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Genotype and planting date effects on cotton growth and production under south Portugal conditions
II. Monitoring

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Abstract

Monitoring is a frequent practice in the high-yielding cotton producing regions, furnishing precious information to decision making during the growing season and contributing to understand growth and development of cotton plants. The aim of this work was to determine the influence of cultivar maturity type and planting date on the main monitoring indexes: plant height (H), number of main-stem nodes (MSN), height-to-node ratio (HNR) and number of nodes above white flower (NAWF). Six genotypes and three sowing times were studied in one field experiment over two seasons at Comenda Experimental Station, Alentejo, Portugal. Best regressions of H and MSN to accumulated degree days (DD) along the season were quadratic models, with significant differences between genotypes and years. Consequently, heat unit's requirements per each new cm height and new main-stem node (plastochrons) increase linearly. Between genotype H differences were found just after first-flower (550 DD), whilst MSN differences were found only after first open boll (1000 DD). Both differences emphasize until the end of the season. Inter-annual differences were also found in H, at first-flower (500 DD) and in MSN, a bit earlier (400 DD). No planting date influence on H or MSN were detected. Best regressions of HNR to DD were inverse models, also with significant differences between genotypes and years. 'Celia' and early planting dates presented lower number of nodes between cotyledon to first fruiting branch (NFFB). Behavior of NAWF since first-flower to cutout (NAWF = 5) was well explained by linear models, regression coefficients (NAWF decrease per day) showed only between genotype differences. Contradictory signs of maturation types were found. Low H and MSN plastochrons and low final vigor index suggest precocity but, in contrary, relatively high NFFB, initial vigor index, final H and high number of days to cutout, suggest late maturing tendencies of our studied cultivars as a whole. Planting date can be underlined as a management practice with relatively low influence on H, MSN, HNR and NAWF evolution. However, especial attention must be given on the influence of planting date on NFFB, once this monitoring index is strikingly linked with precocity, feature particularly important for regions with growing season duration constrains. Further annual monitoring data and analysis is necessary in order to allow their use as decision making tools available to the main cotton producing regions of southern Iberian Peninsula.

Key words: *Gossypium hirsutum,* monitoring, height, number of main-stem nodes, height-to-node ratio, nodes of first fruiting branch, nodes above white flower.

Introduction

The cotton plant has perhaps the most complex structure of any major field crop. Its indeterminate growth habit and sympodial fruiting branch cause it to develop a four-dimensional occupation of space and time [1]. Cotton has a very prominent main-stem, or primary axis, which results from elongation and development of the terminal bud or apical meristem. Throughout the life of each plant the primary axis remains vegetative and develops series of nodes and internodes. The number of nodes and the length of the internodes are determined by genetic and environmental factors such as climate, soil moisture, nutrients, disease and insects [2].

Main-stem node number (MSN) is an accurate indicator of plant physiological age during plant growth prior to anthesis, being their production rate approximately constant, accumulated degree-days related, and not influenced by plant stresses, unless they are extreme [3]. In contrary, plant height (H) - sum of internodes lengths – is a sensitive indicator of accumulated stresses prior to anthesis. That way, the height-to-node ratio (HNR), given by the ratio between H to MSN, expresses plant height as a function of plant age, crop's early season environmental stress level and source strength to support carbohydrate supply to reproductive sinks later in the season [4].

In each main-stem node one main-stem leaf is found with two axillary branch buds. Of the first four to seven main-stem nodes (not counting the cotyledonary node) the first axillary buds are vegetative and elongate into vigorous vegetative limbs or monopodia [1]. When the plant is induced to flower, the first axillary bud becomes a fruiting branch or sympodia, developing a prophyll, a true leaf and a flower bud (square) which extends away from the main-stem due to the elongation of the internode behind the square and leaf. In the axil of that first sympodial leaf a second leaf and square develop and similarly extend away from the first leaf and square by internode elongation. Repetition of this process produces several squares, leaves and internodes, in a typical zigzag pattern [2].

Since all reproductive branches arise at the base of vegetative main-stem leaves, the initiation and rate of sympodia formation – and therefore new fruiting branch sites – are partially dependent upon vegetative growth [1]. The main-stem nodal position of the first sympodium (NFFB) – node of first fruiting branch – as a major influence on crop earliness and on boll location along the canopy [5]. The NFFB is a characteristic mainly determined by genetics and largely affected by temperature and plant density [2].

As the boll load on the crop develops, the rate of main-stem node production declines and the shedding of squares and bolls increases until the net change in fruit numbers becomes zero [6, 7]. As a cotton plant matures, the addition of nodes in the plant apex slows, and then ceases, due to a shift in balance between plant photosynthetic capacities and assimilates demand. Consequently, first-position white flowers occur progressively closer to the plant apex until flowering ceases. Physiological cutout - cessation of effective flowering because late-developing flowers will not have time to develop into economically viable bolls - has been determined to occur when the number of MSN above the uppermost white flower located at a first fruiting position (NAWF) is 5 [8, 9]. This monitoring indicator give us information about the balance between vegetative and reproductive sink strengths into the plant, and numerically represents the difference between the formation of new MSN rate and the upward stroke of white flowers at first fruiting position rate [4, 10]. Sequential monitoring of NAWF can thus be used to determine the number of days from planting until NAWF = 5 - physiological cutout date - providing a temporal measure of maturity that can be compared among diverse environments without requiring multiple harvests [11].

The chronologic production of new main-stem nodes, branches, flowers and fruits is very predictable in the cotton plant, being influenced by genetics and environmental factors, mainly temperature, available soil moisture and nitrogen [12, 13].

