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Day-degree Units and Time in Relation to Vegetative Development and Fruiting for Three Cultivars of Cotton[1]

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ABSTRACT

In a test of two Upland cotton (*Gossypium hirsutum* L.) cultivars and one Pima (*G. barbadense* L.) cultivar planted on five dates, fewer days were required to produce first true leaf, square, and flower stages as the date of planting was advanced from 1 April to 27 May. Days from planting required to produce open bolls decreased as planting temperatures approached an optimum, then increased for the last planting date. Differences among planting dates for cumulative day-degree units needed to produce flowers and true leaves were non-significant, whereas those needed to produce the square and open boll stages were significant. The boll period increased with delay of the flower and harvest stages as the season progressed. The numbers of day-degree units and heat units were negatively correlated with the length of the boll period. The number of day-degree units gave a better estimate of boll period by harvest week than the number of heat units. Boll period was influenced more by reductions in day-degree units in 'Pima S-4' than in the two Upland cultivars.

Additional index words: Boll period, Heat units, Fruiting response, Vegetative growth, Planting date, *Gossypium hirsutum* L., *Gossypium barbadense* L.

ARID regions have wide diurnal temperature fluctuations – often up to 28 C. The average annual diurnal variation at El Paso, Texas, is near 17 C. In the El Paso area, cotton is planted under conditions of suboptimum soil temperature, declining soil moisture, and increasing concentration of soluble salts. When temperatures are suboptimum, the time required for germination and emergence is increased.

Holekamp et al. (6) stated that cotton planting should be delayed until the 10-day average minimum soil temperature at the 20-cm soil depth has reached 15.6 C. Soil temperature data for El Paso indicate that the recommended temperature in the seed zone is not achieved until early May. However, cotton is normally planted in the El Paso Valley in April when temperatures in the seed zone (5-cm soil depth) are about 12.8 C and air temperatures may drop below 0 C at night.

Bilbro (1) reported that prebloom periods ranged from 88 days, for a 10 April planting, to 53 days, for 10, 20, and 30 June plantings at Lubbock, Texas. The decreases in prebloom period was the result of increasing air and soil temperatures as the season progressed from spring to summer. In a comparison of 19 thermal-unit methods, he found that the best was one in which an adjustment was made for high-temperature stress, when the daily maximum exceeded 32 C. The adjustment for temperatures above 32 C implies that excess thermal-units lengthen the prebloom period.

Boll maturation occurring after August in west Texas, New Mexico, and eastern Arizona above 800 m takes place under increasingly lower night temperatures, and, therefore, requires more time. Gipson and Joham (3) found the rate of boll development to be inversely related to both day and night temperature. However, they found that night temperature was the dominant factor influencing boll periods. They concluded that 'Paymaster' (a High Plains, short-season cultivar) was better adapted to low night temperatures than an Acala (full-season) cultivar. Gipson and Ray (4) reported that decreasing night temperatures from 27 to 11 C lengthened boll maturation by 45, 41, 37, 33, and 31 days, respectively, for 'Acala 1517 BR-2,' 'Stoneville 7A,' 'Lankart 57,' 'Stripper 31,' and 'C.A. 491.' Their results indicate the existence of a genetic potential for minimizing the adverse effects of low temperature during the boll-development period.

Hesketh and Low (5) found that the time to formation of flowers or to open bolls decreased steadily as the day temperature was increased from 21 to 30 C for all cultivars. Moraghan et al. (8) found that 11 strains of cotton squared earliest at the intermediate day/night temperatures of 27/22 and 30/25 C. Squaring was latest at the extreme day/night temperatures: 36/31 and 21/16 C. However, time to squaring was not delayed at these temperatures in two of the cultivars, 'King Karajoski 1543' and C.A. 491. 'Pima S-2' was late at 36/31 C but was relatively early at 21/16 C. Quisenberry and Kohel (9) reported that four cultivars responded differently, as measured by boll and fiber properties, to a reduction in the number of heat units (daily mean temperature minus a constant of 18.3 for each day).

The purpose of this report is to discuss changes in periods of vegetative, flowering, and fruit development in three cultivars of cotton as influenced by progressively later planting dates at El Paso, Texas.

