

Cotton Crop Growth and Development Patterns

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Abstract

Summaries of cotton crop phenology, as a function of heat units (HU, 86/55 °F limits) have been developed across a wide range of production conditions in Arizona. Optimum ranges of HU accumulations since 1 January are used to describe optimal planting dates for full season varieties. Basic events such as the occurrence of pinhead squares, squares susceptible to pink bollworm, and first bloom are described in terms of HU accumulations since planting. Fruit retention guidelines and height: node ratios measures a crop's vegetative/reproductive balance, are developed as a function of HUAP. The use of the number of nodes above the top white bloom to the terminal (NAWB) is developed as a measure of a crops progression towards cut-out. Also, the expected ranges of HU's accumulated since planting that are required to accomplish crop cut-out are shown for three general maturity types of Upland cotton.

Introduction

Plants are biological organisms that respond in direct relation to the temperature and environmental conditions to which they are exposed. Therefore, it has been shown for many different crop plants (and insects) that growth and development can be described much more accurately and predictably by the use of some measure of thermal conditions. As a result, various types of heat unit (HU) systems have been developed to assist in predicting and/or projecting plant and insect development. By using HUs, one can describe thermal conditions for specific locations or specific seasons and not assume consistency for locations or years on a calendar basis.

The cotton (*Gossypium spp.*) producing areas of the desert southwest offer many diverse settings. In Arizona, these areas range from elevations less than 100 feet above sea level to over 3,000 feet. Most of the Arizona cotton acreage is situated geographically so that a rather long growing season can be employed production. Important stages in the development of many crops are often described as a range of calendar dates. For example the times for optimum planting are often described as a range of calendar dates, and important crop development stages are described as number of days after planting (DAP).

Relationships describing both cotton crop and pink bollworm (*Pectinophora gossypiella* (Saunders)) development have been formulated to some extent (Fry, 1983; Brown et al., 1990; and Silvertooth et al., 1991a). The HU terms most often used in this case were with 86 and 55 °F, upper and lower limits, respectively. The HU relationships for pink bollworm development have been developed and tested more substantially than those for cotton. The purpose of this paper is to outline the phenological description of cotton crop development on a HU basis.

Methods

Descriptions of optimum planting date times or "windows" have been developed using data collected from a number of date of planting by variety experiments conducted in Arizona (Kittock and Hofmann, 1987; Kittock et al., 1988; Silvertooth et al., 1989a; and Malcuit et al., 1990). Yield responses as a function of date of planting, have been related to HU accumulations since 1 January, on a given planting date. This provides a common basis among locations and seasons (years).

Data on the number of HU necessary to achieve specific points in cotton crop development such as pinhead square, matchhead square, first bloom, and cut-out have been collected in a number of field experiments conducted across Arizona. Upland (*G. hirsutum* L.) varieties that have been used for these measurements include: DPL 90, DPL 77, DPL 50, DPL 51, DPL 5415, DPL 5690, STV 453 and DPL 20. Also Pima (*G. barbadense* L., variety S-6), has been used for pertinent data collection. Because basic plant development patterns relative to HU accumulation after planting (plant phenology) were generally consistent among all varieties, and both species, outlines and descriptions are offered as a general description for all varieties, unless otherwise noted.

In a group of experiments that were initiated to evaluate the response of Upland and Pima cotton to two dates of planting and two dates of irrigation termination, we are developing information that can potentially be of some help for cotton growers making the decision on when to terminate a crop, and what type of yield increases can be expected from those last two or three irrigations (Silvertooth et al., 1989b; Silvertooth et al., 1990; and Silvertooth et al., 1991b). These experiments have been conducted at the Yuma Valley, Maricopa, and Marana Agricultural Centers of the University of Arizona (approximately 150, 1300, and 2000 ft. elevations, respectively) and have also served as a source of plot measurements describing growth and development. Flower counts per unit area and the number of nodes occurring above the top white bloom (NAWB), have been routinely collected and related to crop development and cut-out.

All HU data was obtained from the AZMET system and the weather station in closest proximity to the field location under study.

