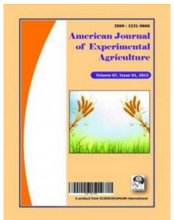

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Phenology, Thermal Integral and Agronomic Yield of Cotton (*Gossypium arboreum* L) at a Function of Date of Planting in Dry Weather

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JMLC and EDL designed the study and wrote the protocol. Author JMLC wrote the first draft of the manuscript. Authors AMR and JMLC reviewed the experimental design. Authors JMEAL, BLL and JALG reviewed all drafts of the manuscript. Authors IBH and JMEAL managed the analyses of the study. Author EDL identified the plants. Authors JMLC, AMR and BLL performed the statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this study was to know the effect of planting date (early and late) on the phenology and thermal integral of an accession of *Gossypium arboreum* L. to evaluate fiber and seed yields and harvest index. Design randomized complete block with four replications (4x3) = 12 experimental units was used. The experiment was carried out at the Universidad de la Cañada in Teotitlán de Flores Magón, Oaxaca, Mexico, from May to October 2012. The experiment was conducted in the field, fertilizing the soil and with a topological arrangement (0.30 x 0.30 x 1.0). Both seed and fiber

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yields were determined gravimetrically, and harvest index by the ratio between the agronomic yield and the biological yield. The results indicate that the highest seed yield, fiber and seed harvest index, was achieved in early planting dates and crop phenology was not altered by treatment effect. From this study it could be concluded that the cotton might be an option to plant under the conditions of the tropical dry forest of Oaxaca.

Keywords: Seed yield; fiber yield; index harvest; accession; Oaxacan deciduous forest.

1. INTRODUCTION

Cotton (*Gossypium spp*) has been cultivated worldwide for many years to extract fibre from its seeds [1], and now becomes more important because of the extraction of secondary metabolites such as fatty acids for human consumption [2]. To obtain the above products, the cotton plant depends on environmental factors such as air temperature, soil moisture, solar radiation and a good supply of macro and micronutrients, which are going to influence directly on the biological and agronomic performance [3].

In this trend, the temperature is a good parameter that has been able to correlate significantly with the ontogenic stages, which traverse a crop and that has been termed phenology [4,5]. Similarly, for these occur, the growing need to accumulate a number of degree-days of development, a phenomenon agronomical known as thermal integral or heat units [6,7]. This phenomenon is useful from an ecophysiological point of view, because it can help predict crop development stages in relation to temperature accumulated, when perform mathematical model, correlating temperature.

Thereon, Díaz et al. [8] used green beans in high valleys like Toluca, and report that the thermal integral can predict the occurrence of phonological stages, from planting to physiological maturity, finding a high correlation coefficient of 0.99 between time and grades-days of development.

Added to this, Morales et al. [9] relate effectively heat units (℃ day^{-1}) with the phenology in sunflower (*Helianthus annuus* L) in dry climate and mentioned that there is a close linear relationship between these and the phenology of *Helianthus*, reporting a high coefficient of determination of 0.97, demonstrating the usefulness grades-days to predict those stages.

With regard to cotton, Fariña and Lorenzini [10] reported that heat units are very practical to determinate the growth potential of cotton during different phonological stages and, also are an important parameter for predicting the agronomic yield for cotton growing regions of Santa Fe in Colombia.

Furthermore, planting dates are a very important factor to consider when establishing a crop in the open, as they mark the period when conditions are optimal for proper germination such as temperature and humidity. Thus, a suitable planting date will allow the crop to be grown under optimal conditions, with a good supply of water and nutrients [11,12].

Therefore, the aim of this study was to determine the phenology, thermal integral and its relationship with both seed and fiber yields in growing cotton at the tropical dry forest of Oaxaca, Mexico. The hypothesis raised was that the thermal integral is a parameter that support to the correctly predicting the ontogenetic stages during the cotton-growing season.

2. MATERIALS AND METHODS

2.1 Crop Conditions

This study was conducted under rainfed conditions at Teotitlán de Flores Magón, Oaxaca, Mexico. This is located at 18°06´ N, 97°06´ W and 980 mamsl. Moreover, it was carried out in a climate $Bs_1e´g$, which corresponds to a dry climate with rainfall of 400 to 600 mm, with a distribution of rainfall that runs from June to September. The temperature swing between the warmest and the coldest month is greater than 14℃, and the hottest month, April, occurs in the area before the summer solstice [13]. The soil in the area is a Luvisol with colluvial debris in formation, with a pH of 6.8, apparent density 1.6 g cm^{-3}, electrical conductivity of 1.7 dS m^{-1} and 1.9% organic matter. The entire experiment was fertilized with 100 kg ha^{-1} of ammonium sulfate (21% N), 60 kg ha^{-1} of triple calcium superphosphate (46% P_2O_5) and 30 Kg ha^{-1} of potassium chloride (60% K_2O) [14], which were applied at planting time. The germplasm used was obtained from an accession of (*Gossypium arboreum* L) identified with the keys to the flora of the Tehuacán-Cuicatlán Valley and located in the town of San Jose Tilapa, Puebla. These were planted under the topological arrangement (0.30 x 0.30 x 1.0) resulting in a population density of 3.3 plants m^{-2}.