MATERIALS AND METHODS

Cultivars were chosen to represent three distinct types of cotton. 'Acala 1517' (*Gossypium hirsutum* L.) represented the long-staple, strong-fibered cultivars developed at high elevation for irrigated production in the western states. Stoneville 7A (*G. hirsutum*) represented cultivars often referred to as Delta types. They have shorter and weaker fibers than the Acalas and were developed for the rain-grown, humid area of the Cotton Belt, but are adapted to a wider area. 'Pima S-4' (*G. barbadense* L.) represented the extra-long-staple, high-strength and fine-fibered, American Pima cotton adapted to the irrigated Southwest.

Seed was started in expanded peat pots on 1, 15, and 29 April and 13 and 27 May in 1971 and 1972. About 5 days after germination at room temperature, the material was transplanted in the field. The field was irrigated about 14 days before the 1 April and 27 May plantings. Supplemental water was hand applied after transplanting to insure stand establishment of spaced plants. The plants were spaced at 60.5 cm intervals on

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Table 1. Number of days, day-degree units, and heat units at five dates of planting for 10 intervals of plant growth and development.

Date of planting	From planting to: True leaf	From planting to: Square	From planting to: Flower	From planting to: Open boll	From true leaf to: Square	From true leaf to: Flower	From true leaf to: Open boll	From square to: Flower	From square to: Open boll	From flower to: Open boll
	No. of days									
1 April	26.5b*	74.0e	97.5e	155.5d	47.5d	71.0c	129.0b	23.5a	81.5ab	58.0a
15 April	25.0b	68.5d	89.0d	144.5c	43.5c	64.0b	119.5a	20.5a	76.0a	56.0a
29 April	23.0b	62.5c	80.5c	140.5bc	39.5b	57.5a	117.5a	18.0a	78.0a	60.0a
13 May	18.5a	55.5b	75.0b	133.0a	37.0b	56.5a	114.5a	19.5a	77.5a	58.0a
27 May	17.5a	49.5a	70.5a	135.0ab	32.0a	53.0a	117.5a	21.0a	85.5b	64.5a
	Day-degree units									
1 April	5,825a	21,005a	33,226a	58,878b	15,180a	27,402a	53,054b	12,222b	37,874c	25,652b
15 April	6,147a	22,611ab	33,331a	57,298ab	16,464b	27,184a	51,151ab	10,720a	34,687b	23,967ab
29 April	6,763a	23,861b	32,932a	58,083ab	17,098bc	26,169a	51,320ab	9,071a	24,222a	25,151ab
13 May	6,301a	23,989b	33,597a	56,038a	17,689c	27,297a	49,739a	9,608a	32,049ab	22,441a
27 May	6,961a	23,595b	33,096a	55,721a	16,634b	26,135a	48,760a	9,502a	32,127ab	22,625ab
	Heat units									
1 April	107a	478c	810b	1,546b	372b	703b	1,439a	332a	1,068a	736a
15 April	121a	538bc	843b	1,556b	418ab	722b	1,435a	305a	1,018b	713ab
29 April	154a	600ab	864ab	1,611a	446a	710b	1,457a	264a	1,011b	747a
13 May	155a	615a	969a	1,582ab	461a	815a	1,428a	354a	967c	613b
27 May	159a	625a	916a	1,582ab	466a	757ab	1,423a	292a	957c	666ab

* Means followed by the same letter within each column for number of days, day-degree units, and heat units are not significantly different at the 0.05 level of probability.

beds 96.5 cm wide. A randomized, complete block design with six replications was used. Each single-row plot consisted of 30 seedlings, of which about 15 were used. The soil of the experimental area was a Harkey-Saneli-Vinton-Gila alluvial complex of coarse silty-loamy, mixed, calcareous, thermic material.

When transplanted, the cotton seedlings were in the cotyledonary stage. Physiological development stages were identified as follows: first true leaf, square, flower, and open boll. As plants developed squares, eight consecutive plants were selected in each plot. Flowers were tagged on the six inner plants of these eight.

Flowers were tagged daily beginning with the first flower and continuing until frost. The number of flowers per six-plant plot was determined for each week. Open bolls were harvested weekly from each plot until 2 weeks after killing frost. Boll period was the number of days from flower (anthesis) to open boll. Maximum and minimum ambient air temperatures were recorded daily. Five-day average maximum and minimum temperatures were obtained from 1 March through 31 October.