Plant mapping is a major and precious tool to the decision making process during the growing season, like vegetative-reproductive equilibrium management, nitrogen fertilization, irrigation and insect pests control, being a very common practice in the USA cotton belt [14, 15]. Monitoring techniques are also very useful in order to acquire data that allow researchers and producers to look for and to understand the morphological and physiological basis related to growth, yield and yield components [4, 13, 16, 17]. The main data used in monitoring a cotton crop along the season are the main-stem node number (MSN), plant height (H), height-to-node ratio (HNR), number of nodes between cotyledon to first fruiting branch (NFFB) and the MSN above the uppermost white flower located at a first fruiting position (NAWF) [10, 13, 17, 18].

For the Spanish cotton belt (Guadalquivir Valley, Andalusia) few monitoring data are available. Studies about the influence of sowing under plastic mulch in final H and HNR [19] and underlined monitoring data [20], like vigor index until first-flower and NAWF since first-flower to cutout, as important tools to quantify plant development and as relevant frames to be used on several crop management practices.

Despite the ancient and recent attempts to introduce the cotton crop in Portugal, there's no available data of crop monitoring in this country. Data collected along many years will be necessary to establish a baseline for what's the typical growth habit of a cotton cultivar in a given environment, so we must begin this work from now on. The purpose of this experiment was to obtain relevant monitoring data on six genotypes of upland cotton sown at three planting under southern Iberian Peninsula conditions.

Material and Methods

Cultural details: Field experiments was hand sown using acid delinted seeds of Carmen, Celia, Crema, Flora, Lacta and Sonia upland cotton cultivars, 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. Final plant density was of 9.5 plants m^{-2}. A completely randomized design was used with three replications in plots of 10 m x 5 m.

Description of temperature, temperature thresholds, growing degree-days (DD) and other cultural details such as fertilization and pest control management are presented in the first part of this article. All production practices were made trying to maintain plants in non-stressed conditions due to available water and nutrients. Not withstanding insect controls, important damages on squares and bolls were observed both years, due to rough and cotton bollworms.

Measurements: Weekly harvests of 3 plants per genotype x planting date combinations were made randomly in each field plot, beginning 7 June in 2002 and 13 June in 2003. Plants clearly shorter or higher than the rest, having damaged terminals, near plot borders and the adjacent plants to previous harvested sites remained unharvested [10]. In each sampling, measures of plant height (H), number of main-stem nodes (MSN) excluding the cotyledonary node, main-stem nodal position of the first sympodium (NFFB) and the number of MSN above the uppermost white flower located at a first fruiting position (NAWF) were collected in order to get relevant data of plant monitoring. Height-to-node ratio (HNR) was computed as H/MSN.

Data analysis: Regressions of monitoring data to DD or days after planting (DAP) were fitted in order to obtain the most adequate evolution pattern of each indicator of plant status and time or accumulated temperature. When convenient the derivative of each model was calculated in order to get growth tendencies per unit DD or time, as well as the reciprocal of growth rate which gives the number of DD or days necessary to increase each new cm height or plant main-stem node, known as plastochrons [21]. All statistical analysis was performed with SPSS for Windows standard version 9.0. In some cases, no experiment year, variety or planting date differences were detected, so means and statistics were calculated and presented using averaged data.

Results

Height (H) and number of main-stem nodes (MSN): Best fitted models of the observed H and MSN data to DD were quadratic, for the 6 genotypes, 3 planting dates and 2 experiment years. Quadratic regressions of H and MSN to DD for each planting date averaged over genotypes were not significantly different, both in 2002 and in 2003. These results allow us to determine H and MSN quadratic regression constants per genotypes with the 3 planting dates averaged data each year (Table 1). Quadratic relations of H and MSN to DD mathematically imply linear increases of plastochrons, i.e. heat units requirements per each new cm or each new main-stem node.

Genotypes: In the early part of the growing season all genotypes had similar H (Fig. 1). However, just after 550 DD (first-flower) and until the end of the season 'Crema' H became significantly higher than 'Celia', 'Sonia' and 'Flora'. Thereafter, all genotypes H increased smoothly until the end of the season except 'Lacta', where H continued to increase at a higher rate, diverting initial similar H to significantly higher values after 1000 DD. This diversion was very distinct comparing with 'Celia', 'Sonia' and 'Flora' trends. At the end of the season, inclusively, 'Lacta' surpasses height of 'Crema', variety which remains higher than those genotypes at this time. 'Lacta' H growth tendency was probably a result of some imbalance between vegetative and reproductive structures occurred just after the first-flower, due to young boll shedding, insects and overall low boll load. Late in the season (1150-1200 DD) 'Carmen' equals 'Crema' H and 'Flora' becomes significantly shorter than those two genotypes plus 'Lacta'. Calculated maximum H from the fitted regressions (Table 1) were 'Carmen' 125 cm, 'Celia' 112 cm, 'Crema' 119 cm, 'Flora' 101 cm, 'Lacta' 140 cm and 'Sonia' 115 cm. H growth tendency and final H results of the two extreme maturing type genotypes ('Celia' early-medium and 'Sonia' medium-late), which presented very close values, were unexpected.

In what concerns to the evolution of the heat requirements per each new cm height (plastochron), we found a continuous growth since the beginning to the end of the cycle. In the early part of the growing season all genotypes had values ranging from 5.2 to 5.8 DD cm^{-1} (0.172-0.192 cm DD^{-1}), except 'Crema' only 4.2 DD cm^{-1} (0.238 cm DD^{-1}). This 'Crema' higher height growth rate detected until the beginning of flowering can be an important and useful feature, namely through a better capability of young plants to rise above weeds and to radiation intercept at regions where temperatures early in the cycle are a common constrain for cotton growth. At 600 DD plastochron of 'Crema' and 'Lacta' were coincident (7.7 DD cm^{-1}) and both lower than the heat requirements of the other genotypes, which were comprehended between 8.7 ('Carmen') and 9.6 ('Flora'). After 600 DD the consistent smaller increase of 'Lacta' plastochron enforced 'Lacta' H to attain significantly higher values at the end of the cycle, although the greater increase of 'Crema' heat units needs tended to approach and inclusively surpassed the estimated plastochrons of all the other four genotypes at the end of the cycle.

