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# Genotype and planting date effects on cotton growth and production under south Portugal conditions
## I. Phenology and growth analysis

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## Abstract

Genotype earliness and date of sowing are two of the most critical aspects in the management of cotton (*Gossypium hirsutum* L.) in Mediterranean climates, where low temperatures at sowing and low temperatures and raining during boll period and harvest are the main weather constrains of the season length. The aim of this work was to determine the influence of cultivar maturity type and planting date on phenology and growth indexes. Six genotypes and three sowing times were studied in one field experiment conducted in 2002 and 2003 at Comenda Experimental Station, Alentejo, Portugal. No significant differences were accounted between genotypes in each phenological phase periods and in the whole growing season durations. Inversely, planting date delay had a clear impact on shortening of some phenological periods, namely, planting-emergence (-7.5 days), emergence-first square (-19 days) and first flower-first open boll (-15.5 days). The poor heat unit accumulation and unfavorable high-day and low-night temperatures registered after 15 August deeply affected the boll period duration, which surpass the standards higher limit intervals referred for California and Andalusia. Logistic growth asymptote (A) varied significantly with genotype (64.9 to 229.5 g plant$^{-1}$) and year (84.1 to 165.6 5 g plant$^{-1}$) but without any regular pattern between planting dates. The number of days after planting to reach maximum growth rate (C) decreased significantly with planting date delay (122.8 to 98.7 DAP) and varied significantly between both years (104.6 to 117.7 DAP). In contrary, the B constant (maximum relative growth rate) experienced no significant differences between the two factors in study (0.075 g g$^{-1}$ day$^{-1}$). Genotype and planting date had significant impacts on relative growth rate (RGR) (0.065 to 0.105 g g$^{-1}$ day$^{-1}$) and net assimilation rate (NAR) (8 to 13 g m$^{-2}$ day$^{-1}$), in the beginning of the season and on absolute growth rate (G) (1.7 to 3.4 g plant$^{-1}$ day$^{-1}$), leaf area index (LAI) (2.6 to 4.6) and crop growth rate (GCR) (13.1 to 26.7 g m$^{-2}$ day$^{-1}$) in the mid and late season. The two former growth indexes reach higher values in the early growth stages, decreasing deeply thereafter until the end of the season. On contrary G, LAI and CGR presented a bell-shaped distribution pattern along the season, with peak CGR taking place 15 to 30 days after the beginning of the flowering period and peak LAI 22 to 30 days after peak CGR. However, data analyses of those growth indexes reveal inconsistent variation patterns among the two studied factors. It was concluded that further studies using a larger range of maturity type cultivars are necessary in order to provide valuable phenological and growth indexes baseline values for cotton grown in the southern Iberian Peninsula.

***Key words:** Gossypium hirsutum,* phenology, growth analysis, genotype earliness, planting date.

## Introduction

Upland cotton is a major economic crop in some southern regions of Greece and Spain, where about 500 thousands hectares are annually seeded. Since 2001 some attempts are in progress in order to introduce this crop in Portugal [1]. At those Mediterranean type climates the growing season duration is a main constraint, limited by low temperature at sowing and low temperature and raining during maturation and harvest [2], implying poor field emergences [3, 4], small boll maturation periods and low fiber quality[5, 6]. To overcome the restricted growing season duration, planting date [7], seeding under plastic mulch [8, 9] and genotype earliness [10, 11] are important considerations in crop management. However, the relatively high labor and material costs drawn in mulching during the first stages and the continuous decrease in crop profitability lead to a tendency of plastic cover discard as a management key factor [2, 12]. That way, the choices of planting date and genotype earliness [13] seem to remain the two major tools of crop management at marginal regions.

Temperature functions as a primary factor controlling cotton plant growth rate and time interval between unlike events [14]. The durations of planting to first square and first flower to open boll are the two main periods in which genotypic and genotypic x environment variability is most frequently accounted [14-16] whereas the first square to first flower period seems to be a more genotypic independent, published time gaps and heat units requirements of cotton phenology unlike events commonly observed at the Spanish cotton belt (Guadalquivir Valley, Andalusia) [14, 17-19]. For this region 84% of the produced fiber became from flowers opened between 500 and 890ºC days [17], the equivalent of the period 80-95 days after planting (DAP) [19].

In regions with high solar radiation, as occur in the Guadalquivir Valley, high leaf area indexes (LAI) must be achieved for accomplish high yielding cotton crops, attaining maximal crop growth rates (CGR) of 17-19 g $m^{-2}$ $day^{-1}$ during the flowering period[19]. Under irrigation optimal LAI is around 5 [17]. Others compared the influence of irrigation systems and water supply levels on cotton production and earliness management [20] and the evapotranspiration deficit as a management tool based on cultivar earliness, growing season length and water availability [21]. Unfortunately, besides maximum LAI values, those two authors don't report any further growth parameters or phenological data. The behavior of 'Coker 310' seeded under and without plastic mulch, at Alcalá del Río (37º20'N), Spain, showed great differences in LAI during the first stages, with the mulched treatments reaching higher values [8]. However, the initial differences progressively decline along the growing season. Significant planting date effects were detected on the observed LAI until 90 DAP, with the late plantings reaching higher values in shorter periods after planting, but they were not able to find LAI intergenotype differences at first flower [7]. However, in other experiments, those authors find significant differences of peak LAI between genotypes and between planting dates, reaching the short season cultivars and the late sowing dates the lowest peak LAI values [7, 22]. Leaf shape also has a great influence on LAI, with a tendency of the okra leaf genotypes to reach lower values at the same DAP [23, 24]. The relationships between LAI, CGR and net assimilation rate (NAR), as well as their impact on cotton yield, were widely studied [22-27]. The earlier peak CGR relatively to peak LAI and the following decline of CGR due to NAR deep decrease, attributed to canopy leaf aging and progressive unfavorable environmental conditions after summer solstice, are the leading motives of cotton canopy inefficiency. Under these circumstances, cultivar earliness and planting date are potential instruments that can be used in order to enhance cotton growth behavior.

Unfortunately, there's a lack of available data and general information about this issues obtained in the Iberian Peninsula, so the purpose of this experiment was to characterize the phenology and to obtain relevant growth indexes data on six genotypes of upland cotton sown at three planting dates.

**Table 1.** Description of varieties.

| Genotype | Growing season | Precocity index (%)[b] | Leaf type | Origin |
|---|---|---|---|---|
| Carmen (Sicala V2)[a] | medium-late | 87 | normal | CSIRO (Australia) |
| Celia (Sicala 40) | eary-medium | 93 | normal | CSIRO (Australia) |
| Crema 111 (KC311)[a] | medium | 86 | normal | Stoneville (USA) |
| Flora (Sicot 41) | medium | 89 | normal | CSIRO (Australia) |
| Lacta (Siokra V-17) | medium | 90 | okra | CSIRO (Australia) |
| Sonia (Sicot 70) | medium-late | 87 | normal | CSIRO (Australia) |

[a] Solely 'Carmen' and 'Crema' cultivars are responsible for more than 46,000 hectares of cotton crop in south Spain per year. [b] Percentage of first harvest on total seed-cotton yield ($E_6$ precocity index[68]).

**Table 2.** Monthly temperature and thermal units summary for 2002 and 2003 at Comenda Experimental Center, Caia, and correspondent 30 year's mean data for Elvas.

| Month | Temperature (°C) | | | Thermal units[a] | | |
|---|---|---|---|---|---|---|
| | 2002 | 2003 | Elvas | 2002 | 2003 | Elvas |
| March | 12.6 | 13.1 | 11.7 | 0.0 | 0.0 | 0.0 |
| April | 14.6 | 14.1 | 13.8 | 0.0 | 0.0 | 0.0 |
| May | 17.4 | 20.3 | 17.3 | 74.4 | 164.3 | 71.3 |
| June | 22.9 | 24.4 | 21.5 | 237.0 | 282.0 | 195.0 |
| July | 25.6 | 25.0 | 24.7 | 328.6 | 310.0 | 300.7 |
| August | 24.6 | 27.8 | 24.5 | 297.6 | 396.8 | 294.5 |
| September | 20.9 | 23.5 | 22.2 | 177.0 | 255.0 | 216.0 |
| October | 17.6 | 16.6 | 17.4 | 80.6 | 49.6 | 74.4 |

[a] [(máx. temp. + min. temp.)/2 – 15°C].