Results

Planting date can have an impact on subsequent crop management. A series of date of planting by variety experiments (Kittock and Hofmann, 1987; Kittock et al., 1988; Silvertooth et al., 1989a; and Malcuit et al., 1990) have shown that full-season varieties have greater yield potential over a single fruiting cycle or when extended into a top crop, and maintain best yielding potentials, if planted relatively early. For example, early planting dates in central Arizona would translate roughly to a window extending from about 20 March to 20 April. In terms of HU, this would be approximately between 300 to 900 HU accumulated since 1 January (Figure 1). Delays in planting past this "window" with the full season varieties (i.e., Pima S-6, DPL 77, DPL 90, STV BR 110, STV BR 115, and S-1001, just to name a few) often result in taller, more vegetative plants that do not initiate fruiting as well as those planted earlier, and are thus more difficult to manage. A further refinement in the general window for planting full season type of varieties can be developed from recent date of planting by irrigation termination experiments (Silvertooth et al., 1990 and Silvertooth et al., 1991b) where it has been shown that full season varieties (including Pima) show a consistent decline in yield potential when planted after about 700 HU since 1 January. The opening of the window in terms of achieving satisfactory soil temperatures at seeding depth ($\geq 60^{\circ}\text{F}$) most often does not occur before 450 HU after 1 January. Therefore, the "general" window for full season varieties is described as a 300 - 900 HU window, and an "optimum" window as 450 - 700 HU since 1 January (Figure 1). This window has implications for not only maintaining yield potentials for full season varieties, but also for cultural control of pink bollworm (Brown et al., 1992).

Early Season Developmental Events

The development of cotton plants in the early stages of the growing season can be predicted rather well by measuring HU accumulations since the date of planting. As shown in Figure 2, pinhead square, first square size susceptible to pink bollworm (susceptible square), and first bloom can be expected to occur when approximately 700, 900, and 1200 HU have accumulated since planting, respectively. These HU accumulations after planting (HUAP) are not offered as exact or absolute values, and in practice these values should be regarded as general signposts where the occurrence of such events may be expected to occur. For example, the presence of pinhead squares in a field should be expected at about 700 HUAP, but could be noticed as early as 600 HUAP. This should hold if plants are initiating first fruiting branches five to seven nodes above the cotyledonary nodes. If plants are initiating first fruiting branches substantially above node seven, then the occurrence of pinhead squares, and all subsequent events will also be delayed accordingly. One should also take into account plant to plant variability and also variability that can occur within a field or among fields in terms of microclimate differences; where warmer spots or areas have a tendency to have faster developing plants. Scouting fields for pinhead squares, matchhead squares, and first bloom can help establish criteria for early season management for insects (pinhead square treatments for pink bollworms for example), plant growth regulators, and nitrogen (N) applications.

Earlier reports of differences in the occurrence of pinhead square, for example between Upland and Pima cotton (Brown et al., 1990), could be largely attributed to measurements with earlier Pima varieties such as Pima S-5 and earlier; which commonly initiate fruiting at higher nodes than many of its Upland counterparts.

General Flowering Curve

The general flowering curve is commonly used to describe the growth stages for cotton (Figure 3). The shape and pattern of this curve will actually vary in response to variety, fruit load development, location, soil conditions (water, fertility, salinity, etc.), weather conditions, and other factors affecting crop productivity. It can be seen from the general form of Figure 3 however that the bulk of a cotton crop's yield potential is derived from the first cycle fruiting period. Therefore, it is in the best interests of cotton farmers and managers to have a means of tracking of a crop's development pattern and to have a relative basis for evaluation. A major factor affecting the productivity of a cotton crop is the vegetative/reproductive balance that is achieved or maintained over the course of a season. Maintaining this balance becomes the essence of cotton crop management. The common question often centers around what constitutes a well-balanced crop in terms of vegetative/reproductive development. In an effort to address this issue, an analysis of growth and development has provided several interesting patterns.

HU/Node

Plant measurements collected at several locations over the past several seasons have resulted in the information shown in Figures 4-10. Figure 4 illustrates the generation of mainstem nodes as a function of HUAP for a) Upland and b) Pima cotton. These curves represent data sets collected from non-stressed plots using several Upland varietal types and Pima S-6. In general, it can be shown from these figures that mainstem nodes are generated rather consistently over the season, at a rate of approximately one node per 100 HUAP. There is slightly more variation with the Pima Cotton than the Upland, particularly very early in the season where it takes more HU/node for the Pima. This is another factor that sometimes causes a delay in the occurrence of the first pinhead squares in relation to Upland varieties. However, Pima cotton still commonly initiates first fruiting branches between nodes five and seven, it just takes longer to generate the early nodes in some cases. This variability has not been great enough to warrant a separate early season development line for Pima as shown in Figure 2.

Height: Node Ratios

Since mainstem nodes are produced rather consistently barring conditions such as water or N stress, or terminal

loss; a simple expression of a plant's vegetative tendencies would come from the extent of internode elongation. Therefore, a measure of a plant's height: mainstem node ratio could serve as an expression of this relationship, as long as some basis or standard of comparison would be available. The general plant height (inches): node ratio relationships developed in this research program are shown for Upland and Pima cotton in Figure 5, based upon four years of data. Height: node ratio curves for several specific varieties have also been developed with a few examples shown in Figure 6. Basically, the response pattern for height: node relationships over the season is very similar for each of these general (Figure 5) or specific cases (Figure 6). In fact, the mathematical models used to describe these variety specific curves or relationships (Figure 6) are not significantly different than the general curves in Figure 5.