The day-degree units were determined by subtracting a constant (K = 12.8 C) from the daily maximum temperature. This constant was used as the temperature below which cotton plants do not develop (10). Values below the constant were not considered to have a negative effect. The day-degree units for boll opening were determined by summing available day-degree units from flowering to open boll on a weekly basis. The middle of the week of flowering was considered to be day one and the day-degree units were summed for the average number of days for boll maturation, i.e., $Tm_1 + Tm_2 \ldots + Tm_n - nK$. The day-degree units for plant growth and development were determined in the same manner as the day-degree units for boll periods. For example, the maximum temperature on the date of planting became Tm_1, and the stage of development (e.g., open boll) might have been Tm_{155}. Boll period is presented as an average over all dates of planting within each cultivar.

A heat unit is the average daily temperature − 12.8 C. Heat units were summed over the growth period.

RESULTS AND DISCUSSION

Plant Growth and Development Stages

Time Intervals. With delayed plantings, significantly fewer days were required for seven of the 10 intervals of plant growth and development, all beginning at either planting or first true leaf stages (Table 1). The percentage reduction in number of days ranged from 11.2% for the first true leaf to open boll stage of development up to 34.0% for the planting to true leaf stage. Only two of the seven stages had less than a 25% reduction in the number of days from early to late planting. The average change per 2-week delay in planting ranged from 2.2- to 7.5-days.

Only two intervals of plant growth – planting to open boll and first true leaf to open boll – showed an increase in the number of days required for development for the 27 May over the 13 May planting (Table 1). The increase in number of days from the planting, first true leaf, square and flower stages to open boll reflects an increasing length of time from flowering (anthesis) to open boll (boll period), a consequence of bolls maturing under decreasing minimum (night) temperatures beginning in August. The non-significant variation among the first four dates of planting for days required for the square to flower and open boll stages, and for the flower to open boll stage indicate that time had a greater influence than temperature. These three intervals for the first four planting dates were in Staten's (10) optimum temperature range (above 12.8 C).

Brown and Ware's (2) critical minimum temperature of 15 C appears closely related to flower production (Figure 1). All flowers producing open bolls occurred when minimum temperatures were above 15 C.

Day-degree Units. There was a significant reduction in day-degree units as planting was delayed for five intervals of plant growth (Table 1) – all stages involving the open boll, and the square to flower interval. Two intervals of plant growth – from the plant and first true leaf stages to square – had significant increases in day degree units. The non-significant variation among dates of planting for day-degree units in three intervals of plant growth – the planting stage to the first true leaf and flower, and the first

Table 2. Correlations between two measures of cumulative temperature and the number of days required for 10 intervals of plant growth and development.

	Intervals of plant growth and development									
	From planting to:				From true leaf to:			From square to:		From flower to:
Measure of cumulative temperature	True leaf	Square	Flower	Open boll	Square	Flower	Open boll	Flower	Open boll	Open boll
Day-degree unit	−0.71	−0.82	0.00	0.89*	−0.67	0.70	0.82	0.88*	−0.70	−0.34
Heat unit	−0.24	−0.71	−0.06	0.81	−0.77	−0.95*	0.85	0.06	0.10	−0.70

* Correlation coefficient significant at the 0.05 level of probability.

Table 3. Number of days from open flower to open boll for 12 weeks of flowering in three cultivars at El Paso, Texas, in 1971 and 1972.

	Cultivar		
Week of flowering	Acala 1517	Stoneville 7A	Pima S-4
1	51.4a*	58.0a	60.4a
2	53.5ab	56.6a	59.9a
3	56.9abc	58.6a	61.4a
4	58.4abc	60.4ab	61.4a
5	58.6abc	63.2abc	63.6a
6	62.1bcd	66.1abcd	66.7ab
7	63.5bcd	69.1bcde	70.6abc
8	66.2cd	71.6cdef	74.0bc
9	71.3de	76.0def	76.8bc
10	76.9e	79.8f	79.6c
11	78.8e	80.2f	76.0bc
12	76.5e	77.0ef	69.5abc

* Means followed by the same letter within each column are not significantly different at the 0.05 level of probability.