2.2 Phenology, Thermal Integral and Agronomic Yield

The phenology of cotton was determined with the keys extended BBCH [15]. The thermal integral was calculated by the residual method of Snyder [16], by the equation:

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

where; *TI*, is the thermal integral; *T*max and *T*min, are the maximum and minimal temperatures, respectively; and *Tb*, is the basis temperature of culture (12℃). Both maximum and minimum temperatures and precipitation during the growing season were determined using an automated weather station Davis vantage pro-2. Both seed yield and fiber yield were determined with an analytical balance, weighing the total seed and fiber produced by cotton capsule and expressing the result in g $plant^{-1}$ for each case. The harvest index was calculated by the expression:

$$HI = \frac{AY}{BY}$$

where: *HI*, is the harvest index and *AY* and *BY*, are the agronomic yield and biological yield, respectively. It is worth mentioning that the agronomic yield was determined for both seed and fiber.

2.3 Experimental Design and Statistics

It was a randomized complete block design with three replications with the following model:

$$Y_{ijk} = \mu + \tau_i + \beta_j + \varepsilon_{ijk}$$

where Y_{ij}, is the response variable of the *i*-th planting date in the *j*-th repetition, μ, is the true overall average; τ_i, is the effect of the *i*-th planting date; β_j, is the effect of the *j*-th block and ε_{ij}, is the error of the *i*-th planting date in the *j*-th block [17]. Thus, the treatments were four planting dates, two early: May 15 and May 30, and two late: June 15 and June 30, resulting in twelve experimental units, where a plant is an experimental unit. The variables that were significant, they apply the comparison test of Tukey HSD, with a significance level of P = .05 of error probability.

3. RESULTS

3.1 Crop Conditions

In Fig. 1, maximum and minimum temperature and average monthly precipitation is shown during ontogenic cycle of the cotton crop, and was observed that the maximum temperatures occurred during the month of May, oscillating between 40 and 35℃, while the minimum temperature was presented in October, at an interval of 24 to 15℃. Likewise, most precipitation was observed from June to September and from the date of planting to maturity, the amount of precipitation was 198 mm. It is noteworthy that under these conditions the crop is properly developed and adapted to the conditions of the study area.

3.2 Phenology, Thermal Integral and Agronomic Yield

The phenology for the four planting dates is presented in Table 1. It is observed that there were no significant differences (P > .05) between planting dates for phenological stages V_1, V_n and V_6, but not for the reproductive stage R_n, where most lasting, 120 days, occurred in the early planting date (May 15), beating the May 30 date, who only provided a duration of 90 days. Late planting dates, June 30 and 15, were statistically equal to 80 and 70 days respectively, so the largest crop cycle was presented at the May 15 with 225 days, so that, as was increasing the planting date, crop cycle was shorter.

The thermal integral is presented in Figure 2. It is appreciated that the data obtained to a linear model was fitted with a high coefficient of determination .99. For each planting date, the accumulated thermal integral was 2800, 3065, 3075 and 3100℃ day^{-1}, for June 30 and 15, and May 30 and 3, respectively.

Both yield seed and fiber, and harvest index, were presented in Table 2. Treatments for both yield seed and fiber, and seed harvest index showed highly significant differences (*P* = .01). The coefficient of variation varied from 12 to 25%, which allows asserting that the data obtained are acceptable. Means test treatments for early planting dates (May 15 and 30) were statistically higher (*P* = .05) than treatments late planting date (June 15 and 30), with 93.17 and 89.45 g plant^{-1}, and 65.11 and 63.41 g plant^{-1}, respectively. The fiber yield showed the same trends as the seed yield, so, early planting dates had the highest yield of fiber with 46.05 y 41.11 g plant^{-1}.

The *HI* reached their maximum values in the early planting dates (May 15 and 30) with 0.33 and 0.29, significantly outperforming (*P* = .05) the late planting dates, who only obtained 0.23 and 0.22, respectively.

4. DISCUSSION

Referring to the data of sowing date, these were compared with data reported by Palomo et al. [14], where mentions that despite significant differences between different areas of studio and genotypes used, length of the growing cycle remained constant up to 220 days.