A height: node ratio baseline (Figure 5) can be used at any point in the season (HUAP) to evaluate vegetative/reproductive balance. For example, if a set of measurements were collected in a given field at first bloom (approx. 1200 HUAP) and an average height: node ratio of 1.5 were determined, this would indicate the field is developing vegetative tendencies and possibly suggest some management action is necessary to correct the situation. On the other hand, if the same field produced an average height: node ratio of 0.8, any attempts to reduce plant height should not be pursued and a further evaluation concerning possible crop stresses should be considered. These ratios do not provide absolute boundaries for what would describe a vegetative or well-balanced plant, but rather a general guideline for reference.

Fruit Retention/Plant Mapping

One of the factors which is directly linked to a crop's vegetative tendencies is that of fruit or boll load. The best control of a cotton plant's height is a well developed boll load. Figure 7 represents the general, optimal fruit retention patterns that can be expected for Upland and/or Pima cotton. This information was derived from plant mapping measurements collected over the past four seasons (1988-1991) across Arizona using the first two fruiting positions nearest the mainstem, for a given fruiting branch, and potentially a total of 20 mapped fruiting branches. This curve relates the generally optimal level of total fruit retention (squares, blooms, and bolls) over time or HUAP. Several interesting points can be drawn from this figure. First of all, we see that cotton plants commonly begin fruiting with a high retention tendency (> 80%), then progressively and naturally lose fruit (abortion of squares and small bolls) over the season to a point where at season's end a total harvestable fruit retention level of approximately 50% (\pm 5-10%) can represent optimal yielding potentials for Upland and Pima varieties grown in the desert regions of Arizona. Therefore, we see that the plant has a structural or genetic potential that is limited by physiological constraints. For example experiments which have shown substantial yield enhancements with cotton grown under elevated concentrations of CO₂ in glasshouse atmospheres is not due to more fruiting sites being produced, but rather a higher level of sites retaining fruit (higher fruit retention %) (Mauney and Hendrix, 1988).

Therefore, we can see that some degree of fruit loss and abortion can be expected, but we would always be interested in what extent should be expected. Knowing the stage of growth (or HUAP) we could then perform a plant mapping on a field of interest and compare its average fruit retention level to the curve in Figure 7 to determine if an excessive amount of fruit loss has occurred. If so, appropriate management responses may be taken such as applying a plant growth regulator, evaluating the N fertility status, or improved pest management. Plant mapping information can also be used with height: node ratios for evaluating a field's possible vegetative tendencies, or lack thereof.

NAWB

The measure of the NAWB is a possible indicator of the stage of development that a crop has achieved (Table 1). These relationships have been developed from field measurements for bloom counts per unit area and NAWB as a function of HUAP. Examples of these relationships are shown in Figures 8-10, where bloom counts/50 ft.² are shown on the left ordinate (y) axis, the NAWB on the right ordinate axis (shown with the dashed line), with both plotted as a function of HUAP. A rather clear and consistent relationship between the flower counts and NAWB can be drawn from these figures as outlined in Table 1. Fortunately, this relationship holds for various variety types (Figures 8-10) and even for Pima when it is emphasized that NAWB

measurements in this case pertain only to first or second fruiting branch positions on mainstem nodes, and not vegetative or lateral branches.

Therefore, a simple way of determining how a crop is progressing over the first fruiting cycle is by measuring the average NAWB, which can be counted quickly and easily. The points in Table 1 then provide a general indication of crop progression towards cut-out.

From Figures 8-10, one can also see that cut-out is approached for all variety types as the $NAWB \leq 5$. However, cut-out will occur later (greater HUAP) for more indeterminate varieties such as DPL 90 (Figure 8a) or Pima S-6 (Figure 10). Cut-out will not occur at a precise HU value, but will usually occur over a range of HUAP (Table 2) as a function of boll load and/or crop stresses encountered. For example, a full season variety with a strong boll load (refer to plant mapping fruit retention levels) should possibly show signs of progressing towards cut-out ($NAWB \approx 5$) near 2500 HUAP. If the plant is carrying a very light boll load, the progression towards cut-out will be delayed.

Summary

Growers in Arizona and the desert southwest face many challenges and obstacles in an effort to maintain adequate return from cotton production systems. The development of a better understanding of crop dynamics, potentials, and limitations is a necessary goal of agronomists and producers alike. Consideration of crop growth and development expected as a function of actual weather conditions (HU) instead of a calendar, may offer some advantages to growers in crop management. This is particularly true in terms of integrating crop management and pest management factors.

The cotton growth and development relationships outlined in this paper offer what are hopefully useful guidelines for evaluating a cotton crop's status over the season. It is the intention of this paper to present a background and description concerning the development of these guidelines, and also to provide the necessary information which can be used as a set of graphic references.