Table 4. Day-degree units from open flower to open boll for 12 weeks of flowering in three cultivars at El Paso, Texas, in 1971 and 1972.

	Cultivar		
Week of flowering	Acala 1517	Stoneville 7A	Pima S-4
1	24,971a*	26,018a	27,103a
2	24,146b	25,945a	27,224a
3	24,765a	25,605b	26,383b
4	23,970b	25,316b	26,038c
5	23,412c	24,739c	24,739d
6	22,840d	23,957d	23,957e
7	22,698d	23,956d	23,960e
8	21,963e	22,485e	22,485f
9	19,839f	20,703f	20,621g
10	18,378g	18,403g	18,378h
11	15,348h	15,348h	15,302i
12	12,632i	12,632i	12,586j

* Means followed by the same letter within each column are not significantly different at the 0.05 level of probability.

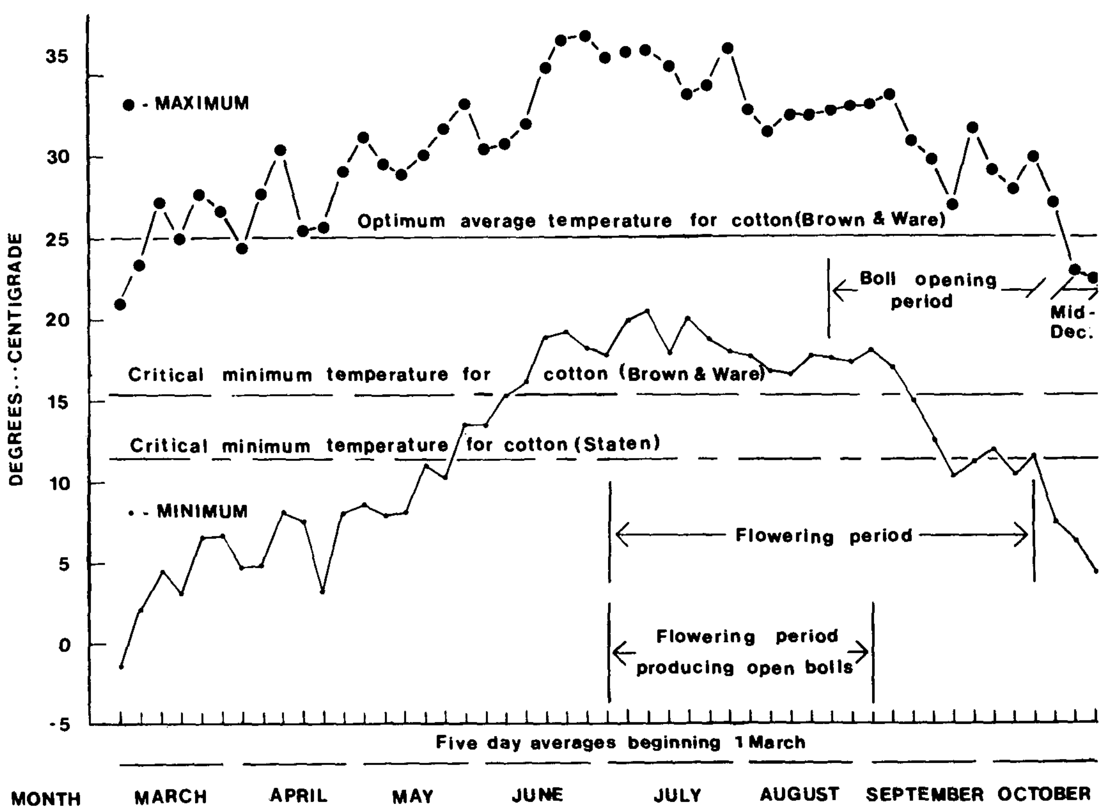

Fig. 1. Average 5-day maximum and minimum ambient air temperature from March through October at El Paso, Texas, in 1971 and 1972, showing temperatures critical for growth of cotton and timing of various stages of cotton development.

Table 5. Correlation between two measures of cumulative temperature and the number of days required for boll development in three cultivars measured by week of flowering and harvesting.