Inter-genotype MSN differences were relatively constant along the growing season and without significance until first-open boll, 1000 DD (Fig. 2), moment when 'Lacta' MSN became significantly higher than that of 'Celia', 'Flora' and 'Sonia'. At that time 'Lacta' required only 86 DD to form a new node, while the other genotypes needed something between 100 ('Carmen' and 'Sonia') and 120 DD MSN^{-1} ('Flora'). As expected the MSN production rate of each genotype was approximately constant since the early stages to early flowering (500-550 DD) although their absolute values were not. In fact, until 6 MSN, the initial MSN growth rate comprehended between 0.025 and 0.033 nodes DD^{-1} for all genotypes, corresponding to a plastochron of 30-40 DD MSN^{-1}. Just prior to anthesis (450 DD) MSN growth rate decreased to 0.019-0.024 nodes DD^{-1} (40-50 DD MSN^{-1}), and during the flowering period to 0.017-0.020 nodes DD^{-1} (50-60 DD MSN^{-1}). Calculated maximum MSN from the fitted quadratic regressions (Table 1) were: 'Carmen' 22.9, 'Celia' 21.2, 'Crema' 22.7, 'Flora' 21.5, 'Lacta' 25.3 and 'Sonia' 22.6, 'Lacta' final MSN being significantly higher than that estimated for 'Celia', 'Flora' and 'Sonia'. Once 'Lacta' presented relatively lower MSN and H plastochrons later in the cycle, equilibrate results of 'Lacta' HNR were expectable.

Table 1. Constants of quadratic regression [a] of main-stem height (cm) and number of main-stem nodes to degree-days after planting (°C day[b]) averaged over planting dates.

	Genotype					
	Carmen	Celia	Crema	Flora	Lacta	Sonia
Main-stem height						
2002						
A	-27.0 ab	-19.9 ab	-28.0 ab	-17.9 a	-31.4 b	-23.8 ab
B	0.210 a	0.170 b	0.205 a	0.151 b	0.215 a	0.189 a
C	$-9.2\text{x}10^{-5}$ c	$-6.1\text{x}10^{-5}$ ab	$-6.7\text{x}10^{-5}$ abc	$-5.0\text{x}10^{-5}$ a	$-8.3\text{x}10^{-5}$ abc	$-8.2\text{x}10^{-5}$ bc
R^2	0.920	0.906	0.926	0.906	0.900	0.892
SE[c]	9.22	9.71	11.02	9.22	12.07	9.83
2003						
A	-45.6 a	-56.2 a	-57.9 a	-59.5 a	-63.5 a	-62.9 a
B	0.290 b	0.337 ab	0.353 a	0.350 a	0.329 ab	0.341 ab
C	$-1.2\text{x}10^{-4}$ a	$-1.6\text{x}10^{-4}$ ab	$-1.7\text{x}10^{-4}$ b	$-1.8\text{x}10^{-4}$ b	$-1.4\text{x}10^{-4}$ ab	$-1.6\text{x}10^{-4}$ ab
R^2	0.918	0.867	0.901	0.881	0.934	0.917
SE	10.43	12.41	10.51	10.54	10.72	10.36
Number of main-stem nodes						
2002						
A	-5.2 c	-5.4 c	-0.9 a	-1.4 b	-1.6 b	0.3 a
B	0.043 a	0.040 a	0.030 bc	0.033 bc	0.037 ab	0.028 c
C	$-1.9\text{x}10^{-5}$ d	$-1.7\text{x}10^{-5}$ cd	$-9.7\text{x}10^{-6}$ a	$-1.4\text{x}10^{5}$ abc	$-1.5\text{x}10^{-5}$ bcd	$-1.1\text{x}10^{-5}$ ab
R^2	0.953	0.937	0.946	0.954	0.905	0.950
SE	1.16	1.35	1.24	1.03	1.68	0.98
2003						
A	-1.96 a	-1.93 a	-2.92 a	-3.76 a	-4.29 a	-2.84 a
B	0.042 a	0.042 a	0.044 a	0.049 a	0.049 a	0.043 a
C	$-1.7\text{x}10^{-5}$ a	$-1.8\text{x}10^{-5}$ a	$-1.9\text{x}10^{-5}$ a	$-2.3\text{x}10^{-5}$ a	$-2.0\text{x}10^{-5}$ a	$-1.9\text{x}10^{-5}$ a
R^2	0.903	0.923	0.888	0.907	0.912	0.911
SE	1.71	1.38	1.78	1.59	1.87	1.57

All R^2 significant at $P<0.001$. Values within a line followed by the same letter are not significantly different by the LSD test ($P<0.05$). [a]Model $y = a+bx+cx^2$. [b]$T_0 = 15$°C. [c]SE = regression standard error.

Years: In 2003 early planting was made about 1 month earlier than in 2002. However, 2003 low temperature at the beginning of the growing season led to slow initial plant growth and low H values (Fig. 3). However, after 250 DD more favorable temperatures for cotton growth in 2003 allowed higher plant internodes increase than in 2002. Same initial temperature dependent MSN response was not found, 2003 MSN being always greater than 2002 MSN, as the respective plants were, in fact, more aged in each moment. MSN and H evolution patterns along the cycle were very similar in 2002, with growth curves almost parallel. Between experimental years H significant differences were found since 500 DD until the end of the season, whilst significant differences of MSN were found earlier, since 400 accumulated DD. At the end of the season averaged over genotypes and planting dates maximum H and MSN were 100 cm and 19.6 nodes, in 2002, and 123 cm and 23.2 nodes, in 2003.