References

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Table 1. Relationships between cotton growth stage and the number of nodes above the top white bloom (NAWB).

<u>Growth Stage</u>	<u>NAWB *</u>
Early Bloom	9 - 11
Peak Bloom	7 - 8
Cut-out	≤ 5

* NAWB, first or second position fruiting sites on mainstem fruiting branches.

Table 2. General cut-out occurrences for cotton variety types commonly grown in Arizona.

<u>Variety Type</u>	<u>HU at Cut-Out *</u>
Short Season	2000-2700
Mid Season	2300-3000
Full Season	2500-3200

* Heat Units (86/55 °F) accumulated since planting.

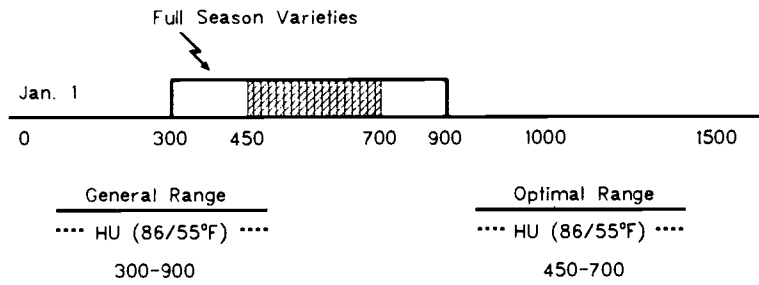


Fig. 1. Optimum planting ranges for full season cotton varieties (Upland and Pima) as a function of heat unit (86/55°F) accumulations since 1 January, for Arizona cotton growing areas.

Planting Date	500	700	900	1000	1200	1500
HU (86/55°F)						

Fig. 2. Early season cotton plant development as a function of heat units (86/55°F).

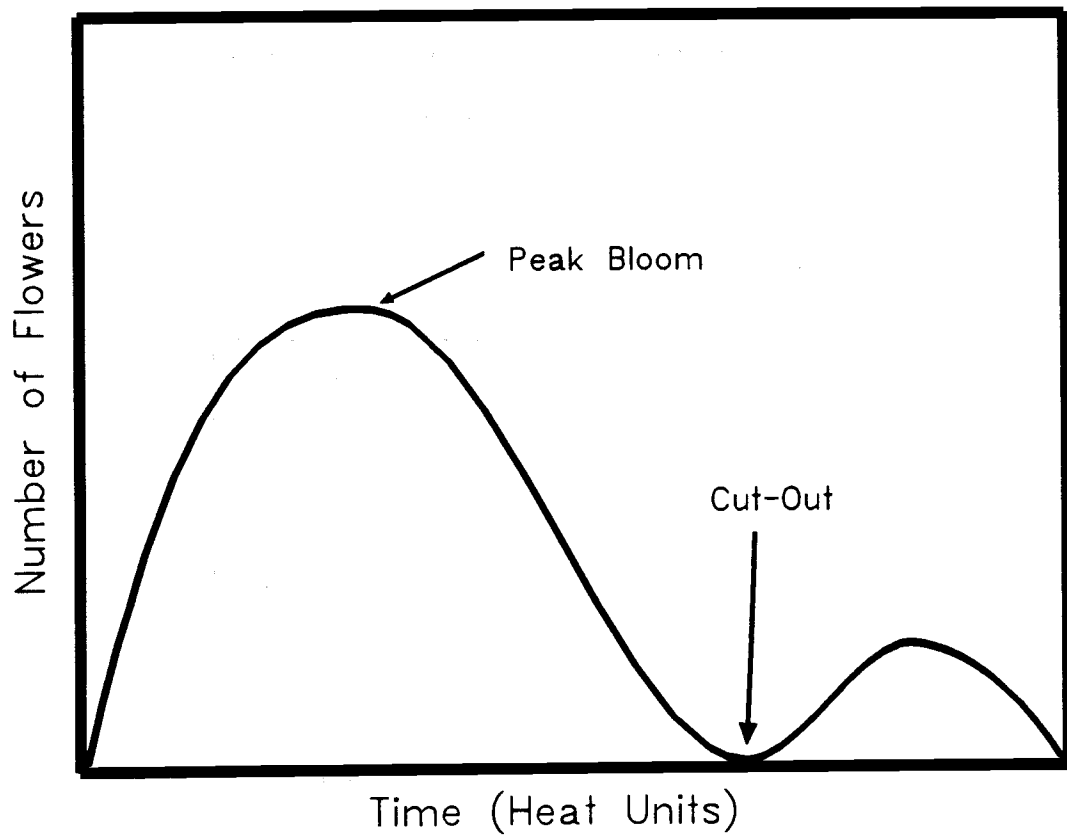
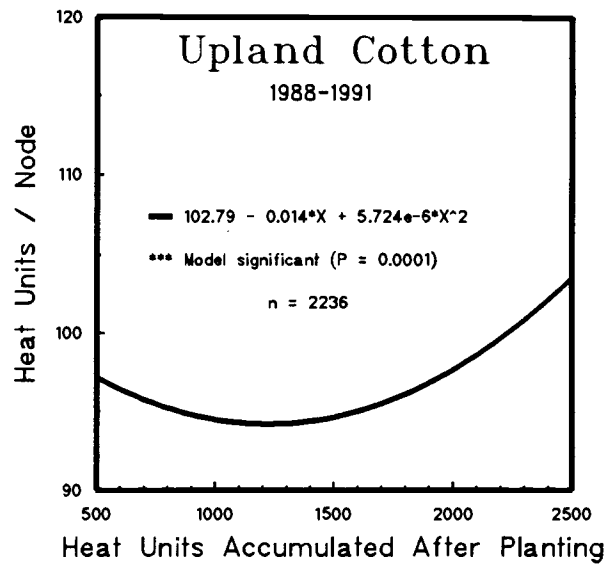