## Material and Methods

***Cultural details:*** Field experiments were hand sown using acid delinted seeds of Carmen, Celia, Crema, Flora, Lacta and Sonia upland cotton cultivars (Table 1) in 3 planting dates each year (19 and 30 April and 13 May in 2002, and 20 March, 3 and 17 April in 2003) at 5 cm deep and 1 m row-width (18 seeds $m^{-2}$) at the Comenda Experimental Center, Caia, Alentejo, Portugal (38°54'N, 7°03'W, 169 m altitude), on a sandy Xerofluvent, Fluvent, Entisol. Seeded plant population was 18 seeds $m^{-2}$, and averaged genotype and planting dates emerged plant population reached only 9.5 plants $m^{-2}$. A completely randomized design was used with three replications in plots of 10 m x 5 m.

Temperature data were recorded using temperature sensors and data loggers (Spectrum Technologies, Inc.), in order to evaluate the relation of this primary control factor of cotton growth with phenology and growth parameters results. Growing degree days were determined using 15°C (60°F) lower threshold and no upper threshold (Table 2).

Soil water content was monitored with Watermark soil moisture sensors and loggers (Spectrum Technologies, Inc.) and maintained in adequate available water thresholds to plant growth using drip irrigation. Crop evapotranspiration, determined by Penman method and adjusted with the cotton crop coefficients [28] was 795 and 767 mm, in 2002 and 2003, respectively, entirely compensated by irrigation.

Fertilizer was applied broadcast at a rate of 45 kg $ha^{-1}$ N:P:K prior to planting and additional 180 kg $ha^{-1}$ N at first square. Weeds were controlled with trifluralin (48% w/v), benfuresate (40% w/v) and fluometuron (50% w/v) preplant application and by hand in row and mechanical between row weeding along the growing season. Insect infestations were controlled as needed with dimethoate (40% w/v), endosulfan (38% w/v), lambda-cyhalothrin (20% w/v) or metomil (20%) w/v) sprays. In spite those insect controls in both years, important damages on squares and bolls were observed due to rough bollworm (*Earias* spp.) and cotton bollworm (*Heliothis* spp.) (Lepidoptera: Noctuidae). In 2003 *Aphis* spp. (Hemiptera: Aphididae) damages was also noted.

***Measurements:*** Weekly harvests of 3 plants per genotype x planting date combinations were made randomly in each plot, leaving unharvested the plot border and the adjacent plants to previous harvested sites. In each sampled plant, leaves were separated from the rest of the above ground structures, in order to determine leaves area. In each 2002 sampling, leaves were digitally photographed and their area measured using the Image Tool for Windows Version 3.0 package, developed by the University of Texas, Health Science Center, San Antonio. In 2003, leaf area was estimated by linear regression equations fitted with 2002 leaf area and dry weight data per each genotype and planting date. After leaves area measurement, total plant and leaves dry weights were determined after drying for 48 h at 100°C.

***Data analysis:*** Functional approach to plant growth analysis [29] was determined from a logistic equation adjusted by non-linear regression of total plant dry weight (DW) observed data and from a linear regression adjusted to leaf area rate (LAR) data, both with days after planting (DAP) as the independent variable[30]:

$$DW = \frac{A}{1 + e^{(-B(DAP - C))}} \qquad LAR = \frac{LA}{DW} = a + bDAP\ ,$$

where LA means leaf area.

Absolute growth rate ($G = BDW - \frac{BDW^2}{A}$), relative growth rate ($RGR = B - \frac{BDW}{A}$) and crop growth rate ($CGR = \left(BDW - \frac{BDW^2}{A}\right)$ *x plant density*) were directly calculated from logistic curve, and net assimilation rate ($NAR = \frac{B - \frac{BDW}{A}}{LAR} = \frac{B - \frac{BDW}{A}}{a + bDAP}$) both from logistic curve and LAR straight line. Using total leaf dry weight (LDW) to LA quotient, specific leaf area ($SLW = \frac{LDW}{LA} = a + bDAP$) was also determined from a linear regression with DAP. Non-linear quadratic equations were fitted between leaf area index (LAI) and DAP.

All statistical analysis was performed with SPSS for Windows Standard Version 9.0. In some cases, no experiment year differences were detected, so means and statistics were calculated and presented using both year data. In general, the planting date's differences of 1 month imposed between the first and third planting treatments and the 1 month earlier plantings of 2003 relatively to 2002, were almost absorbed and annulled by plant growth and development during the growing seasons. This result had as a general consequence a lesser number of DAP requisite to reach the same event, 2002 relatively to 2003, and also the later planting date relatively to the earlier ones. Because of this plant growth behavior, all the Figs. are plotted against calendar dates and not against DAP.

## Results

***Phenology:*** In 2003 sowing date was 1 month earlier than in 2002, having seedlings in 2003 experienced quite lower soil temperatures during all the emergence period, inclusively below the $t_0$ of 15.5°C rule-of-thumb [31]. This constraint, added to the observed soil crust 2-3 cm thick [32], outcome in greater planting-emergence periods and in significant lower plant densities in 2003 than in 2002 (8.0 *versus* 11.1 plants $m^{-2}$). Inversely, from May to September (emergence-first square to boll growth and development period) 2003 temperatures were much more favorable for cotton growth than those logged in 2002, which were able to compensate the relative delay observed in the beginning of the growing season. Consequently, the whole growing season duration results were approximate for both years of the experiment. Unfortunately, no significant differences were detected between genotypes in the durations of the distinct phenological phases. Probably, to find distinct phenotypic characteristics, varieties with greater differences of total growing season durations shall be chosen. In fact, none of the 6 genotypes used was very early or very late-season

In the phenological period's planting-emergence, emergence-first square and first flower-first open boll, a clear tendency of shorter duration was observed with planting delay, plant behavior that almost shades off the 1 month planting date imposed difference. Same tendency was observed by other experiments conducted at Narrabri (30°13'S), Australia [22]. However, the eight cultivars used by those authors presented a maturity type broader interval, so they were able to detect significant inter-genotypic differences between the number of days from sowing to maturity. For all planting dates we observed similar period's durations in the first square-first flower phase (21 days), confirming that this phase seems to be a very conservative characteristic of the species[14, 16] (Table 3).

Relevant information can also be drawn out from day-night temperature regimes impact on cotton phenology rather than mean temperature, which is more important to analyze if daily temperature exceeds 30.5-32.0°C and if night temperature falls below 15.0-16.5°C, since temperatures outside these extremes have a very negative influence during the boll period and maturation[33]. Hourly logged data on experimental site allows us to quantify 35 days, in both years, in which daily temperatures exceed that higher limit, and 48 and 30 days in which daily temperatures were below the lower limit, in 2002 and 2003, respectively. In the next phenological phase (first open boll to harvest) we recorded 38 and 35 days in which night temperature extremes were below 15.0-16.5°C, in 2002 and 2003, respectively. In 2003, 14 days registered daily extreme temperatures higher than 30.5-32.0°C.

Analyzing 2002 and 2003 temperature data framing on the thermal kinetic window for the cotton species (23.5-32.0°C) [34], we found that 73 and 59% of the total hourly temperatures registered between emergence and harvest were lower than the lower thermal kinetic window limit, in 2002 and 2003, respectively. Higher temperatures than the highest established limit [34] were registered in 6 and 11% per each year.

***Total plant dry weight (DW, g plant$^{-1}$):*** Significant differences were found in A and C logistic constants between the two experimental years (Table 4). The higher value of DW (constant A) observed in 2003 (165.6) was probably due to three motives. The higher total growing season heat units, the higher total hours within the thermal kinetic window and the lower plant density registered in this experimental year, stand that allows less inter-plant competition and relatively larger individuals. In what refers to C constant, we found that plants reached maximum absolute growth rates, according to the logistic equation, precisely when they had half their maximal DW, in a minor number of DAP in 2002 (104.6) than in 2003 (117.7). However, considering the earlier planting date of 2003, the logistic inflection point occurred during an overlapped calendar period, although rather sooner in that year (17 July to 13 August) than in 2002 (2 to 26 August).

