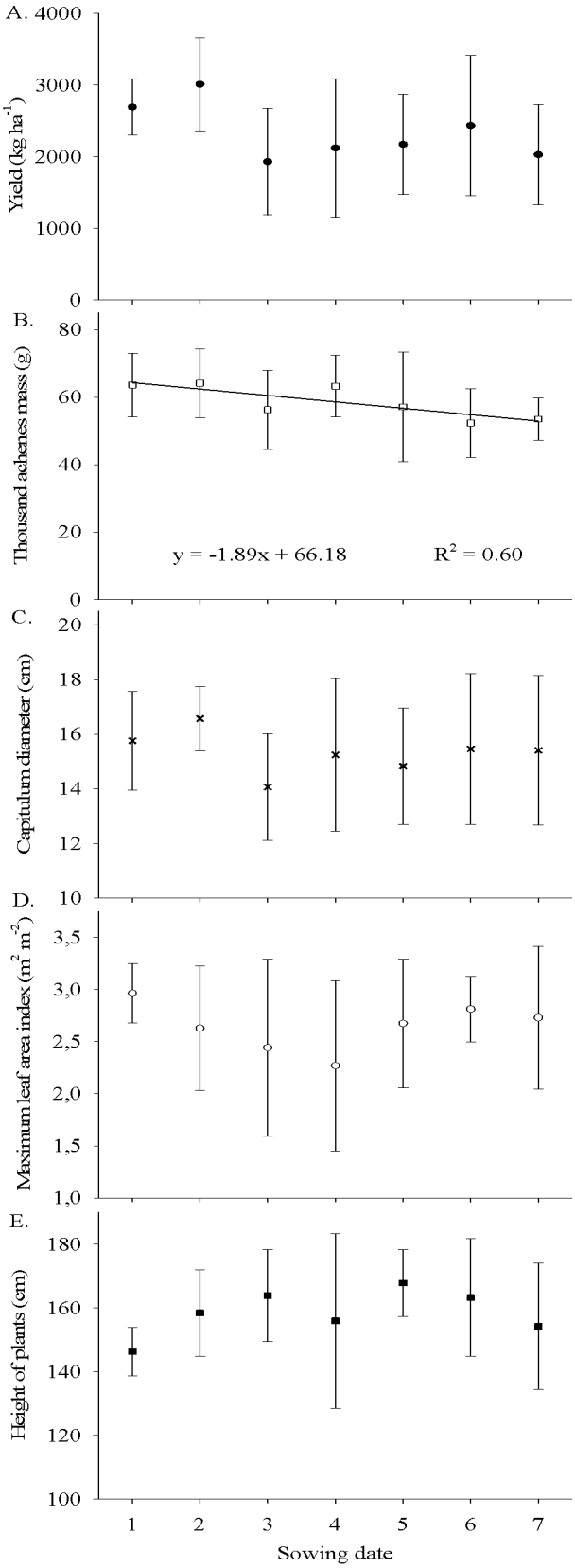


Figure 2. Mean, standard deviation and trend (significance $p < 0.05$) of yield (A), weight of thousand achenes (B), capitulum diameter (C), maximum leaf area index (D) and plant height (E) of sunflower sowing from August (1) to February (7) during 2007 and 2012

correlation (Kumari et al., 2012). Therefore, this feature is important for selection of genotypes, as capitulum of larger size tend to have a higher proportion of large and heavier achenes (Alkio et al., 2003). Other variables also affect yield, albeit with less significance.

An overview of the results of five years of experiments can be seen in Figure 2. The yield tended to decrease ($y = -103.96x + 2754.7$; $R^2 = 0.19$) from early to later sowing dates, with the highest average in September, followed by August and January, while the lowest average was in October sowing date (Figure 2A). The weight of thousand achenes also shows a slight downward trend in later sowing dates (Figure 2B).

A reducing trend has been reported by Loose et al. (2012) for the severity of leaf spots on sunflower plants at delayed sowing dates. Such data is confirmed by present results. In turn, the capitulum diameter showed no significant tendency (Figure 2C). The overall view of the present results shows a reduction of yield with delayed sowing dates. Similar finding was also observed in researches carried out in Argentina by De la Vega & Hall (2002). Moreover, the September sowing date had the highest average yield, capitulum diameter and weight of thousand achenes, being the best sowing period.

The growth variables of maximum LAI and height of plants showed quadratic trend ($y = 0.0481x^2 - 0.39x + 3.24$; $R^2 = 0.41$), but, respectively, with a positive and negative coefficients. The maximum LAI showed a tendency to increase in the early and late sowings and to decrease in October and November (Figure 2D). The plant height showed opposite trend than that of maximum LAI, decreasing at early and late sowing dates ($y = -1.385x^2 - 12.41x + 136.56$; $R^2 = 0.51$), with the highest values at intermediate sowing dates. Nevertheless, low plant height was recorded at the November sowing date and the standard deviation was high (Figure 2E). The high standard deviation of this sowing date might be explained by the high temporal variability of environmental conditions in this period, especially water excess or deficit.

Conclusions

1. The best sowing period to reach higher yield of the sunflower crop in Santa Maria is early September.

2. In El Niño years sowing dates from August to November lead to reduced yield due to plant diseases and negative effects on plant emergence.

3. In normal or La Niña's years, there is a tendency to reduce the weight of thousand achenes and yield with late sowing date.

4. The capitulum diameter has higher correlation with yield than weight of thousand achenes, maximum leaf area index and plant height.

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