During the early part of the season 2002, plants developed 1 new cm height every 5.3-5.9 DD, whilst in 2003 plants developed the same unit height in only 3.0-3.5 DD. That initial per year difference of 2.3-2.4 increased until 2.9 at 600 DD soon after first-flower. Thereafter, plastochron increase grew significantly more in 2003, resulting in both years' equal requirements of 15.7 DD cm^{-1} close to 875 DD. At 1000 DD 2003 doubles 2002 plastochron, attaining 40 DD per each new cm plant height.

What concerns to MSN inter annual variability, during the early part of the growing season plants grown in 2002 had greater plastochron than in 2003 (30-35 *versus* 26-28 DD MSN^{-1}). However, in contrary of the occurred with H data, that difference continuously decreased thereafter and until 750 DD, value of accumulated degree-days that corresponds to equal year-to-year heat units requirements per each new MSN - 71.5 DD MSN^{-1}, inclusively, at the beginning of the flowering period, 2002 and 2003 MSN plastochron resembling already with 48-50 DD MSN^{-1} and 42-46 DD MSN^{-1}, respectively.

Height-to-node ratio (HNR): Best regressions of HNR to DD were inverse models. Significant differences between genotypes and years were found. Until 250 DD 'Crema' HNR (1.2) was lower than 'Flora' (1.9) and 'Carmen' (2.5) HNR (Table 2 and Fig. 4). Thereafter, until 550 DD, the HNR of all genotypes varied between 4.0 and 4.4, with no significant differences. However, after the beginning of the flowering period, HNR of 'Crema' continued to increase at a higher rate than that of the other genotypes, becoming HRN significantly higher than in 'Carmen', Lacta', 'Flora' and 'Sonia' since 800 DD and, inclusively, higher than 'Celia' at the last harvest (1200 DD). At this time 'Flora' internode length was lower than in 'Crema' and 'Celia'. The HNR intervals ranges at the first square were 2.1 ('Lacta') to 3.9 ('Carmen' and 'Celia'), at first-flower 3.2 ('Lacta') to 4.7 ('Crema') and at first-open boll 4.9 ('Flora') to 6.2 ('Crema'). Final HNR's were: 'Crema' 6.3, 'Celia' 5.7, 'Carmen' and 'Lacta' 5.4, 'Sonia' 5.3 and 'Flora' 5.1. The greater plant growth and development H and MSN noted in 'Lacta' was, as expected, a balanced and proportioned result, once 'Lacta' HNR, as a plant vigor index, was not significantly higher than that observed in the other genotypes. In the other hand, 'Crema' H grew faster than plant age, what can indicate, in fact, a greater vegetative tendency of this genotype.

During the early stages, until 300 DD, 2003 HNR of 3.2 was lower than 2002 HNR of 3.8 (Table 2 and Fig. 5). Thereafter until 500 DD that sequence tended to invert, HNR 2003 becoming higher than HNR 2002 since 550 DD (5.0 and 4.6) until 1050 DD (5.3 and 5.0). At the end of the cycle both years HNR converge. There was no significant difference between years (average value of 5.2).

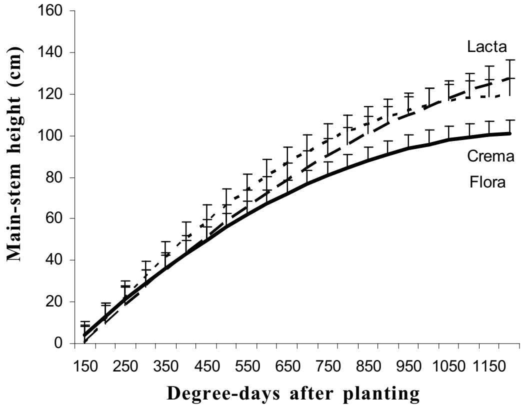

Figure 1. Relationship between main-stem height (cm) and degree-days after planting (°C day, t_0=15°C) averaged over experimental years and planting dates. Only selected genotypes were plotted for more clearness. Vertical bars = +1 standard error.

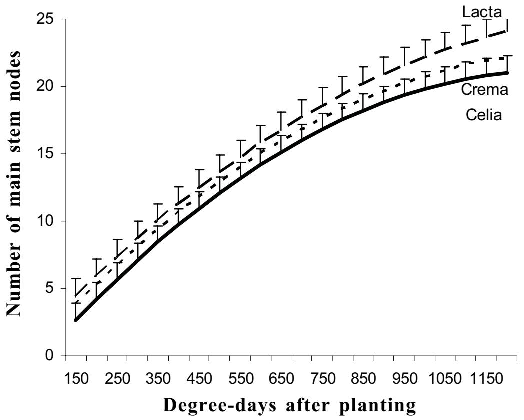

Figure 2. Relationship between number of main-stem nodes and degree-days after planting (°C day, t_0=15°C) averaged over experimental years and planting dates. Only selected genotypes were plotted for more clearness. Vertical bars = -1 and +1 standard error.

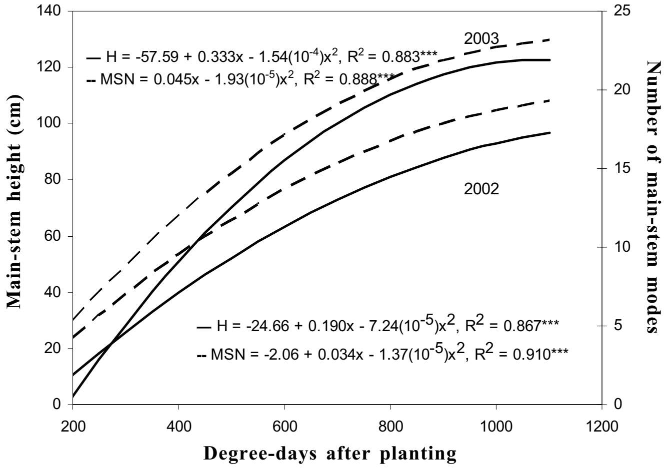

***Figure 3**.* Relationship between main-stem height (H, cm) and number of main-stem nodes (MSN) to degree-days after planting (°C day, t_0=15°C) averaged over genotypes and planting dates.