The analysis of logistic growth behavior between the 3 planting dates in each experimental year only reveals statistical differences in C constant, with a significant decrease from the earlier to the latter planting date. This result supports the observed phenological data and shows a positive relation between phase duration and planting earliness (Table 4). In fact, the number of DAP to reach DW/2 was increased from 95 to 116 in 2002 and from 103 to 130 in 2003, from late to earlier planting dates, respectively.

The analysis of logistic growth behavior between the 6 genotypes in each planting date and experimental year revealed statistical differences in A constant in the medium and late-planting dates, in 2002, and in all the 3 planting dates of 2003, and in C parameter only in the earlier planting date that year (Table 5). No regular inter genotypes rankings were found in these statistical differences for both years and planting dates. In fact, for example, in 2002, the major A constant was attained by 'Lacta' in the medium planting and by 'Crema' in the late-planting treatment, with 'Flora' and 'Sonia' presenting the lower ones, respectively. In 2003, we found the major A constant in 'Celia', in the earlier planting, the lower one in 'Flora' in the medium planting and 'Sonia' and 'Crema' with the late-planting major A constants. No differences were detected between the B constants adjusted for the 6 genotypes. Once the C constant equals the number of DAP necessary to reach the greater plant growth rates, it will be understandable that any genetic earliness will have an influence upon this constant reduction. However, no consistent inter-genotypes differences were accounted for this constant, result that agrees with the upper considerations about varieties growing season durations used in this study. Those data allow us to infer that genetic differences in per plant cotton growth behavior tend to exhibit consistently and in more extent in the maximum DW attained (A logistic constant). In the opposite, the B constant, corresponding to the maximal relative growth rate, or specific growth rate [35], tends to be a very conservative cotton biological characteristic.

***Absolute growth rate (G, g plant$^{-1}$ day$^{-1}$):*** The instantaneous slope drift from the logistic equation results in bell-shaped curves with lower values at the beginning and at the end of the growing season, and with a maximum when DAP equals the C logistic constant, which G value can be calculated as AB/4 [35]. The planting date influences on each variety G are shown in Fig. 1. Planting date delay had a positive impact in G maximum value on 'Carmen', 'Crema', 'Flora' and 'Lacta', which increased from early to late planting treatments. The G maximum reached by 'Crema' and 'Lacta' in late planting was significantly higher than in the two earlier treatments. An inverse behavior was noted on 'Celia', with significantly lower G values for the late planting treatment since 26 July to 23 August, during the first flower-first open boll period. G maximum of 'Crema' at late planting (3.4 g plant$^{-1}$ day$^{-1}$) was significantly higher than all the other genotypes and planting dates G maximum. 'Sonia' planting delay effects on G during the initial and the last growth periods were opposite, showing planting delay, a negative impact until soon after the first flower and, inversely, a positive impact on G values later in the season, after 9 August. In Carmen and Sonia genotypes, planting date delay also had a significant impact delaying the day of the year in which G maximum occurred, showing these varieties having less time recover capability than all the others. Planting dates averaged G maximum values range between 2.2 ('Carmen') and 2.7 ('Crema') g plant$^{-1}$ day$^{-1}$, 'Flora' planting dates average being the exception, with an average G of 1.9 g plant$^{-1}$ day$^{-1}$. The initial growth rates recorded in this study (0.5 g plant$^{-1}$ day$^{-1}$) were very similar to those observed until 56 days after emergence, with 'DES119' in a soil-plant-atmosphere (SPAR) apparatus growing in the lower day/night temperature imposed cycles (20/12°C) [15]. Maximum G of 2.4 g plant$^{-1}$ day$^{-1}$, occurring 56 days after emergence, was reached in the 30/22°C day/night temperature cycles, which are more favorable for cotton growth than that registered in our experimental site early in the season. Nevertheless, their maximum G can be placed in our 3 planting dates and 5 genotypes interval of 2.2-2.7 g plant$^{-1}$ day$^{-1}$.

***Relative growth rate (RGR, g g$^{-1}$ day$^{-1}$):*** The planting date influences on each variety RGR are shown in Fig. 2. From the logistic equation the maximum RGR value is given by the B constant, and occurs when the plants are in very early stages. The B constant behavior was analyzed in the total plant dry weight part. The deeper RGR decrease was noted for all genotypes and planting dates at the beginning of the flowering period. Significant differences in 'Carmen' and 'Crema' RGR were found between the late and the two earliest planting dates, since the beginning of the observation period until 110-140 DAP, when plants were in the first flower-first to open boll period. Equal tendency ($0.05<P<0.10$) was observed in 'Lacta'. At the end of the growing season in the latest planting date, 'Lacta' and 'Sonia' still had RGR with positive values (0.015-0.017 g g$^{-1}$ day$^{-1}$), when all the other genotypes and planting dates were near zero. This behavior can be a symptom of some re-growth tendency of those two genotypes when planted late.

***Net assimilation rate (NAR, g m$^{-2}$ day$^{-1}$):*** For all genotypes and planting dates NAR's evolutions went crescent until the beginning of the opening flowers, following thereafter a long and intense decreasing period until the end of the season. No NAR differences were found between genotypes but, in contrary, some differences between planting dates were accounted. 'Celia', 'Flora' and 'Sonia' late planting date NAR's were significantly lower than the respective NAR's obtained in medium and early planting treatments (Fig. 3). This difference happened until 12 July (60-86 DAP) in 'Sonia' and until 16 August (95-121 DAP) in 'Celia' and 'Flora'. The former date corresponds to the end of first square-first flower period, and the last one to last quarter of first flower-first open boll period. 'Lacta' demonstrated an opposite behavior, with the late planting date having the highest NAR until 9 August (88-114 DAP). No significant differences between planting dates were found in 'Carmen' or 'Crema'.

***Leaf area rate (LAR, cm$^2$ g$^{-1}$) and specific leaf weight SLW (g m$^{-2}$):*** No planting date's or experimental years differences were found on LAR or SLW. The ratio between leaf area and total respiratory tissues DW (LAR) shows a negative trend along the growing cycle. In contrary, SLW presented a crescent tendency (Table 6). Significant differences in LAR slopes and intercepts were found only between 'Lacta' and 'Crema', with the former genotype presenting a smooth decrease (-0.51 *versus* - 0.60 cm$^2$ g$^{-1}$ day$^{-1}$) and a lower maximal leaf area per unit entire plant DW (114.3 *versus* 128.9 cm$^2$ g$^{-1}$). All genotypes showed a leaf thickness increase tendency along the cycle. Significant differences in leaf thickness increase rates were found between 'Celia' (0.17 g m$^{-2}$ day$^{-1}$) and 'Sonia' (0.06 g m$^{-2}$ day$^{-1}$). Also differences in SLW intercept were found, the okra leaf type presenting higher initial leaf thickness (78.1 g m$^{-2}$) than all the other genotypes (mean 58.2 g m$^{-2}$).

**Table 3.** Accumulated duration (AD, days) and heat units after planting (HUAP, °C day) of the different cotton phenological stages, for 3 planting dates, in 2002 and 2003.

| Year and growth period | Planting date | | | | | |
|---|---|---|---|---|---|---|
| | Early | | Medium | | Late | |
| | AD | HUAP | AD | HUAP | AD | HUAP |
| 2002[a] | | | | | | |
| Planting to emergence | 10 | 88.0 | 5 | 25.8 | 7 | 55.3 |
| Emergence to first square | 70 | 365.9 | 59 | 299.9 | 53 | 355.9 |
| First square to first flower | 91 | 552.8 | 80 | 486.8 | 74 | 549.5 |
| First flower to first open boll | 154 | 1022.5 | 150 | 982.6 | 144 | 1015.5 |
| First open boll to harvest | 204 | 1137.8 | 193 | 1072.4 | 180 | 1069.3 |
| 2003[b] | | | | | | |
| Planting to emergence | 25 | 3.1 | 18 | 6.1 | 13 | 19.3 |
| Emergence to first square | 92 | 344.0 | 78 | 346.7 | 71 | 410.9 |
| First square to first flower | 113 | 510.4 | 99 | 513.1 | 92 | 563.6 |
| First flower to first open boll | 162 | 992.9 | 148 | 995.6 | 141 | 1046.1 |
| First open boll to first harvest | 205 | 1243.4 | 191 | 1246.1 | 184 | 1296.6 |
| Second harvest | 231 | 1251.6 | 217 | 1254.3 | 210 | 1304.8 |

[a] Planting dates : first 19 April ; second 30 April; 13 May. [b] Planting dates : first 20 March ; second 3 April; 17 April.