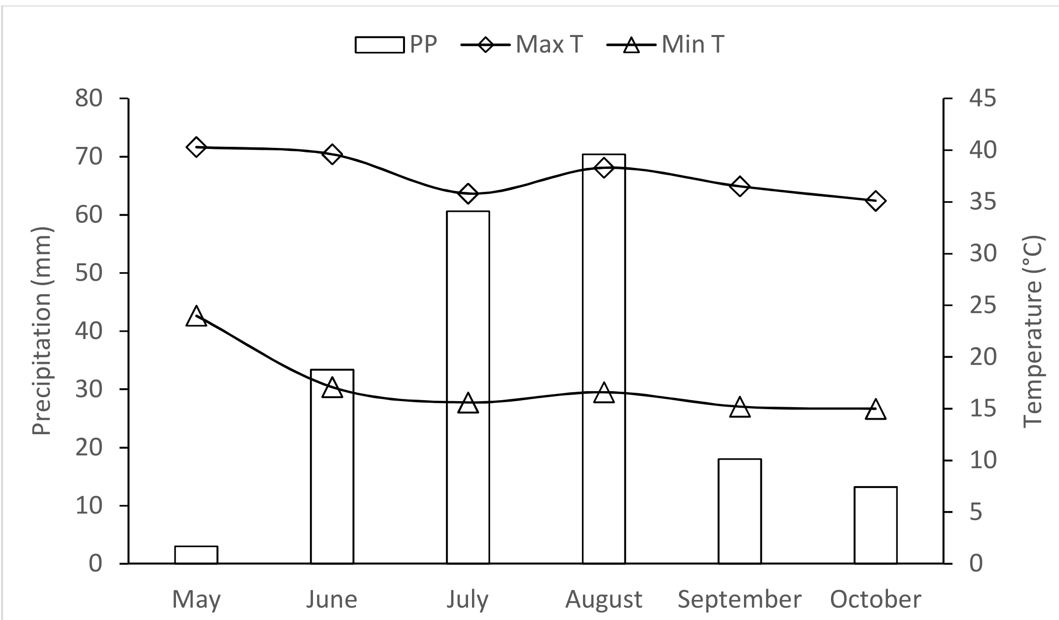

Fig. 1. Monthly mean temperatures maximum and minimal (Max T and Min T), and precipitation (PP) in the cultivation of cotton (*Gossypium arboreum* L.), during the May-October cycle at Teotitlán de Flores Magón, Oaxaca, México. 2012.

Table 1. Planting dates and phenological estage of cotton (*Gossypium arboreum* L.) in the Oaxacan deciduous forest, during May-October cycle, 2012

Planting date	Phenological stage				
	V_1	V_n	V_6	R_n	DC
	Days				
June 30	12.00[a¶]	49.00[a]	57.00[a]	74.00[c]	192.0
June 15	12.00[a]	48.00[a]	57.00[a]	80.00[c]	197.0
May 30	15.00[a]	45.00[a]	53.00[a]	90.00[b]	203.0
May 15	15.00[a]	40.00[a]	50.00[a]	120.00[a]	225.0
HSD				7.4	
CV %	22.33	16.80	27.27	20.12*	

*[¶]means within the column with the same literal, are statistically equal according Tukey (P = .05). V_1, sprouting; V_n, leaves 1, 2, 3, 4 y 5; V_6, sixth leaf; R_n, reproductive stages. HSD, honest significant difference; CV, coefficient of variation; DC, duration of cycle. * significant at P = .01.*