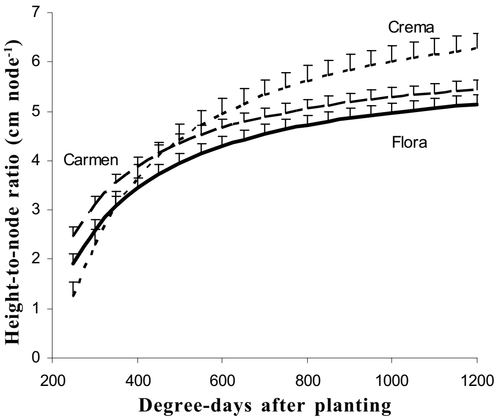

Figure 4. Relationship between height-to-node ratio (cm node^{-1}) and degree-days after planting (°C day, t_0=15°C) averaged over experimental years and planting dates. Only selected genotypes were plotted for more clearness. Vertical bars = +1 standard error.

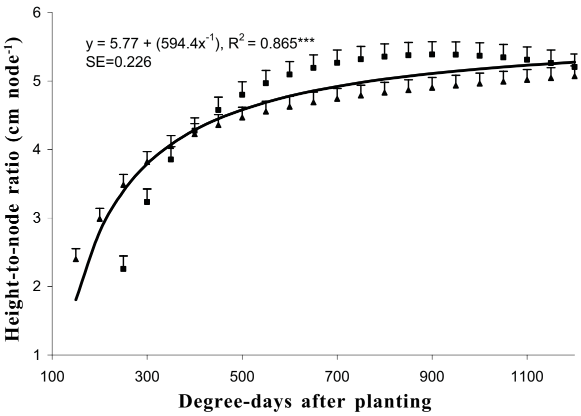

Figure 5. Relationship of height-to-node ratio (cm node^{-1}) to degree-days after planting (°C day, t_0=15°C) averaged over genotypes and planting dates. Bold triangles and squares correspond to 2002 and 2003 observed data. Vertical bars = +1 standard error.

Node of first fruiting branch (NFFB): NFFB results were significantly different between genotypes and planting dates (Table 3). 'Celia' was the cultivar with lowest NFFB averaged over years and planting dates (5.8) and also lower than in 'Flora' (5.9 *versus* 6.5) in 2002 and in 'Flora' and 'Lacta' (5.8 *versus* 6.5 and 6.4) in 2003. Probably induced by 2002 results, once no significant differences were accounted in 2003, NFFB grew with planting date delay, reaching early planting 6.1 and the late planting 6.4. Our results reflect the NFFB behavior as an inherent genotype trait, once no inter genotypes significant differences were detected in durations of phenological periods (see first part of this article).

Nodes above white flower (NAWF): According to purposed methodology [11], linear regressions between NAWF and DAP able us to determine the number of DAP to cutout (NAWF = 5) and the effective flowering period, estimated as the difference of DAP to cutout and DAP at first-flower (Table 4). The intercept inform us the probable NAWF when DAP tends to zero and the slope corresponds to the rate of NAWF decrease per day. Significant negative slopes of regression translate linear NAWF decreasing trend along the growing season.

Significant differences in the intercept and slope were found between genotypes. 'Celia', 'Crema' and 'Sonia' intercepts were lower than calculated for 'Carmen' and 'Flora'. Precisely the opposite occurred with slopes, presenting the former genotypes small NAWF decrease per unit time than the last ones. Regardless, that opposite behaviors have jointly the same result tendency on the number of days after planting to reach cutout, once high NAWF decrease per day starting from high NAWF, as observed in 'Carmen' and 'Flora' pursued the result of low NAWF decrease per day starting from low NAWF, as observed in 'Celia', 'Crema' and 'Sonia'. Fitted DAP to cutout ranges from 90 ('Celia') to 107 ('Carmen') and 108 ('Lacta'), which indicates some earliness tendency of the former. Significant differences between genotypes were calculated on effective flowering periods. In fact, calculated values varied from negative ('Celia') to 17 days ('Lacta'). That is to say, 'Celia' reached cutout at the same number of DAP, or inclusively prior, the number of DAP to first-flower. 'Sonia' showed same trend. In contrary, 'Carmen' and 'Lacta' effective flowering periods were the largest ones.

No significant differences were found between the slopes of planting dates averaged over genotypes and experimental years, or between the slopes of experimental years averaged over genotypes and planting dates. However, we found a tendency

Table 2. Constants of inverse regression [a] of height-to-node ratio (cm node^{-1}) to degree-days after planting (°C day[b]) averaged over planting dates.

	Genotype					
	Carmen	Celia	Crema	Flora	Lacta	Sonia
			2002			
b	-239.4 a	-277.1 a	-879.2 d	-618.2 b	-890.8 d	-695.5 c
R^2	0.777	0.853	0.991	0.989	0.995	0.974
SE[c]	0.198	0.177	0.124	0.103	0.1	0.175
			2003			
b	-2013.1 a	-2446.7 b	-3111.2 c	-4112.8 d	-9060.1 e	-3761.8 cd
R^2	0.904	0.883	0.789	0.708	0.612	0.809
SE	0.101	1.373	2.478	4.07	11.107	2.82

All R^2 significant at $P<0.001$. Values within a line followed by the same letter are not significantly different by the LSD test ($P<0.05$). [a]Model $y = a+b/x$. [b]T_0=15°C. [c]SE=regression standard error.