Fig 3. Generalized flower curve for Arizona cotton varieties.

A



B

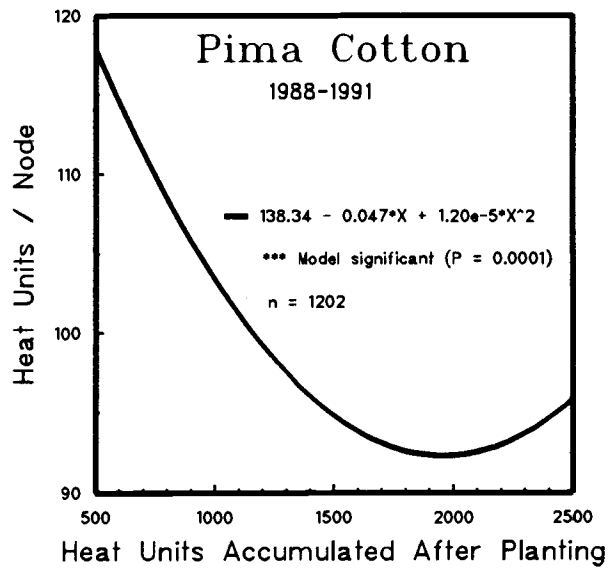
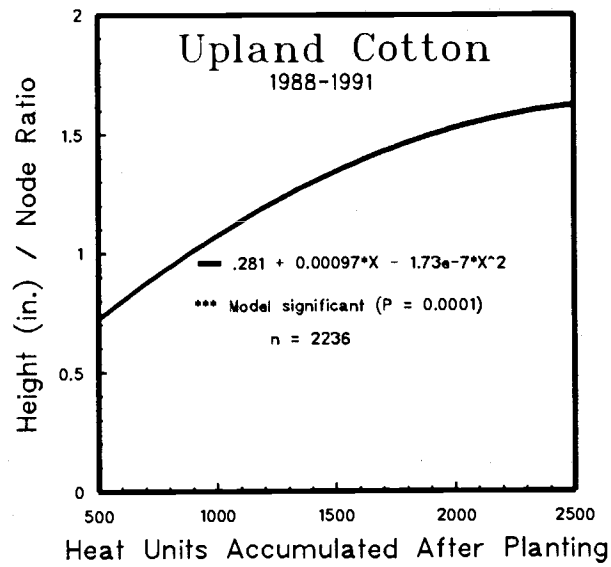


Fig. 4. Heat unit/node as a function of heat units accumulated after planting for A) Upland, and B) Pima cotton.

