Cotton Growth and Development Patterns


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. Basic phenological 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 (HUAP). Fruit retention guidelines and height: node ratios, which measure a crop's vegetative/reproductive balance, are developed as a function of HUAP. Similarly, the rate of canopy closure is described in terms 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 crop's 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 Upland and Pima 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 4,000 feet. Most of the Arizona cotton acreage is situated geographically so that a rather long growing season can be employed. 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; Silvertooth et al., 1989; Silvertooth and Terry, 1989; Silvertooth et al., 1990; Silvertooth et al., 1991a, and Silvertooth et al., 1991b). The HU terms most often used in this case were with 86 and 55°F, upper and lower limits, respectively. The purpose of this paper is to outline the phenological description of cotton crop development on a HU basis and update baselines offered in earlier papers (Silvertooth et al., 1992; Silvertooth et al., 1993; and Silvertooth, 1994). Information resulting from the development of these type of growth descriptions can serve as reference points or baselines in the development of management techniques oriented at ultimately improving cotton production efficiency in Arizona and the irrigated southwest.
Methods

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. Approximately 25 sites across southern Arizona have been utilized for sequential sampling each season, for the purpose of developing this database over seven crop seasons (1989 through 1995). Field sites have ranged from the Colorado River Valley on the west, through the extensive cotton producing areas of central Arizona, to the higher elevations of southeastern Arizona. Numerous Upland (G. hirsutum L.) varieties have been used for these measurements. Pima (G. barbadense L.) varieties S-6, and S-7 have been used for pertinent data collection. Care has been taken in removing any cases from this database if water or nutrient stress became limiting to growth, or if pest control was not optimal. 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.

Approximately every 14 days a complete set of plant measurements (plant height, mainstem node numbers, bloom counts per 167 ft.² area, nodes above the top white bloom (NAWB), percent fruit retention, length of the top five nodes, and percent canopy closure) were taken from each plot. Plant maps were also made from each study area. All HU data was obtained from the AZMET system and the weather station in closest proximity to the field location under study.

For the development of descriptive baselines, all data were modeled in accordance to procedures outlined by Steele and Torrie (1980), Neter et al., 1983, and the SAS Institute (1988). Figures describing growth parameters are commonly structured with an average baseline drawn from the best mathematical model (strongest fit) with the upper and lower thresholds being drawn from the 95% confidence intervals for each model.

Results

Early Season Development

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 1, 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 it’s Upland counterparts.

General Flowering Curve

The general flowering curve is commonly used to describe the growth stages for cotton (Figure 2). 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 2, 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 the 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 and Node Production Relationships

Figure 3 describes plant height development in terms of mainstem node number, a very linear process. Figure 4a illustrates the generation of mainstem nodes as a function of HUAP, and Figure 4b outlines the relationship regarding HU/node as a function of HUAP. 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.

Height to Node Ratios (HNR)

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 plants height: mainstem node ratio (HNR) 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 Figures 5 and 6, respectively. The HNR curves for specific varieties or variety types have also been developed. However, only very minor differences exist. Therefore, they have been developed collectively by species (Upland and Pima). A HNR baseline can be used at any point in the season (HUAP) to evaluate vegetative/reproductive balance. 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

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. Figures 7 and 8 represent the general, optimal fruit retention (FR) patterns that can be expected for Upland and Pima cotton. This information was derived from plant mapping measurements using the first two fruiting positions nearest the mainstem, for all fruiting branches. This curve relates the generally optimal level of total FR (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 FR level of approximately 50% (± 5%) 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). We also find that late season FR levels of 40% or less indicate serious losses in yield potential and poor yield prospects.

Although, 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) and estimate of FR compared to average FR levels on the curve in Figures 7 and 8 can be used 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 water and N fertility status, or improved pest management. Plant mapping information can also be used with HNR for evaluating a field's possible vegetative tendencies, or lack thereof.
Nodes Above the top White Bloom (NAWB)

The measure of the NAWB is a possible indicator of the stage of development for a crop (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 9-12, 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, and even for Pima when it is emphasized that NAWB measurements in this case pertain only to first fruiting positions (closest to the mainstem) on true fruiting branches, 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 9-12, one can also see that cut-out is approached for all variety types as the NAWB = 5. However, cut-out will occur later (greater HUAP) for more indeterminate varieties such as DPL 90 or Pima. 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 = 5) near 2500 HUAP. If the plant is carrying a very light boll load, the progression towards cut-out will be delayed.

Length of the Top Five Nodes (LT5)

Due to the fact that the active growth zone for the mainstem exists in the upper portions of the plant, near the terminal, attention has been given to the development of a standard measurement which could focus on this critical region. Since the upper five nodes are commonly those still undergoing rapid elongation, the measurement of the length of these top five nodes (LT5) has been advocated by some as having a strong potential for development into a sensitive vigor index. Theoretically, this measurement can be argued as having some of the greatest potential as a vigor index, particularly since one is most interested in what is happening with recent plant growth, not necessarily what took place weeks ago. Essentially, the LT5 measure is very close to the HNR when plants are small, but the HNR continues to look at all mainstem nodes, while the LT5 focuses on the active growth zone. However, when an index is being developed using only five nodes, an error in counting nodes, by even one node, causes a much greater error in the final measurement and its reference to a standard baseline. Accordingly, standardization of the technique among workers in the field would also be difficult to accomplish. Therefore, the potential of gaining greater sensitivity can be easily lost by simple errors in technique.