($0.05<P<0.10$) of slope increase from the earlier to the late planting date, denoting a tendency of lower needs of time to reach cutout with planting delay. Nevertheless this tendency, calculated effective flowering periods were similar (11 to 13 days). Inverse tendency was found between 2003 and 2002, denoting 2003 a smaller NAWF decrease with DAP. This tendency can be due to the imposed difference between first planting dates. Also similar effective flowering periods were calculated in both years (13-15 days). Regardless the non-significant differences between years of NAWF decrease per unit time, the number of DAP to cutout reveals an important difference of 21 days. Tendencies between planting dates and year-to-year slope differences have contributed to converging the date of the year at which cutout occurred in all genotypes (end of July to beginning of August).

Table 3. Node of first fruiting branch.

	Year		
	2002	2003	Mean
Genotype			
Carmen	6.3 ab	6.3 ab	6.3 ab
Celia	5.9 b	5.8 b	5.8 c
Crema	6.1 ab	6.0 ab	6.1 bc
Flora	6.5 a	6.5 a	6.5 a
Lacta	6.3 ab	6.4 a	6.3 ab
Sonia	6.3 ab	6.3 ab	6.3 ab
Planting date			
Early	6.0 a	6.2 a	6.1 a
Medium	6.3 b	6.2 a	6.2 b
Late	6.4 b	6.4 a	6.4 c
Mean	6.2	6.2	

Values with the same letter in a column and within a treatment are not significantly different by the Tukey test ($P<0.05$).

Discussion

Height (H) and number of main-stem nodes (MSN): In a two years and five genotypes study at Shafter (35°32'N), California, USA, the most indeterminate genotypes ('Acala SJ-2' and 'Acala SJC-1') produced final high H of plants (130 and 106 cm) whilst the most determinate cultivars ('2086' and '2280') produced smaller ones (87 and 80 cm) [22]. Excluding our highest ('Lacta') and lowest ('Flora') final H results, the other four genotypes final H framed indeterminate cultivars [22]. None of our six genotypes can be compared with the most determinate cultivars used by those authors. 'Archeo' grown at Policoro (40°02'N), Italy [23], reached the maximum H of 120 cm, very similar to 'Crema' and close to 'Carmen' and 'Sonia'. Examples are available of standard final H for two local obtained cultivars ('Maria del Mar' and 'Tabladilla 16') and for 'Coker-310', grown in the Guadalquivir Valley, Spain, ranging from 122 to 134 cm, values that encompass only our tallest genotypes ('Carmen' and 'Lacta') [20]. 'Aria', 'DP50' and 'Acala SJ-2' varieties, grown at Larissa (39°63'N), Central Greece, in the no Pix growth regulation treatment, 109, 112 and 120 cm plant heights were found at harvest, respectively, and only 85 and 95 cm with 'DP20' and 'Eva', at Giannitsa, in North Greece (40°47'N), where growing season is especially limited[24]. The season duration of the genotypes used by those authors at Larissa (short, medium and late) fits well final H values obtained with three out of six genotypes used in the present work, 'Flora' with shorter plants and 'Carmen' and 'Lacta' with taller ones being the outsiders. In contrary, final H results at two latitude degrees upper than Comenda, Alentejo, with short season genotypes were much smaller than ours[24].

Table 4. Intercepts (a) and slopes (b) of linear regressions[a] of nodes above white flower (NAWF) to days after planting (DAP) and derived results of DAP to NAWF = 5 and effective flowering period, for each genotype, planting date and year.

Variable	a (NAWF)	b (NAWF day^{-1})	NAWF = 5 (DAP)	Effective flowering period (days)
Genotype				
Carmen	14.6 a	-0.090 b	107	16
Celia	9.8 b	-0.054 a	90	-
Crema	10.5 b	-0.053 a	104	13
Flora	13.4 a	-0.079 b	106	15
Lacta	11.4 ab	-0.059 ab	108	17
Sonia	10.2 b	-0.056 a	94	3
Planting date				
Early	12.6 a	-0.068 a	112	11
Medium	13.0 a	-0.080 a	101	12
Late	13.3 a	-0.087 a	96	13
Year				
2002	12.6 a	-0.080 a	95	13
2003	12.6 a	-0.065 a	116	15

Values with the same letter in a column and within a treatment are not significantly different by the Student *t*-test ($P<0.05$). All R^2 significant at $P<0.001$. [a]Model NAWF = a+bDAP.

As occurred is this study, significant differences in final MSN were found, the most indeterminate cultivars having higher MSN (23.5-23.6 nodes plant^{-1}) than the most determinate ones (21.4-21.7 nodes plant^{-1}) [22]. Observing this maturation types grouping and our final MSN results, 'Celia' and 'Sonia' will be framed as determinate cultivars and all the others will be located as in-between determinate and indeterminate types.

Experiments using 'Acala SJ-2' showed heat units requirements of 50 DD MSN^{-1} from emergence to node 15, similar to the lower value of the 50-60 DD MSN^{-1} observed in our experiment [3,4]. In the 'Acala SJ-2' thirteen replicated experiments from 1982 to 1989, at Shafter (35°32'N), California, USA, a linear relationship between the MSN and DD since 150 to 850 DD (t_0 = 60°F) was found, corresponding to a unique plastochron of 43 DD MSN^{-1} (t_0 = 60°F) prior to anthesis [3]. In contrary, our quadratic relation between MSN and DD, implying a linear increase of heat units requirements per each new node along the growing season, don't confirm that this plant monitoring indicator is not influenced by physiological or environmental conditions, even prior to anthesis. Considering all the growing season a cubic relation between MSN and DD can be found [3]. In a nine genotypes study with different maturity types on a glasshouse experiment (t_0 = 12°C), significant differences were found on MSN plastochrons (observed from the beginning of flowering) varying between 34.6 (early type) to 39.8 DD MSN^{-1} (medium-late type) [7]. That interval is comparable with our own interval but when plants were in the first growth stages. At Maricopa (33°10'N), Arizona, USA, MSN and H fitted to DD quadratic equations, with constants apparently very similar to ours [25]. However, these models deeply underestimate our MSN and H values. In fact, only growth patterns can be comparable. That discrepancy between both models can be explained by the genotypes used. Lesser DD needs per each cm height and node number formation of the 6 genotypes used in our experiment can be a clear sign of short-season and determinancy characters, best suited to site climatic constraints. In fact, those authors worked with 'Deltapine 90', a late season variety with strong indeterminate growth habit.