A



B

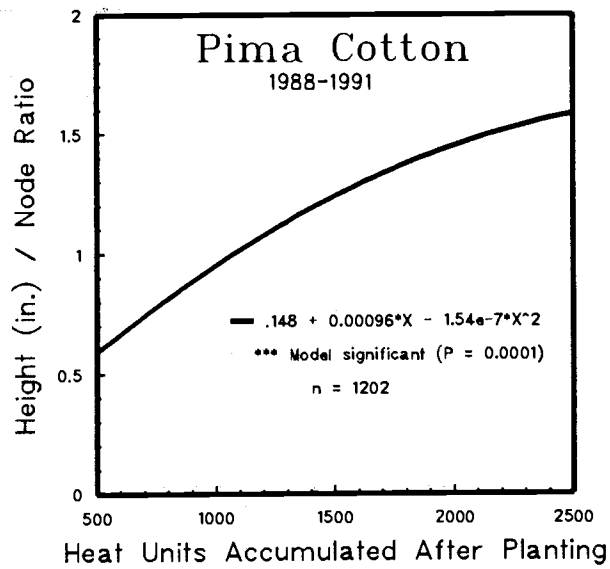
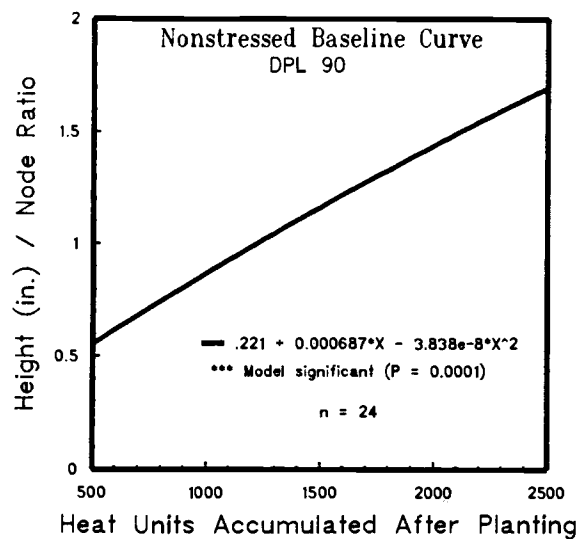
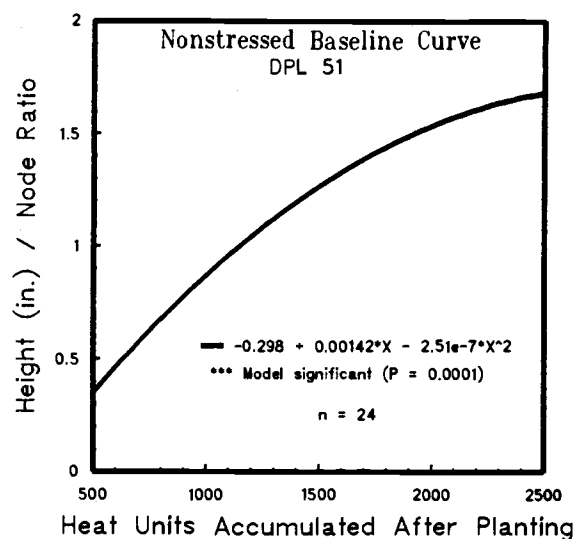


Fig. 5. Height (in.) / node ratio as a function of heat units accumulated after planting for A) Upland, and B) Pima cotton.

A



B



C

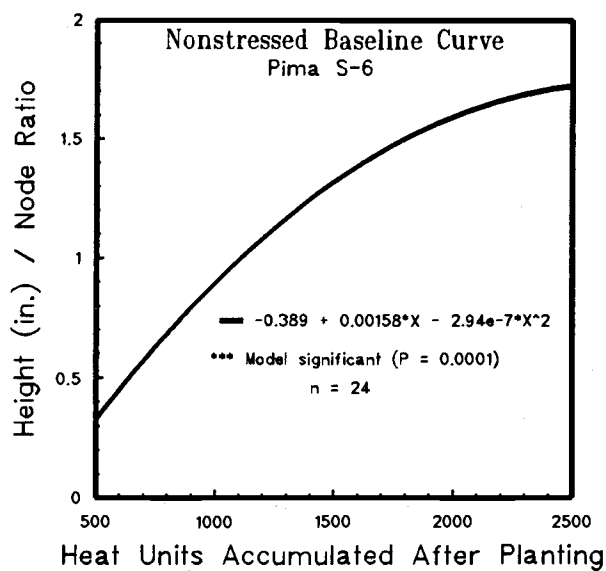


Fig. 6. Height (in.)/node ratio as a function of heat units accumulated after planting for A) DPL 90, B) DPL 51, and C) Pima S-6.