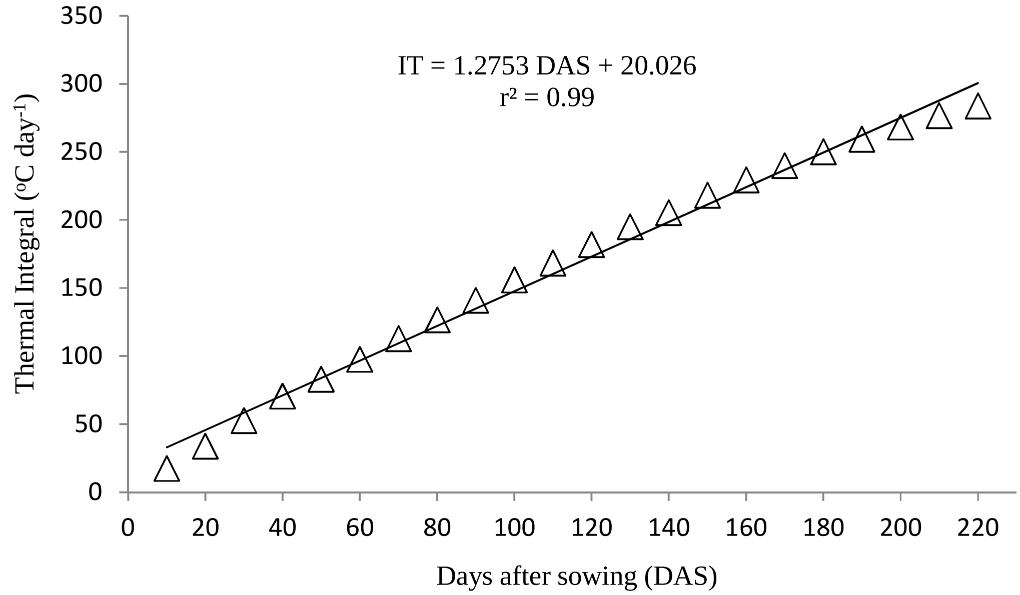

Fig. 2. Adjust of thermal integral in cotton (*Gossypium arboreum* L.) in the Oaxacan deciduous forest in Teotitlán de Flores Magón, during May-October cycle, 2012. DAS, Days After Showed

Table 2. Both seed and fiber yields, and harvest index of cotton (*Gossypium arboreum* L.), in the Oaxacan deciduous forest, during May-October cycle, 2012

	Yield		*HI*	
	Seed	Fiber		
	g plant^{-1}		Seed	fiber
June 30	63.41[b¶]	23.12[b]	0.22[b]	0.11[a]
June 15	65.11[b]	29.33[b]	0.23[b]	0.12[a]
May 30	89.45[a]	41.11[a]	0.29[a]	0.16[a]
May 15	93.17[a]	46.05[a]	0.33[a]	0.18[a]
HSD	4.22*	6.91*	0.20	
CV %	20.33	25.71	18.90	12.14

*¶means within the column with the same literal, are statistically equal according Tukey (P = .05). HSD, honest significant difference; CV, coefficient of variation; HI, harvest index. * significant at P = .01.*

In the case of the thermal integral, the values obtained in this work, in degrees per day of development, coincide with those reported by Escalante et al. [18], they reported that working with beans, get a thermal integral of 300 UC in the conditions of Iguala, Guerrero. Likewise, is possible to assume that the sowing of different species in similar climates have a similarly thermal integral, varying only the basis temperature of germination of the crop, which is taken as reference for the calculation of the thermal integral. In other studies of this nature, Morales et al. [9] reported a thermal integral of 2400 UC, working with sunflower. These data differ from those reported in the present study despite being oilseed species, but these discrepancies are attributed to the different environments in which they conducted studies, addition to having great phenotypic plasticity cotton accesion to adapt to high rates of radiation having the Oaxacan decidious forest.

The results of seed yield for late planting dates coincide with those reported by Palomo et al. [14]. They reported seed yields 67.8 g plant^{-1}, considering that the density used was 7.0 plants m^{-2}. The consistency of these data with those of the present study could be attributed to both cultivars were planted in a dry climate, homogenizing somehow factors such as temperature and precipitation, which allowed experiments were equal environmental conditions.

In the case of early planting dates, fiber yield from this experiment differ from those reported by Palomo et al. [19], due to they reported 24.9 g plant^{-1} and in the resent study feather yield 46.05 g plant^{-1} was obtained, i.e. there was a difference of 84%. This is attributed to the different response of the genotypes used in the assignation of dry biomass towards feather (fiber), because *Gossypium arboreum* L. has a greater phenotypic plasticity generated by self-pollinitation and therefore has a larger gene pool than cv. Laguna 89, used in the comparative study.

The fact that the harvest index reach their peak in the early planting dates, is attributed to these plants had a higher crop cycle, allowing a greater synthesis of carbohydrates, due to the extension of the reproductive phase as mentioned in phenology. In addition, this allowed the translocation to seed and fiber, increasing the *HI*, biological phenomenon well explained by Salisbury and Ross [20] and Taiz and Zeiger [21]. They mentioned that when crop plants are subjected to a stint as the crop cycle, this tend to shorten their ontogenic cycle, many times by spending photosynthates in aerial biomass production, mainly in leaves and branches, instead of biomass allocation in seed.

5. CONCLUSION

The highest yields of both seed and fiber were obtained in early plantings, while crop phenology was altered by sowing dates. In early planting dates, reproductive stage was reached, while in late planting dates occurred otherwise. Moreover, the accumulation of heat units was higher at early planting dates, reaching up to 3075℃ day^{-1}. Thermal integral is a tool which is possible to use for predicting the phonological stages and its duration in the cultivation of cotton. Finally, the cotton crop could be an option for grown under the conditions of the deciduous forest of the state of Oaxaca.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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