**Table 4.** Estimated values and standard errors (in parenthesis) of the logistic constants adjusted to DW evolution along DAP for 2002 and 2003.

| | | Planting date | | | |
|---|---|---|---|---|---|
| | | Early | Medium | Late | Pooled |
| 2002 | A | 85.8 a<br>(1.945) | 83.8 a<br>(2.207) | 84.4 a<br>(2.550) | 84.1 a<br>(1.459) |
| | B | 0.086 a<br>(0.010) | 0.101 a<br>(0.015) | 0.098 a<br>(0.016) | 0.087 a<br>(0.008) |
| | C | 115.8 a<br>(1.528) | 106.0 b<br>(1.671) | 94.7 c<br>(1.910) | 104.6 a<br>(1.162) |
| 2003 | A | 155.7 a<br>(5.870) | 179.8 a<br>(7.489) | 162.8 a<br>(6.881) | 165.6 b<br>(4.952) |
| | B | 0.075 a<br>(0.011) | 0.069 a<br>(0.010) | 0.073 a<br>(0.012) | 0.062 a<br>(0.006) |
| | C | 129.8 a<br>(2.377) | 122.3 a<br>(2.535) | 102.7 b<br>(2.667) | 117.7 b<br>(1.952) |

First three columns values with the same letter in a line are not significantly different by the *t*-Student test ($P<0.05$). Last column comparisons made between same constants.

**Table 5.** Estimated values of the logistic constants adjusted to DW evolution along DAP for 6 genotypes and 3 planting dates with 2002 and 2003 separated data. Data shows only constants where significant differences were detected.

| | 2002 | | 2003 | | | |
|---|---|---|---|---|---|---|
| | Planting date | | | | | |
| | Medium | Late | Early | | Medium | Late |
| Genotype | A | A | A | C | A | A |
| Carmen | 84.9 ab | 76.4 bc | 130.5 c | 119.7 c | 167.9 a | 154.7 ab |
| Celia | 79.1 bc | 87.6 bc | 192.3 a | 131.7 abc | 204.0 a | 148.6 ab |
| Crema | 89.8 ab | 117.1 a | 141.4 abc | 125.6 abc | 220.1 a | 184.6 a |
| Flora | 67.4 c | 75.6 bc | 172.8 abc | 140.8 abc | 108.1 b | 129.0 c |
| Lacta | 104.3 a | 85.3 b | 176.4 ab | 141.6 a | 229.5 a | 164.2 ab |
| Sonia | 78.9 bc | 64.9 c | 138.9 bc | 123.1 bc | 168.8 a | 190.4 a |

Values with the same letter in a column are not significantly different by the *t*-Student test ($P<0.05$).

**Table 6.** Linear regression coefficients of leaf area rate (LAR) and specific leaf weight (SLW) in function of DAP, estimated with 3 planting dates and 2002 and 2003 pooled data.

| | | Genotype | | | | | |
|---|---|---|---|---|---|---|---|
| Growth index | | Carmen | Celia | Crema | Flora | Lacta | Sonia |
| LAR ($cm^2 g^{-1}$) | a[a] | 120.6ab[b] | 115.7a | 128.9b | 118.7ab | 114.3a | 119.2ab |
| | b | -0.57ab | -0.57ab | -0.60b | -0.57ab | -0.51a | -0.56ab |
| | $R^2$ | 0.85 | 0.84 | 0.88 | 0.86 | 0.80 | 0.84 |
| SLW ($g m^{-2}$) | a | 58.7a | 51.9a | 65.2a | 55.3a | 78.1b | 60.0a |
| | b | 0.08ab | 0.17a | 0.11ab | 0.14ab | 0.14ab | 0.06b |
| | $R^2$ | 0.80 | 0.91 | 0.76 | 0.80 | 0.78 | 0.77 |

[a] a = intercept and b = slope [b] Means with the same letter in a line are not significantly different by the *t*-Student test ($P<0.05$).

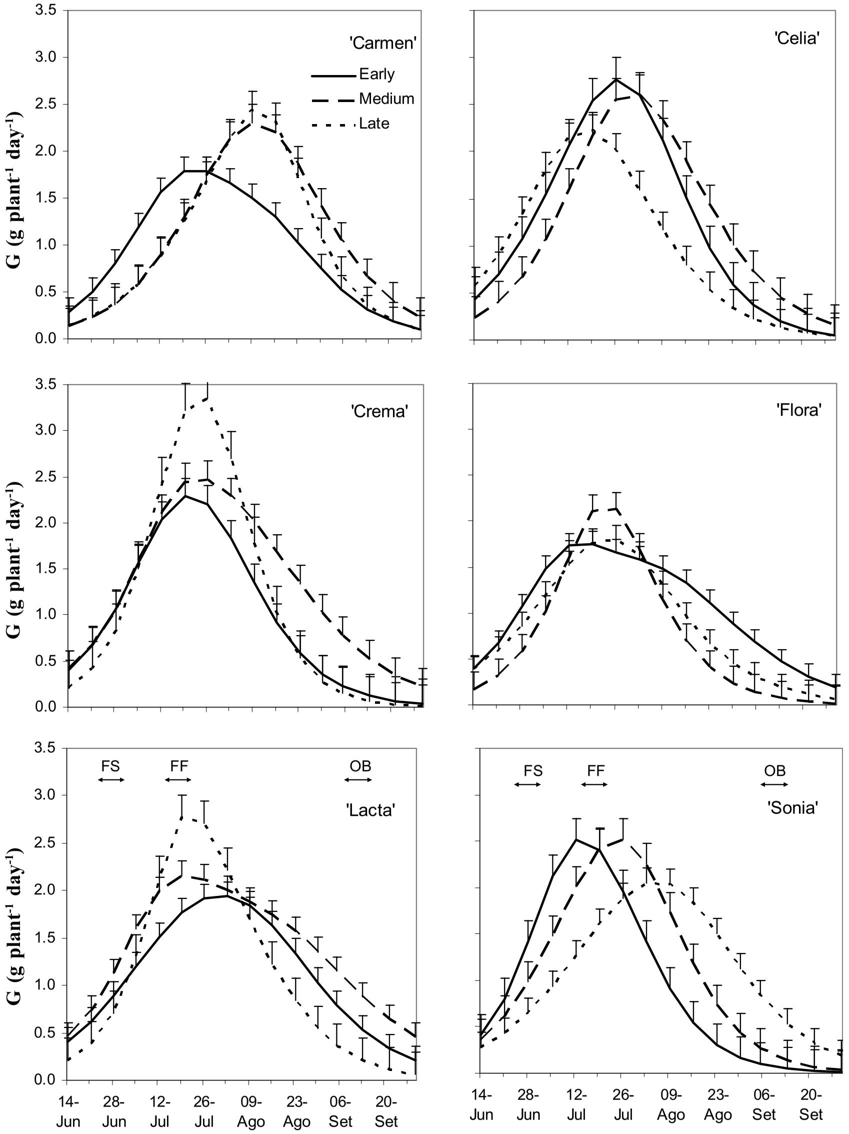

***Figure 1.*** Absolute growth rate (G, g plant$^{-1}$ day$^{-1}$) of 6 upland cotton genotypes sown in early, medium and late planting dates, with 2002 and 2003 pooled data. FS = first square, FF = first flower, OB = first open boll. Left and right arrows indicate the beginning of each phase for early and late planting dates. Vertical bars = +1 standard error. Initial and final growing season data not shown for simplicity.