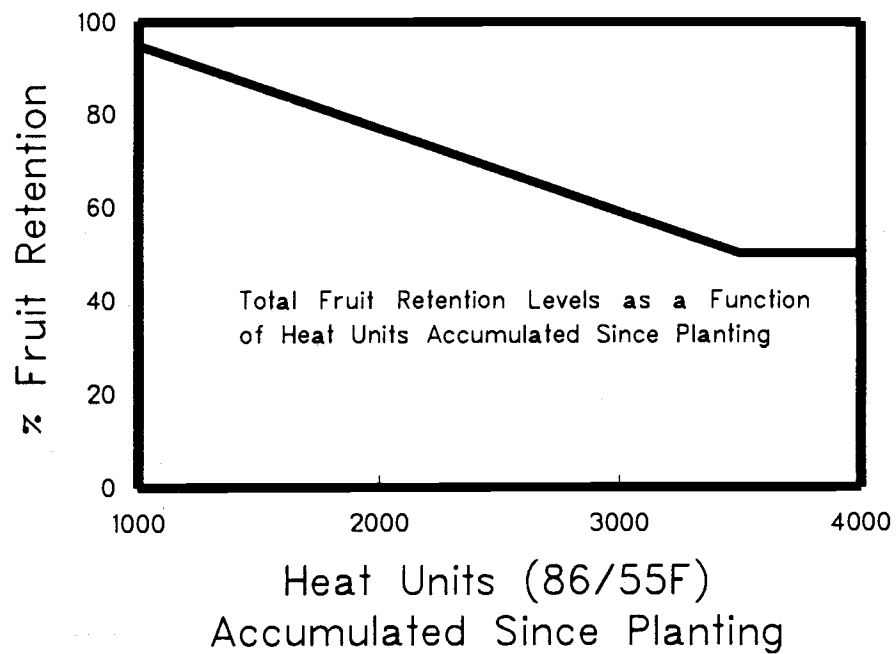
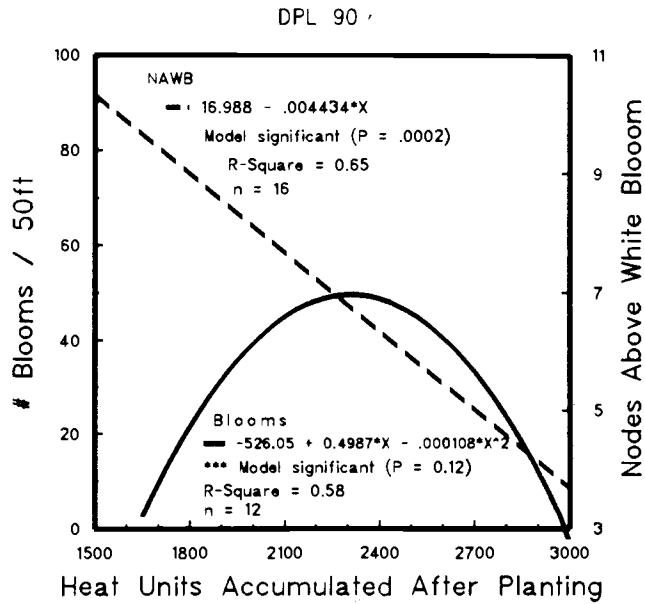


Fig. 7. General total fruit retention levels for Arizona cotton.

A



B

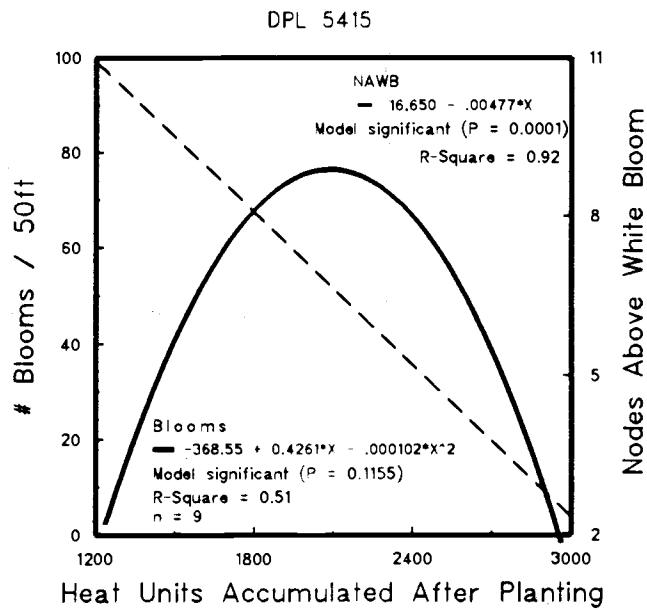
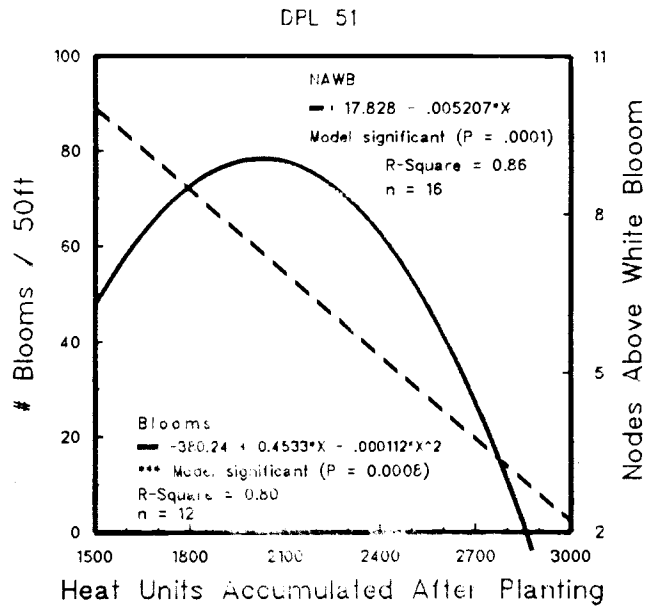


Fig. 8. Blooms/50 ft. and nodes above white bloom as a function of heat units accumulated after planting for A) DPL 90, and B) DPL 5415.