Measure of cumulative temperature	Boll period measured by flower and harvest week					
	Week of flowering			Week of harvesting		
	Acala 1517	Stoneville 7A	Pima S-4	Acala 1517	Stoneville 7A	Pima S-4
Day-degree unit	−0.89**	−0.83**	−0.70**	−0.94**	−0.95**	−0.97**
Heat unit	−0.90**	−0.83**	−0.66*	−0.55*	−0.89**	−0.45

*,** Indicate that r is significant at the 0.05 and 0.01 levels of probability, respectively.

true leaf stage to flower – indicates that temperature had a greater influence than time.

Fruiting forms initiated under cool spring temperatures and devloping under increasing summer temperatures require more day-degree units than fruiting forms initiated under high summer temperature and developing under decreasing temperatures beginning in August. Thus, higher temperatures during the period of early boll set are not as effective per degree as lower temperatures during the development of later boll set. Beginning with early August flowers, the entire boll period was during increasingly cooler night temperatures.

May through September day-degree units were correlated with average Pima yield (r = 0.59*)[3] and with average Upland yields (r = 0.64**) in New Mexico from 1963 through 1978 (7). The correlation of Pima and Upland average lint yields (r = 0.63**) for the 16-year period indicates the two cottons respond similarily to the available day-degree units.

Heat Units. The estimate of heat units, involving the minimum temperature, responds differently than day-degree units (Table 1). Day-degree units are more closely correlated than heat units with days for growth from planting to open boll and from square to flower (Table 2). However, heat units were more highly correlated than day-degree units with days for growth from true leaf and flower to open boll. These differences in correlations further suggest that different stages of growth (e.g., planting to true leaf, first true leaf to flower, square to flower and flower to open boll) have independent responses to temperature and time. Critically limiting temperatures differ with the stage of growth.

Development from Flower to Open Boll in Relationship with Week of Flowering

The boll period ranged from 51.4 days for Acala 1517 (week 1) to 80.2 days for Stoneville 7A (week 11) (Table 3). Acala 1517, Stoneville 7A, and Pima S-4 had boll periods of 51.4, 58.0, and 60.4 days, respectively for the 1st week of flowering.

The increase in boll period averaged less than 2 days per week for flowers that bloomed during the first 4 weeks. Flowers that bloomed during the 4th through the 8th weeks of flowering averaged 2.6 days longer for boll maturation with each delay of 1 week in flowering, whereas those that bloomed during weeks 9 and 10 averaged 4.1 days longer with each delay of 1 week. The shorter boll periods for weeks 11 and 12 were caused by killing frosts. The increases in time for boll period from early- to late-season flowers were 27.4, 22.2, and 19.7 days for Acala 1517, Stoneville 7A and Pima S-4, respectively. Acala 1517 and Stoneville 7A produced flowers during the same flower week for all dates of planting. Except for planting date 1 April, Pima S-4 produced flowers a week later than the two Upland cultivars.

Through the 8th week of flowering, Acala 1517 required fewer cumulative day-degree units for boll maturation than Stoneville 7A, which in turn required less than Pima S-4. The average number of available day-degree units for the boll period decreased by 360 units with each successive week of flowering through the 7th week (Table 4). Flowers produced during the 8th week required 1,230 fewer day-degree units than those produced during the previous week. The average number of day-degree units decreased by 1,940 with each delay of 1 week in flowering during the last 4 weeks. Among the possible explanations for the sharp change in time and day-degree units are: (a) there may have been a surplus of day-degree units for the early-season flowers, even though the days required for boll maturation increased during the first 10 weeks of flowering (this explanation is supported by the reduction in number of day-degree units required to advance from the flower to the open boll stage with delayed plantings); (b) temperature above a critical threshold may inhibit boll maturation; (c) with or without a surplus of day-degree units in the early weeks of flower, an increase in time can partially compensate for fewer day-degree units.

Most bolls produced during the last 2 or 3 weeks of flowering were killed before opening by frost. The influence of the reduced number of day-degree units on boll period was greater in Pima S-4 than in the two Upland cottons; the ensuing desiccation of the carpels hastened opening, and hence decreased the boll period. The last week of flower averaged about 12,600 day-degree units for each cultivar, or one-half the day-degree units available for early season flowers.

Correlations of boll periods with day-degree units and heat units indicate that both measurements are about equally valid (Table 5). Both measures of temperature required for boll maturation support the conclusion that decreasing night temperatures increase the net effect of each degree unit.