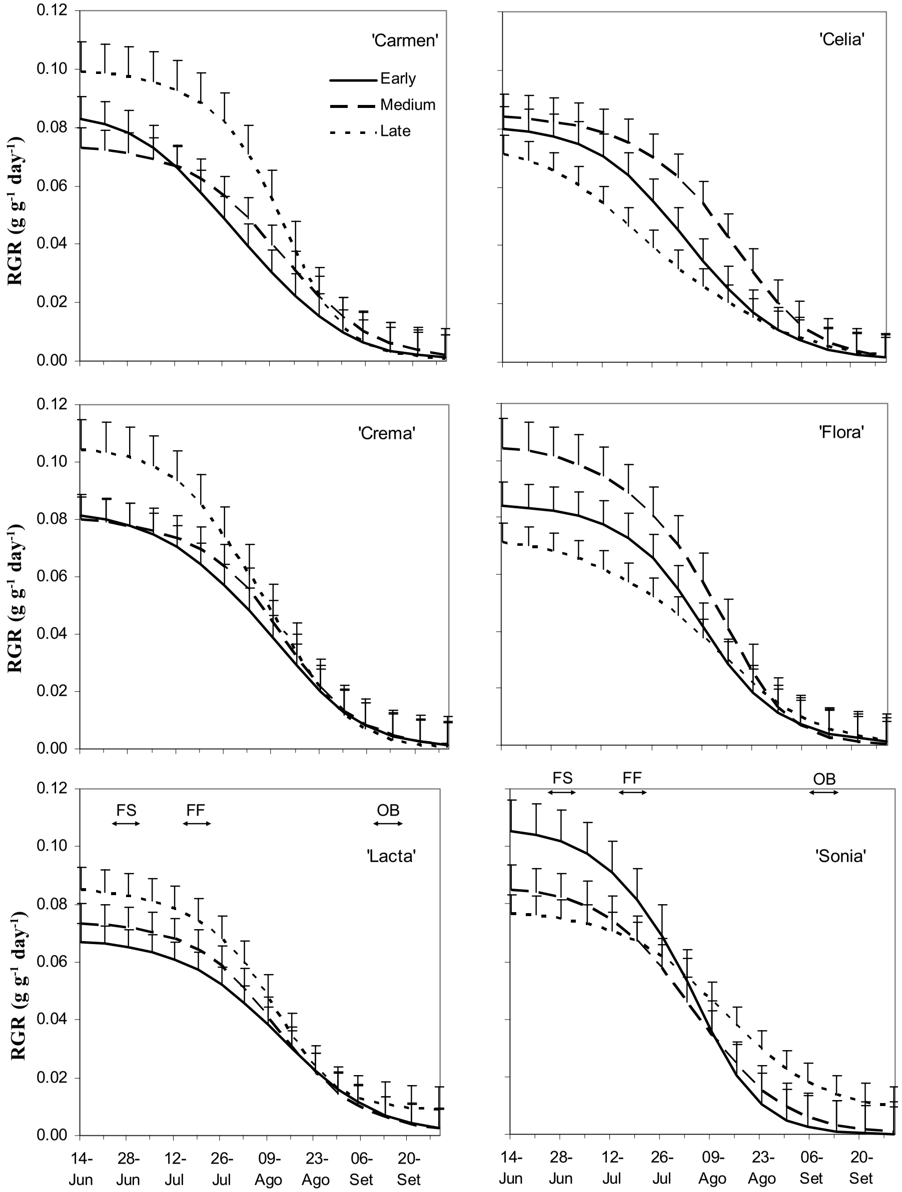

***Figure 2.*** Relative growth rate (RGR, g g$^{-1}$ day$^{-1}$) of 6 upland cotton genotypes sown in early, medium and late planting dates with 2002 and 2003 pooled data. FS = first square, FF = first flower, OB = first open boll. Left and right arrows indicate the beginning of each phase for early and late planting dates. Vertical bars = +1 standard error. Initial and final growing season data not shown for simplicity.

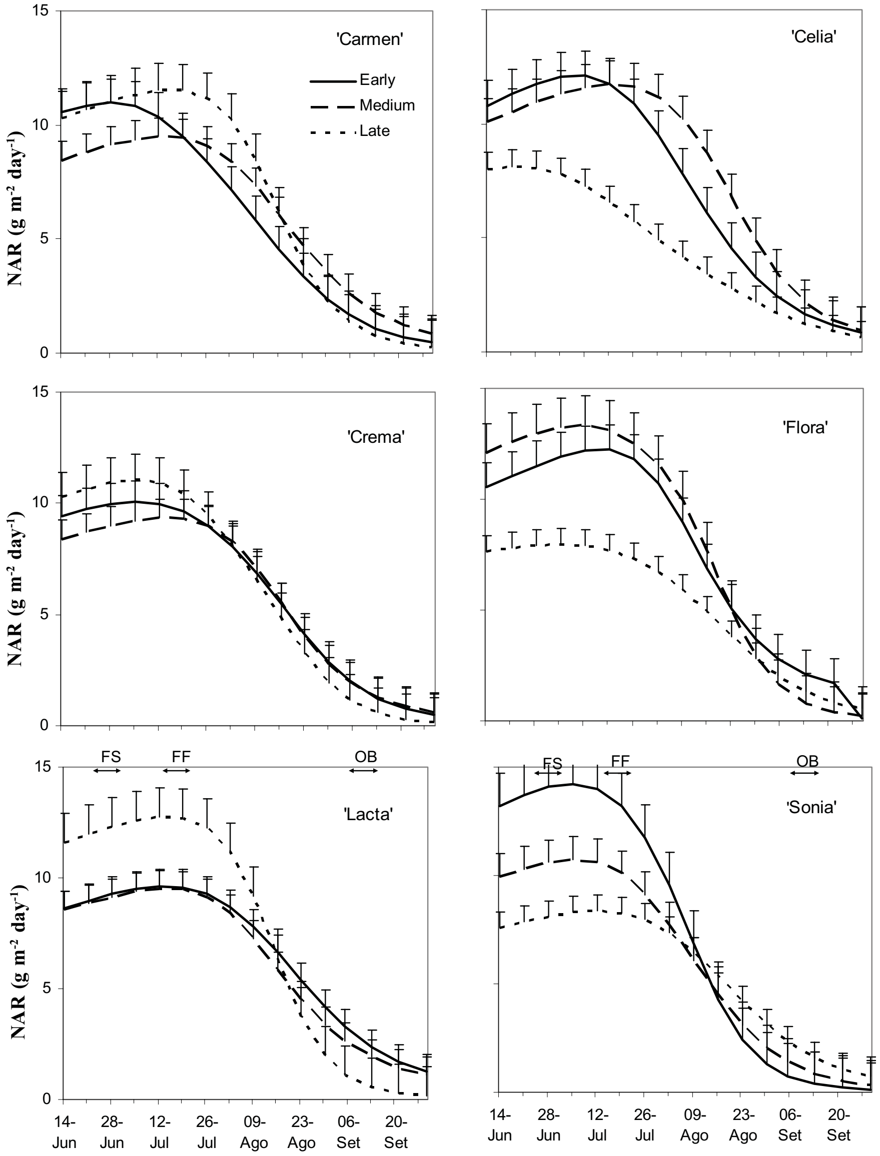

***Figure 3.*** Net assimilation rate (NAR, g $m^{-2}$ $day^{-1}$) of 6 upland cotton genotypes sown in early, medium and late planting dates with 2002 and 2003 pooled data. FS = first square, FF = first flower, OB = first open boll. Left and right arrows indicate the beginning of each phase for early and late planting dates. Vertical bars = +1 standard error. Initial and final growing season data not shown for simplicity.

***Leaf area index (LAI, $m^2$ $m^{-2}$):*** LAI differences between planting dates were found in 'Sonia' since 5 July until 30 August, the late planting presenting significantly lower values than the other two treatments (Fig. 4). For 'Carmen', 'Crema' and 'Lacta' some significant differences in LAI were accounted between planting dates only after 9 August, and until mid September, when LAI values were still relatively high. Comparatively to the other genotypes, planting date exerted a relatively small effect on the LAI of 'Celia' and 'Flora' along the growing season. LAI = 1 was attained in late June (50-100 DAP), near the moment of first visible square. Planting date delay had a clear effect on increasing inter-genotypic data variability of LAI maximum, ranging from 2.6 ('Flora') to 4.2 ('Crema') in the late and from 2.8 ('Flora') to 4.6 ('Lacta') in the medium planting date, whereas in the earlier planting LAI maximum ranges only from 3.1 ('Celia') to 3.6 ('Sonia'). Maximum LAI was attained by all genotypes and planting dates in mid to late-August, near 1 month after first flower appearance, during boll development stage. LAI maximum values averaged genotypes pooled data varies from 3.3 (early planting) to 3.7 (medium planting) and 3.4 (late planting). LAI maximum of 'Carmen', 'Crema' and 'Lacta' tended to increase with planting date delay. Late in the season, in our medium planting date treatment, 'Lacta' LAI reached significantly higher values (4.6) than the normal leaf type genotypes.