A



B

Variety by 49" Row Spacing (MAC 1991)

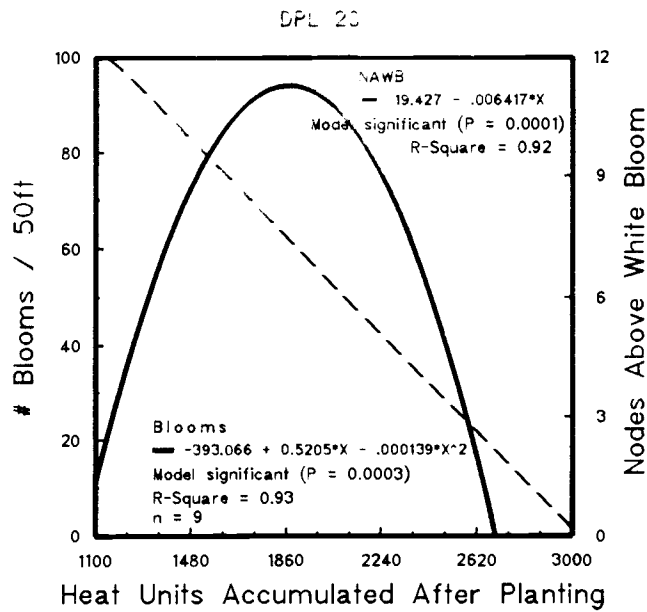


Fig. 9. Blooms/50 ft. and nodes above white bloom as a function of heat units accumulated after planting for A) DPL 51 and B) DPL 20.

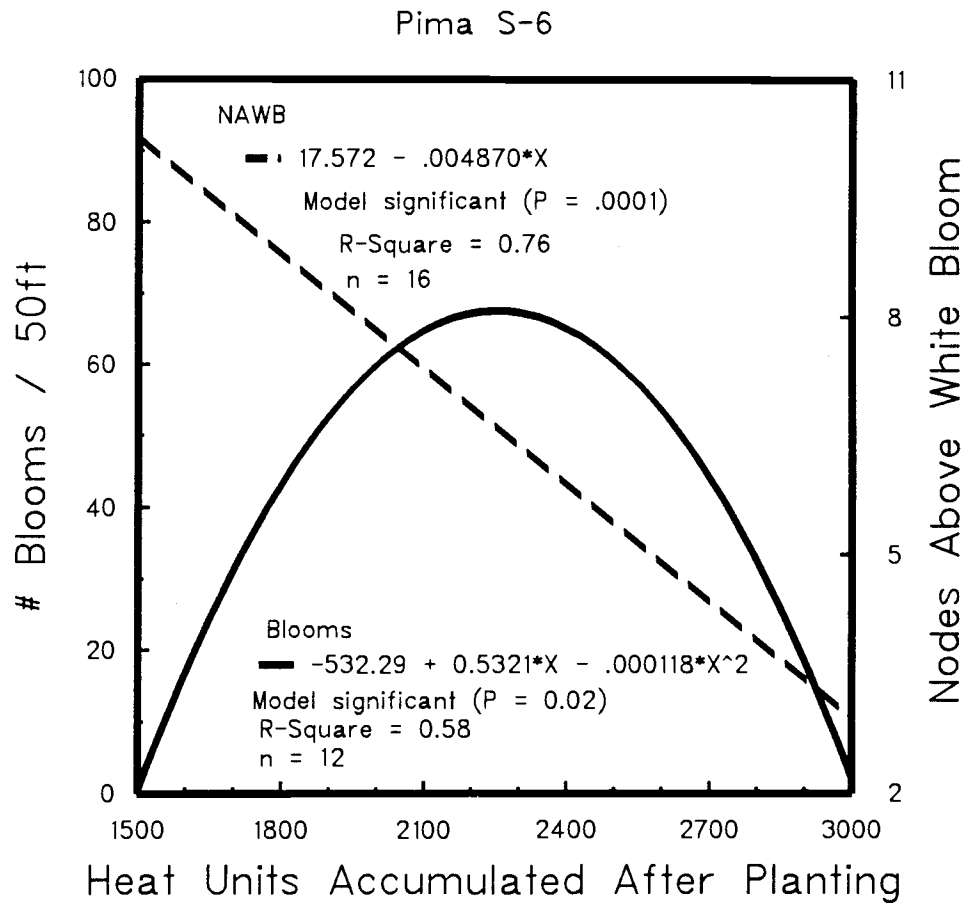


Fig. 10. Blooms/50 ft. and nodes above white bloom as a function of heat units accumulated after planting for Pima S-6.