Development from Flowering to Open Boll in Relationship with Week of Harvesting

The time from flower to open boll varied from 49 to 89 days (Table 6). Acala 1517 averaged 4.3 and 7.4 fewer days for boll maturation than Stoneville 7A and Pima S-4, respectively. The increase in boll period from early to late harvested bolls was 34.6, 30.9 and

[3] *, ** significant at the 0.05 and 0.01 levels, respectively.

Table 6. Number of days from open flower to open boll for 16 weeks of harvesting in three cultivars at El Paso, Texas, in 1971 and 1972.

Week of harvest	Cultivar: Acala 1517	Stoneville 7A	Pima S-4
1	48.8a*	55.7a	
2	54.0b	56.5a	
3	54.7b	56.2a	58.1a
4	55.3b	58.2ab	60.1ab
5	56.7bc	59.3abc	60.5ab
6	58.4bcd	61.3bcd	62.2abc
7	60.0cd	63.3cde	63.9bcd
8	61.6de	65.0de	65.5cd
9	62.7de	67.1ef	66.8de
10	65.3e	69.5fg	70.4e
11	69.8f	73.0gh	75.2f.
12	72.1f	74.7hi	75.7f
13	73.8fg	75.9hi	77.0f
14	77.8g	77.9i	81.8g
15	83.4h	86.6j	88.5h
16		86.6j	88.9h

* Means followed by the same letter within each column are not significantly different at the 0.05 level of probability.

Table 7. Day-degree units from open flower to open boll for 16 weeks of harvesting in three cultivars at El Paso, Texas, in 1971 and 1972.

Week of harvest	Cultivar: Acala 1517	Stoneville 7A	Pima S-4
1	22,123abc*	23,082ab	
2	23,709a	24,183a	
3	22,899ab	24,222a	23,748a
4	21,133bc	22,651ab	23,703a
5	21,048bc	22,352ab	22,352ab
6	20,637cd	22,097b	22,097ab
7	21,179bc	22,671ab	22,297ab
8	20,352cd	21,484bc	21,100bc
9	18,941de	20,249cd	20,249cd
10	17,748ef	19,248de	18,883d
11	17,023f	18,411e	18,823d
12	14,792g	16,167f	16,567e
13	11,964h	13,663g	14,056f
14	14,056g	14,895fg	13,278f
15	11,176h	12,632g	13,278f
16	10,249h	10,482h	10,971g

* Means followed by the same letter within each column are not significantly different at the 0.05 level of probability.

30.8 days for Acala 1517, Stoneville 7A and Pima S-4, respectively.

Within each date of planting, harvest began the same week for Acala 1517 and Stoneville 7A, except that harvest of Stoneville 7A planted on 29 April and 27 May was delayed by 1 and 2 weeks, respectively. Harvest began 2 or 3 weeks later in Pima S-4 than in the two Upland cultivars for each date of planting; the delay reflects the longer boll maturation of Pima S-4.

Fewer day-degree units were required for boll maturation in Acala 1517 than in Stoneville 7A and Pima S-4 (Table 7); this difference is the result of a 5.9-day shorter boll period in Acala 1517. The premature opening of damaged bolls produced shorter boll periods for the two Upland cultivars for the first week of harvest. This shortening is reflected in a reduced number of day-degree units compared with those required for the next harvest dates. If the first harvest week for Acala 1517 and Stoneville 7A are excluded, the average number of day-degree units per boll period decreased 320 units per week for the next 6 weeks of harvest. For the last 8 weeks of harvest, the average cumulative day-degree units for boll period decreased by about 1,300 units for each delay of 1 week in harvesting. The last week of harvest had only 10,560 cumulated day-degree units.

Day-degree units were significantly superior to heat units in estimating boll periods by harvest week for Acala 1517 and Pima S-4 (Table 5), but the two measures were equally valid for Stoneville 7A.

The shorter boll period for Acala 1517 may be a result of the environment at the site in which this cultivar was developed. The site was at about 1,200 m elevation, and diurnal temperature varied widely, averaging 17 C. Stoneville 7A and Pima S-4 were both developed at sites below 250 m elevation and with high temperatures, in which boll development was not restricted by a short growing season or low temperatures.

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