A general baseline with upper and lower thresholds for the LT5, based on Arizona data, is shown in Figure 13. Note the strong curvilinear nature of the baseline, indicating that the optimal length of this active growing zone changes dramatically with stage in growth. Therefore, one would need to be careful in referencing stage of growth properly, or know HUAP for a field to use this measurement.

Growth Rate (GR)

The growth rate (GR) measurement considers any recent changes in the elongation rate of mainstem internodes, thus potentially indicating any tendencies toward vegetative growth. By common definition, the GR measurement equals the change in plant height / change in node numbers. Therefore, it requires sequential measurements to determine changes since the last time the field was evaluated (measured and recorded). This technique utilizes the same procedure as the HNR, including all mainstem nodes, but it should reflect a greater degree of sensitivity than an HNR alone since recent changes are determined. Like all other techniques, the GR requires a reliable reference baseline.
Growth rate patterns have not been studied extensively across the cotton belt, and therefore, reference baselines are not abundant. However, methods commonly described for conducting a GR and developing a reference baseline, describe the GR as defined above, plotted against a reference node number, or node number midpoint between the two reference dates of sampling, instead of a HU reference. There usually exists a good relationship between node number and HU accumulation, as long as the plant is not in a stressed condition (Figures 1 and 2). The GR curve, based on the Arizona database is shown in Figure 14. In this case, an approximate conversion to HUAP for the mainstem node number on the x-axis requires a simple multiplication of mainstem node number X 100 = HUAP. It is interesting to note that this curve has a distinct peak near peak bloom (20 nodes or about 2,000 HUAP), very similar to the peak for the LT5 curve.

It is also important to point out that the GR curve for Arizona was based on a model for plant height = f(node number), which was a third order polynomial. Taking the first derivative of this third degree polynomial results in a quadratic function describing the change in plant height per change in node number (GR, growth rate) as a function of node number. The GR curve presented in Figure 14 was developed with the following steps:

(1) \[ \text{PH} = 1.465052 + 0.098620 (\text{NDS})^2 - 0.001467 (\text{NDS})^3 \]

(2) \[ \frac{d\text{PH}}{d\text{NDS}} = 0.19724 (\text{NDS}) - 0.00440 (\text{NDS})^2 \]

where: PH = plant height (inches) and NDS = number of mainstem nodes

**Canopy Closure Rate (CCR)**

The canopy closure rate (CCR) which can also be used as a general indicator of crop vigor, similar to the HNR, is shown in Figure 15, also as a function of HUAP for both Pima and Upland cotton. This model is based on 40 inch row spacings. However, field testing with this model has shown it to be very applicable to 36 and 38 inch row spacings as well. In fact, under non-stressed conditions, CCR for 30 inch row spacings is only a few (three to seven) days earlier than 40 inch spacings. The CCR will vary more as a function of variety, population, and plant vigor than for row spacings (30 to 40 inch), based upon recent field testing. Therefore, it is presented as another possible measure of relative crop vigor.

**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, should offer some advantages to growers in monitoring crop growth and condition for efficient management.

The cotton growth and development relationships outlined in this paper are were developed with the intent of providing useful guidelines for evaluating a cotton crop's status over the season. It is the purpose 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.

**Acknowledgement**

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References


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

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>NAWB *</th>
</tr>
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<tbody>
<tr>
<td>Early Bloom</td>
<td>9 - 11</td>
</tr>
<tr>
<td>Peak Bloom</td>
<td>7 - 8</td>
</tr>
<tr>
<td>Cut-out</td>
<td>≤ 5</td>
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* 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.

<table>
<thead>
<tr>
<th>Variety Type</th>
<th>HU at Cut-Out *</th>
</tr>
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<tbody>
<tr>
<td>Short Season</td>
<td>2000-2700</td>
</tr>
<tr>
<td>Mid Season</td>
<td>2300-3000</td>
</tr>
<tr>
<td>Full Season</td>
<td>2500-3200</td>
</tr>
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* Heat Units (86/55°F) accumulated since planting.
Figure 1. Early season developmental timeline.
Figure 2. Generalized flowering curve for Arizona cotton.
Figure 3. Plant height as a function of mainstem node number.
Figure 4a. Development of mainstem nodes as a function of heat units accumulated after planting.

\[ -3.220 + 0.0161x - 1.952 \times 10^{-6}x^2 \]
Figure 4b. Heat units per node as a function of heat units.
Figure 5. Height to node ratio baseline and 95% confidence intervals for Upland cotton.
Figure 6. Height to node ratio baseline and 95% confidence intervals for Pima cotton.
Figure 7. Fruit retention baseline and 95% confidence intervals for Upland cotton.
Figure 8. Fruit retention baseline and 95% confidence intervals for Pima cotton.
Figure 13. Length of the top five nodes as a function of heat units accumulated since planting (HUAP) with 95% confidence intervals.
Figure 14. Growth rate as a function of mainstem node number.

\[ 0.1972x - 0.0044x^2 \]
Figure 15. Percent canopy closure as a function of heat units accumulated after planting.
Figure 9. Blooms/50ft. and nodes above white bloom as a function of heat units accumulated after planting.
Figure 10. Blooms/50ft. and nodes above white bloom as a function of heat units accumulated after planting.
Figure 11. Blooms/50ft. and nodes above white bloom as a function of heat units accumulated after planting.
Figure 12. Blooms/50ft. and nodes above white bloom as a function of heat units accumulated after planting.