Other authors also found between years final H significant differences, but their difference attained only 10 cm, much smaller than ours 23 cm [22]. In Greece, a three genotype average of 113.7 cm was found at Larissa, and an average of only 90 cm in two varieties with more determinate growth habit at Giannitsa [24]. Same tendency were observed in the present work, with greater final plant heights obtained in the experiment year with longer growing season and more favorable temperatures. 'Coker-310' and 'Deltapine 90' in a no plastic mulch treatment at Alcalá del Río (37°20' N), Spain, gave between years final H significant differences, ranging from 94.4 to 126.3 cm [19]. 'Suregrow 125' at Clarkdale (34°46'N), Arkansas, USA, attained H of 93 cm and 87 cm at 3 and 6 weeks after first-flower [26]. Our results of those H were obtained after 900-1000 DD in 2002 and after 600-650 DD in 2003, i.e. just before first-open boll in 2002 and also some weeks after first-flower in 2003. At that time our MSN results were 17 to 19 both years, although MSN was 20.7 and 20.4 [26].

Accordingly with our observations, there are great inter annual differences of DD needs for plant height increase and these differences are exhibited since the younger plant stages and evolutes with different patterns each year. The different behavior soon after first-flower, with 2003 greater increase in H plastochrons, was probably due by one or both of the following reasons: limited carbohydrate production due plant stresses and/or by fruiting structures development that competes with vegetative growth for available assimilates [4].

Our results confirm that H is a more sensitive indicator than MSN, showing the former greater inter-annual and inter-genotypic variability. However, as occurred in the inter-genotype analysis, MSN production rate was not approximately constant since emergence to prior to anthesis [4].

Height-to-node ratio (HNR): Using 'Acala SJ-2' data of 13 locations in the San Joaquin Valley during eight years, a final HNR of 5.3-5.5 was estimated, when plants had 23-24 MSN [3]. However, the 20 high yielding of 104 tests monitored at the same region, from 1982 to 1991, attained final 22.4 MSN and HNR 4.45 cm node^{-1} [4]. The average for 69 locations from 1988 to 1992 final HNR was 4.98 cm node^{-1} for Acala SJ-2 (indeterminate) and 4.17 cm node^{-1} for Acala GC-510 (determinate)[3]. Those investigations, using the same cultivar at identical environmental conditions, attained final HNR differences. Our final HNR of 5.2 is very close to the lower limit of the observed 5.3-5.5 interval [3], and higher than the last two cited investigations. Others also observed HNR year dependence, their final values ranging from 4.3 to 5.6 cm node^{-1} [19]. Spanish examples of standard final HNR for two local and for one foreign cultivar ranges from 4.3 to 4.6 cm node^{-1}, rather lower than our final HNR results of 4.9 to 6.2 [20]. At 3 and 6 weeks after first-flower, HNR reached 4.5 and 4.3 cm node^{-1}, respectively [26]. At that stage we have HNR of 5.1 cm node^{-1}. In a 25 genotypes work more precocious genotypes have lower HNR's, with 4.4 at 50 DAP and 6.3 at 102 DAP [27]. Our HNR results ranged from 2.3 'Crema' to 3.1 'Carmen' at 50 DAP and from 4.2 'Flora' to 4.8 'Crema' at 102 DAP. If that statement were true, we can say that our six genotypes present some higher precocity tendency than the genotypes used by those authors [27].

Some authors found an exponential growth of HNR during the early season, ranging from 2.5 to 4.6 cm node^{-1}, and a plant growth slowed down afterwards presumably due to demand for carbohydrates by fruiting structures[3]. Their vigor index logistic type evolution corresponds to a peak of HNR growth rate near the time of first-flower. Our quadratic model has maximum vigor index growth rate at the beginning of the growing season, significantly higher than 'Acala SJ-2' from the early stages to 17 MSN, point at which both HNR equals 5.07 [3]. Afterwards, until the end of the season, our vigor index became lower than for 'Acala SJ-2'[3] (Fig. 6).

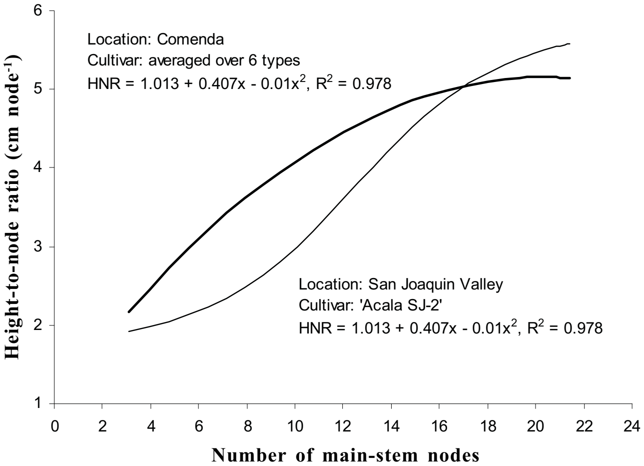

Figure 6. Relationship of height-to-node ratio (HNR, cm node^{-1}) to number of main-stem nodes (MSN) averaged over genotypes, planting dates and years. Narrow line represents HNR logistic growth of Acala SJ-2' [22].