***Crop growth rate (CGR, g $m^{-2}$ $day^{-1}$):*** Derived from the logistic DW growth, CGR evolution dependent to DAP was bell-shaped, like the G curves (Fig. 5). CGR increased since the first stages

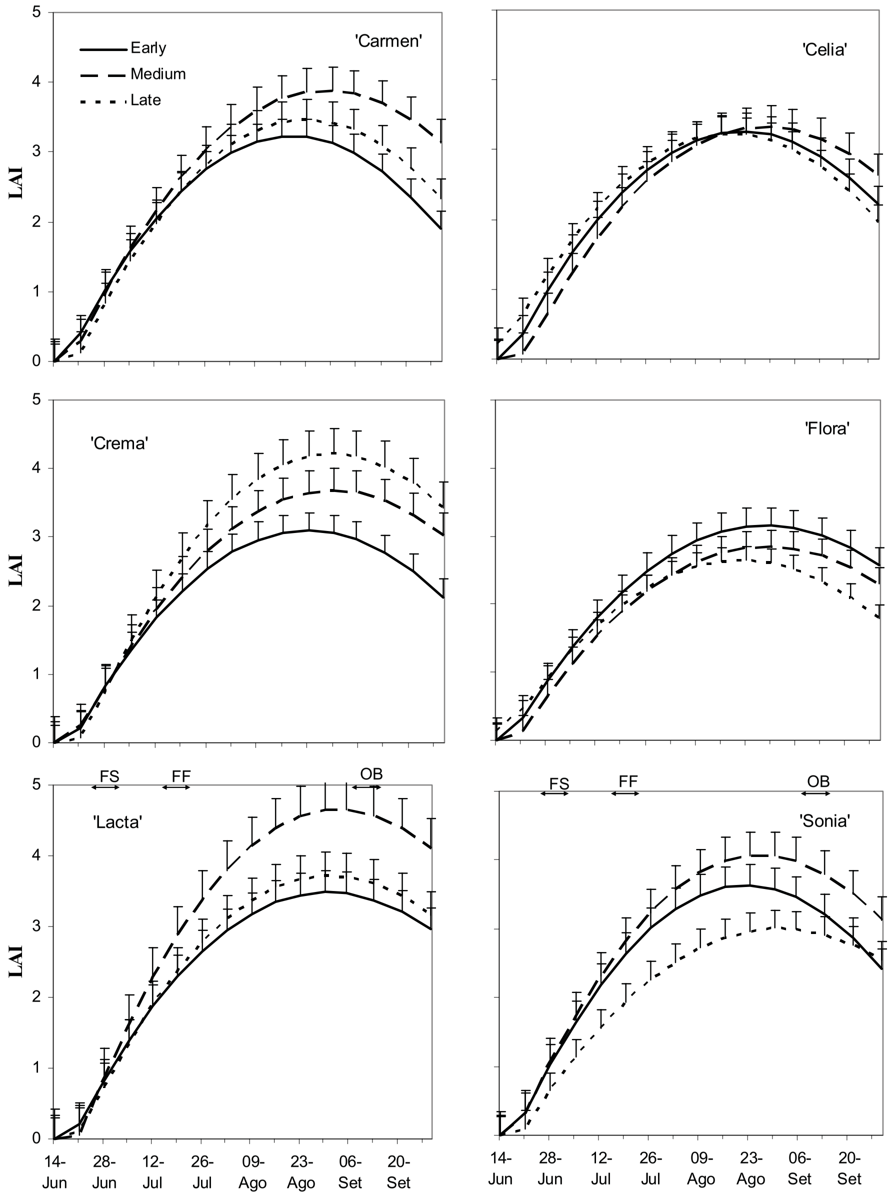

***Figure 4.*** Leaf area index (LAI, m$^2$ m$^{-2}$) of 6 upland cotton genotypes sown in early, medium and late planting dates with 2002 and 2003 pooled data. FS = first square, FF = first flower, OB = first open boll. Left and right arrows indicate the beginning of each phase for early and late planting dates. Vertical bars = +1 standard error. Initial and final growing season data not shown for simplicity.

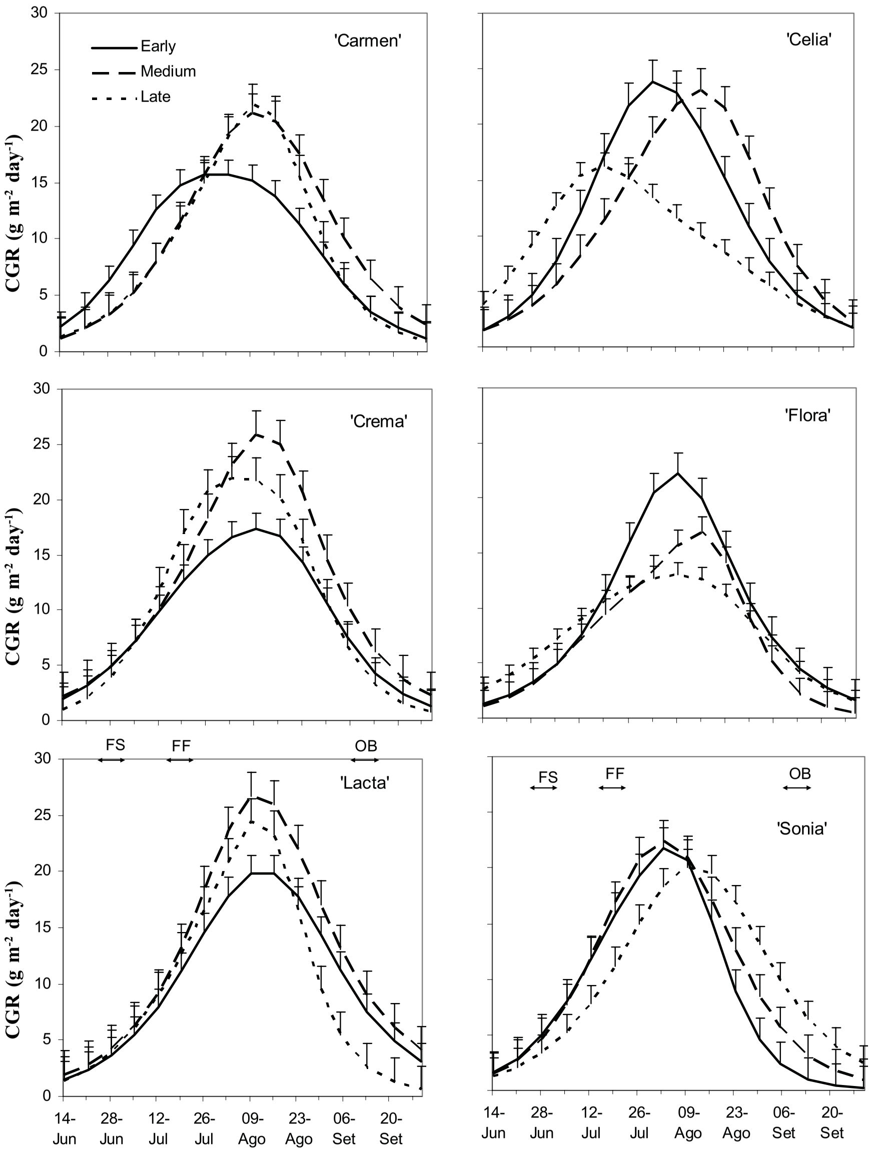

***Figure 5.*** Crop growth rate (CGR, g m$^{-2}$ day$^{-1}$) of 6 upland cotton genotypes sown in early, medium and late planting dates with 2002 and 2003 pooled data. FS = first square, FF= first flower, OB = first open boll. Left and right arrows indicate the beginning of each phase for early and late planting dates. Vertical bars = +1 standard error. Initial and final growing season data not shown for simplicity.

until 100-125 DAP, decreasing thereafter until the end of the season. CGR maximum values showed significant differences between some genotypes and planting dates. In fact, in the early planting date, 'Celia' maximum CGR (23.8 g m$^{-2}$ day$^{-1}$) was significantly higher than that observed for 'Carmen' and 'Crema'. In the medium planting date 'Lacta' (26.7 g m$^{-2}$ day$^{-1}$) and 'Crema' (25.9 g m$^{-2}$ day$^{-1}$) were the genotypes with greater CGR maximum, significantly higher than attained by all the other genotypes. In the later planting date 'Celia' (16.2 g m$^{-2}$ day$^{-1}$) and 'Flora' (13.1 g m$^{-2}$ day$^{-1}$) registered CGR maximum lower than the other genotypes. 'Celia' late planting CGR registered in the first growing stages, until 12 July (60-86 DAP, just before first flower), attained significantly higher values than were registered for the other two planting dates, being very distinct, a relatively backward position of the CGR curve. Same trend was noted in 'Carmen' at early planting date. Delaying planting date had positive impact in 'Carmen', 'Crema' and 'Lacta' maximum CGR. Inversely, a negative impact was noted in 'Celia' and 'Flora'. No relevant effect was noted in 'Sonia', which CGR evolution along the growing season was closely independent of the planting date.

Best fit of maximum CGR to the corresponding LAI was obtained with a power equation, meaning that higher CGR maximum values tend to be associated with higher optimal LAI (Fig. 6). According to this regression, we estimated the optimal LAI per genotype: 2.7 ('Carmen' and 'Celia'), 3.0 ('Crema'), 2.5 ('Flora'), 3.1 ('Lacta') and 2.9 ('Sonia').

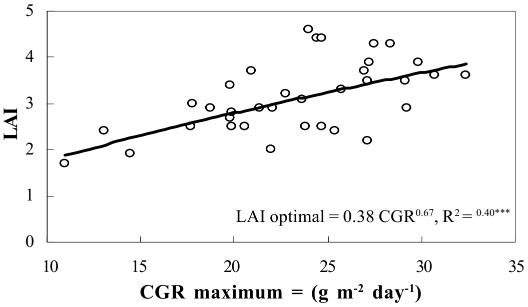

***Figure 6.*** Observed values and fitted power regression between LAI and maximum CGR (g m$^{-2}$ day$^{-1}$), with 6 genotypes, 3 planting dates, 2002 and 2003 pooled data.

## Discussion

Our results fit well the ranges in number of days required for upland cotton quoted for USA [36, 37] and for Spain[19], for all phenological phases, except for first flower-first open boll, which observed duration period was generally higher in this study, probably due to the decreasing temperature after 15 August and until the end of the growing season. Of all the regression attempts in order to fit the durations of each phenological phase to mean temperatures, methodology followed by other authors [14], only the linear one adjusted for first flower-first open boll period outcome significant ($P = 0.0156$): duration (days) = 220.44 - 6.898* x temperature (°C), $R^2 = 0.969$.

In what concerns to the heat units reported by those authors as needed for upland cotton growth and development, they are greater than the heat units observed in this experiment in the first (planting to emergence) and in the last (first open boll to first harvest) phenological periods, precisely the two decisive phases in order to achieve good stand establishment, boll development and maturation and fiber quality. In contrary, heat units referred for emergence-first square period [19, 36, 37] as well as 500 heat units for first flower [17] are lower than observed in this experiment. First flower-first open boll observed heat units are in agreement with those authors data. The observed per phase duration and accumulated heat units divergences to the cited patterns were some way compensated in the whole planting to first harvest period, which ranges for all genotypes and planting dates from 180 to 205 days and from 1070 to 1300°C-days, ranging intervals for the third and first planting dates, respectively. These results were somewhat expected, confirming that the short available growing season due to unadequate low temperatures at early-spring and late-summer are a major constraint for cotton crop in this region [6, 38, 39]. The hourly day-night temperature analysis also confirm the negative impact exerted by low night temperatures during the boll period, perhaps mainly in 2002 [33]. The meaningful disagreement observed between hourly air temperatures and cotton thermal kinetic window or between environment and plant biochemistry, pointed that approximately 70-80% of the growing season is available to improve cotton growth and development through changes in management practices and/or genetics [33].

In the applied logistic growth model, the A constant (max DW) was one that presented more year-to year and between genotypes variations, the B constant (the specific growth rate) was more conservative and the C constant (number of DAP to reach half max DW) one with more planting dates differences.

As expected, RGR decreased along the season, probably due to the forward differentiation of no photosynthetic active tissues allied to a progressive decrease of foliar apparatus efficiency. Our RGR results were much lower than the maximum 5-6 g g$^{-1}$ day$^{-1}$ noted at Wad Madani (14°N), Sudan [40] but, as this author did, we found a RGR deep decrease tendency since the beginning to the end of the growing season. Others [41] found 0.07 g g$^{-1}$ day$^{-1}$ at the beginning of the reproductive period and 0.03 g g$^{-1}$ day$^{-1}$ during boll growth, values something similar to those observed by us. Field studies with 'DPL 50' and 'MD 65-11' isolines at Stoneville (33° 27'N), Mississippi, USA, recorded 0.028 g g$^{-1}$ day$^{-1}$ RGR between 84 and 112 DAP [42], value also quite similar to our observed data.

At the first growth stages cotton leaf area growth and leaves progressive overlapping was compensated by more favorable temperature and income radiation. Thereafter the end of July, despite these good weather conditions, total leaf area and leaf area age and distribution into the canopy resulted in a negative impact over the unit leaf efficiency, with decreasing NAR's until the end of the season [24, 43]. In earlier works a consistent decrease tendency in NAR was not observed along the growing season, showing considerable fluctuations associated with climatic conditions variation and NAR estimation approach [40]. In fact, NAR amplitudes were very important, ranging from 11.3 to 1 g m$^{-2}$ day$^{-1}$. Other pointed out a continuous decrease in NAR, since 10-30 days after emergence to the boll growth period, of 18.7 to 4.8 g m$^{-2}$ day$^{-1}$ [44]. NAR evolution registered in the present study was quite similar to that observed with 'Suregrow 501' at Tifton (31°30'N), Georgia, USA [45]. Those authors registered mean NAR's of 9.9-11.2 g m$^{-2}$ day$^{-1}$ between first flower and peak bloom, followed by a continuous decrease until the end of the season. Initial NAR increase to 6-8 g m$^{-2}$ day$^{-1}$ (40-60 DAP) followed by a continuous decrease to 0-2 g m$^{-2}$ day$^{-1}$ (100 DAP) were observed in 'Stoneville 453', in almost all field years studies [46]. The observation of consistently higher canopy photosynthesis per unit leaf area in okra leaf plants, comparing with normal leafed-plants is broadly accepted [24, 47]. However, our NAR results observed in 'Lacta' didn't confirm that greater unit leaf performance in the okra leaf genotype.

Leaf thickness increase with canopy age observed in the present work was also stated by other authors [48, 49]. Our greater thickness increase rate (0.172) was much smaller than the increase rate of 0.25 found between pinhead square (41 DAP) and boll development stages (89 DAP) with 'Deltapine 20' planted at Fayetteville (36° 05'N), Arkansas, USA[49]. 'Lacta' SLW intercept, and also absolute values along the growing cycle, were significantly higher than the corresponding values calculated for all the other genotypes, as noted characteristic for okra leaf type genotypes [50]. Similar trend was referred for okra leaf type genotypes [23]. However, our values of SLW were higher than observed by these authors, finding also true to the normal-okra differences. The 'Stoneville 506' SLW (65.9 g m$^{-2}$) averaged main-stem and first three sympodial leaves at main-stem node 10, was quite alike our normal leaf type SLW fitted values for the same growth stage [51]. Contrary of our results, there were significant differences in mid-August SLW between early (late April) and late (late May) planting dates, with 47.1 and 59.0 g m$^{-2}$, respectively[52]. Excluding the okra leaf genotype data, for better comparability, in mid August SLW average 5 remaining genotypes was of 70 g m$^{-2}$. SLW is probably positively correlated to net photosynthesis [47, 53]. If this tendency was true, our normal type leaf genotypes will have attained lower NAR's than the okra leaf type, results that we are not able to withdraw in this study (Fig. 3).