Node of first fruiting branch (NFFB): Higher NFFB of late planting dates is in line with statement that low temperature, mainly night temperature, has a direct influence on floral differentiation initiation and NFFB [1]. Low night temperature immediately after emergence is an important environmental factor to reduce NFFB [28]. Studies on indeterminate and determinate cultivars stated that the higher precocity found in the later ones was linked to low NFFB [22]. High plant densities promote higher NFFB, due to major floral failure and shedding of squares and young bolls at the lower fruiting branches, and not due to any inhibition of lower sympodia formation [29, 30]. NFFB is an important morphological indicator closely linked with floral initiation precocity [5, 31]. However, genotype achievement of precocity can be attained by several convergent ways, namely, early beginning of fruiting forms, like lower NFFB and lower DD to first square, or by higher production rate of fruiting sites, like lower vertical and/or horizontal flowering intervals [5, 16, 31]. As we have seen in the first part of this paper, no varieties significant differences were detected in time periods between unlike events [32], like first-square, first-flower or first-open boll, important earliness indicators [33]. In those circumstances, eventual NFFB genotypes differences left over as a reliable index to identify early initiation of fruiting [3]. Extracting from our NFFB results that characteristic can be attributed to 'Celia' and, in less extent, to 'Crema'.

For the most cultivated genotypes at San Joaquin Valley, California, at that time, in a six year observation period, the NFFB varied between 5.3 ('Acala Maxxa') and 6.2 ('DP6100'), whilst the ten years mean of 'Acala SJ-2' NFFB equaled 5.6 [34]. Those values are in general lower than the observed in the present study for all genotypes, planting dates and years. 'Celia' and 'Crema' NFFB are the exceptions, being lower than the NFFB mean of 'DP6100'.

Nodes above white flower (NAWF): Similar relative differences of days to NAWF = 5 were noted in 2 years near Clarkdale, Arkansas, USA [8], i.e. like we stated, no year-to-year NAWF decreasing rate significant differences were detected. Late maturation cultivars tend to reach higher number of days to cutout, with early to late maturation differences raging from 6 to 20 days [8]. The number of DAP to cutout varied between 83 and 89 (1989) and between 76 and 96 (1990) [8]. In this study only 'Celia' and 'Sonia' fitted DAP to cutout can be placed in those intervals, nearby the 1990 higher limit. According with those findings, our six cultivars showed strong late maturation tendency[8]. Our maximal inter-genotype difference of DAP to cutout reached 17-18 days, between 'Carmen'-'Lacta' and 'Celia', whilst they found a much smaller difference in 1989 (6 days) and a similar one in 1990 (20 days). The two former cultivars are medium to medium-late cultivars, whilst 'Celia' is an early-medium season cultivar. However, we observed an inverse and relatively unexpected result in 'Sonia', a medium-late cultivar which only needed 94 days to cutout, only 4 additional days than 'Celia'. Maturity differences among cultivars, e.g. 80-88 in 'Arkot 518' (early maturing) and 90-104 in 'Deltapine 90' (late maturing) DAP to cutout, can be inferred by the number of DAP to cutout, and earliness of cotton was reduced by increasing nitrogen fertilization rates [9]. Calculated once again, according with these findings [9], our fitted DAP to cutout will place our six cultivars in the late maturing group. As we found, differences were also noticed between years in the time required to reach cutout, with a mean difference of 11 days against our 21 days calculated difference. The same authors working with cultivar 'Stoneville 453' at Rohwer (33°49'N) and Keiser (35°41'N), Arkansas, USA, also observed that generous nitrogen fertilizations contributed to higher number of DAP to cutout and higher effective flowering periods [9]. Others [15, 35], working with cultivar 'Deltapine 50', also found significantly higher periods to cutout,changing from 74-86 to 110-120 DAP, with greater nitrogen availability. Our results were relatively high and closely correspondent to the values obtained by those authors with the higher nitrogen rates. Perhaps our results were also due to our nitrogen fertilization (N 225 kg ha^{-1}) which probably forced late season vegetative growth. However, other causes can be the late motives of these results, like the observed insect damages on squares and bolls. In fact, DAP to cutout increases with the increase of first position squares loss, the fact particularly evident when DAP to cutout exceeds 100 days [36]. With cultivar 'Deltapine 51', square loss due to *Helicoverpa* sp. origins higher DAP to cutout, as well as lower retention rates at first positions and higher retention at distal positions in the canopy [37]. In these situations plants have not a fruiting load sufficient to switch from vegetative growth the available assimilates [38]. This explanation can be applied to our NAWF evolution results, also confirming the observations made about HNR.

Conclusions

In line with the general statement that MSN is a good indicator of plant age and H is a monitoring index responsive to plant stresses, this study allows us to confirm that H is a more sensitive monitoring index to inter-annual and inter-genotypic variability than MSN. However, both phenomena plastochrons increases along the growing cycle.

Comparing with cited references, contradictory signs of maturation types were found. Low H and MSN plastochrons and low final vigor index suggest precocity but, in contrary, relatively high NFFB, initial vigor index, final H and high number of days to cutout, suggest late maturing tendencies of our studied cultivars as a whole. Among the six genotypes studied, monitoring indexes of 'Celia' exhibit and join more earliness signals, namely, relatively low NFFB, lower final MSN and lower number of days to cutout.

Planting date can be underlined as a management practice with relatively low influence on H, MSN, HNR and NAWF evolution. However, especial attention must be given on the influence of planting date on NFFB, once this monitoring index is strikingly linked with precocity, feature particularly important for regions with growing season duration constraints.

Observed year–to-year variability of monitoring absolute values, as well as their complex relations with cotton growth responses, wises to continue and extend annual data collecting, in order to establish growth standards and to allow their use as decision making tools available to the main cotton producing regions of southern Iberian Peninsula.

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