As stated elsewhere, the initial growth of the cotton LAI was very slow [54, 55]. The moment when LAI reached 1 (50-100 DAP) was similar to the results obtained by others (LAI = 1 at 65-75 DAP) [56]. However, most of the literature pointed that LAI = 1 takes place earlier in the cycle (LAI = 1.4 at 50 DAP [57], LAI = 0.8 at 43 DAP [58], LAI = 2.97 at 82-102 DAP [59] and LAI = 1.1 at 41 DAP[22, 49]). However, other authors found LAI's prior to 100 DAP (LAI = 0.6 at 88 DAP [60], LAI = 0.7 at 63 DAP [22, 61]) lower or similar as in our study. The effect of planting delay on lowering of attained LAI was detected only in 'Sonia', result generally observed with 'Siokra S324' and 'Siokra L22' at Narrabri (30°13'S), Australia [22]. Higher initial LAI's for earlier planting treatments were also knowledgeable [62]. LAI maximum showed a trend to increase with planting delay in three of our six experimented genotypes, as well as in six of eight other experimented genotypes [22]. Working with 'TAMCOT HQ95' and 'G&P 74+' at Temple (31°06' N), Texas, USA, maximum LAI occurred midway between first flower and first open boll, but as soon as 80-90 DAP with values as high as 5.9 and 6.8 in each experimental year [63]. The time of the year in which LAI maximum occurred in our experiment was similar to others data [54] (late August) though the values reached were much lower, ranging from 5 to 7 [63]. With 1 m row spacing, our maximum LAI values of normal leaf type genotypes were not sufficient to intercept 90% of the incoming radiation [64]. 'Coker-310' and 'Jaen', a local short season cultivar, at the Agriculture Research Centre of Cordoba, Spain, showed no significant LAI maximum differences in full irrigated plants, with values ranging between 3.5 and 4.2, 105 DAP (7 August) [20]. In the same site, other authors found for all the cultivars similar maximum LAI values, ranging between 3.9 and 4.3 [21]. In their Experiments 1 and 2 LAI maximum values always were below 3 [7], and in the unshaded control treatment a LAI maximum of 3.4 was reached at peak flower stage 77 DAP [49]. According to the statements of several researchers, the higher LAI attained by 'Lacta' in the medium planting date (4.6) is precisely the opposite expectable result for an okra leaf genotype [23, 24, 47, 64]. However, also higher peak LAI was found in the early 2000 sowing of 'Siokra V-16', an okra leaf genotype [22].

With the same row-width used in our experiment maximum canopy photosynthesis per unit ground area occurred 90 DAP, 10 to 35 days in advance of our calculated data [24]. The highest maximum CGR observed in this study were similar to the observed 22 g m$^{-2}$ day$^{-1}$ by others [56], although the lowest ones were in line with the CGR values g m$^{-2}$ day$^{-1}$ of other authors: 12-15 [25], 12.7-16.1 [64] and 16.6 [65].

In a 3-year experiment in the Mid-South, USA, an optimal LAI was 4, somewhat higher than our fitted results [66]. Comparing our estimated optimal LAI values per genotype with the LAI maximum attained, also per genotype (Fig. 4), we found that the cotton plants continued to develop new leaves faster than canopy leaf senescence, increasing their leaf areas per unit ground area beyond the values that conduct to higher CGR. Same results have been noted by other authors [25] who estimate a 20 days delay between peaks of LAI and CGR. This discrepancy is more evident in the genotypes that expressed higher LAI maximum values: 'Carmen', 'Crema' 'Lacta' and 'Sonia'. The negative impact of LAI further growth on CGR was also caused by the observed NAR decrease at this stage (Fig. 3), resulting in an out of phase or displacement of LAI and CGR curves. In fact, leaf area growth continued even when solar radiation, air temperature and probably leaf area distribution in the canopy and average canopy leaf age were no more favorable to high NAR and canopy photosynthesis maintenance. Although new leaves with higher photosynthetic rates continue to develop, the canopy photosynthesis rate per unit leaf area declines significantly [24]. LAI increases beyond the LAI value correspondent to maximal dry matter production involves a CGR decline [67].

This apparent displacement between LAI, NAR and CGR is plotted in Fig. 7, with only one genotype and planting date, for simplicity. Until mid-July, as a result of smooth increase and landing NAR values, associated to increasing LAI, CGR grew exponentially. After the end of July NAR was beginning to decrease, probably as a result of decreasing day length, increasing average leaves age and consequently decreasing canopy efficiency. Until the beginning of August, in a first phase, NAR decrease was compensated by increasing LAI, resulting in CGR growth. However, along August, NAR decrease impose a CGR reduction, besides LAI reaching is maximum value at the end of this month. Thereafter, and until the end of the season, both LAI and NAR decreased, resulting in deep CGR decrease.

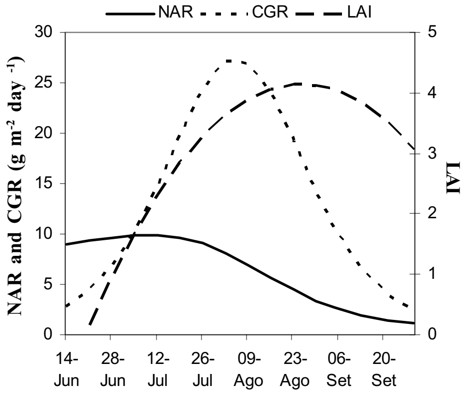

***Figure 7.*** 'Celia' NAR (g m$^{-2}$ day$^{-1}$), CGR (g m$^{-2}$ day$^{-1}$) and LAI in medium planting date treatment with 2002 and 2003 pooled data.

## Conclusions

Our results suggest that no differences in each phenological phase duration, as well as in the whole growing season, can be accounted using early-medium to medium-late genotypes. Inversely, planting date delay clearly impacts on shortening of some phenological periods, namely, planting-emergence, emergence-first square and first flower-first open boll. This duration reduction is probably linked with more favorable temperatures occurred in the first stages at later planting dates. Our observed inter-genotypic and planting date constancy of the first square-first flower duration period confirms the specific and relatively conservative characteristic of this phenological phase. Despite the relatively low temperatures registered after seeding (April, 2002 and March, 2003), of all the phenological phases the boll period (first flower-first open boll) duration was the most far off the standard USA and Spain higher extreme duration interval, probably due to the decreasing temperature registered after 15 August until the end of the season. In fact, those duration phase displacements were accompanied by relatively poor accumulated heat units. Also the number of days with unfavorable high-day and low-night extreme temperatures that were registered during the boll period can be an explanation of that duration phase enlargement. About 70 to 80% of the whole growing season cotton plants have experienced temperatures outside the thermal kinetic window of the species.

As expected, the logistic growth curve fits well to the cotton growth pattern. The A constant parameter was most affected by the genotype treatment, although the C constant parameter was most affected by the planting date delay. Both A and C constants are year-to-year dependent. The specific growth rate given by the B constant experienced no genetic, planting date or experimental year significant differences, representing a very conservative cotton biological characteristic.

Genotype and planting date had significant impacts on the several growth indexes analyzed in this study: RGR and NAR in the beginning of the season, and G, LAI and GCR in the mid and late season. However, we did not verify any genotype or planting date consistent patterns in any of these indexes, being the results somewhat irregular, although our observed data fits well in general the growth analysis data cited by the bibliography.

As expected, higher SLW of the okra leaf variety was observed. In contrary, the similarity of 'Lacta' NAR with the normal leaf type genotypes NAR does not support the theory that okra leaf type genotypes have higher canopy photosynthesis per unit leaf area. Also the relatively high LAI attained with 'Lacta' in the medium planting date was relatively unexpected.

Chronological displacement between NAR, LAI and CGR evolutions along the growing season was confirmed, feature described in several other analyses and frequently underlined as a major constrain of cotton canopy efficiency.

Our results suggest that improved low temperature resistance and higher growth rates since emergence to squaring, will probably allow earlier sowings and shortened planting to square durations. Consequently, more favorable temperatures for boll growth and shorter boll period durations can be attained, avoiding inclement weather late in season. Probably, that attempt will also reach better tuning and persistence of higher NAR and LAI values, ensuing growth efficiency at canopy level.

Further studies using a larger range of maturity type cultivars are necessary in order to provide valuable phenological and growth indexes baseline values for cotton grown in the southern Iberian Peninsula.

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