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Texas.

The full manual is available at http://lubbock.tamu.edu/cottondvd/
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Although successful cotton crop production depends on many factors, it is basically the integration of grower management and weather. The key for producers is to develop a workable system or strategy.

In a systems approach, no single cultural practice can be separated from the others. Each practice affects the others, so that problems or successes in one area will influence all other aspects of production.

To formulate a system and produce an economical crop, farmers should be familiar with several key factors of cotton production, including plant development, irrigation options and management of pests, especially diseases, weeds and insects.

**Plant development**

In its native tropical habitat, cotton is a perennial shrub that may live for many years. As a perennial, it is genetically programmed to survive from year to year, not necessarily to reproduce every year. Therefore, by planting and harvesting each year, cotton producers are forcing a perennial plant to perform as an annual.

Cotton plants will limit fruit production unless all their needs for survival are being met. To produce acceptable yields, crop managers must make sure that the cotton plants’ basic needs for nutrients, water, temperature and sunlight are satisfied so that the plants can produce squares (flower buds) and bolls (fertilized fruit).

Producers can determine whether the cotton crop’s needs are being met by monitoring plant development throughout the season. To make good management decisions, producers need to know the stage of development of the cotton plant. This information is vital to those making decisions on irrigation, fertilization, pest management and harvest.

To assess a cotton crop’s development, producers should use several types of measurements – calculating heat units, noting the progression of fruiting, determining the ratio of plant height to internode length, calculating fruit retention and monitoring the nodes above white flower.

**Heat units**

After moisture, the most important factor in the development of squares and bolls is temperature. For a cotton plant to mature, it must accumulate a certain amount of heat energy from the sun. Researchers have devised a way to describe and measure the relationship between cotton development and temperature – the heat unit concept, or DD60 (degree days using 60 degrees F).

Heat units measure the amount of useful heat energy a cotton plant accumulates each day, each month and for the season. The plant must accumulate a specified level of heat units for it to reach each developmental stage and to achieve complete physiological maturity (Table 2.1). From planting to harvest, cotton plants need a total of about 2,600 heat units to develop to full maturity.

Several systems have been developed to calculate heat units, but the most universal approach is to use the formula:

\[
\text{(Degrees F Maximum + Degrees F Minimum)}/2 - 60
\]

Example: If the high temperature (degrees F Maximum) on a given day is 90 degrees F and the low temperature (degrees F Minimum) is 75 degrees F, then for that day, the plant will accumulate 22.5 DD60s. The calculation:

\[
(90 \text{ degrees F} + 75 \text{ degrees F})/2 - 60 = 22.5 \text{ DD60s}
\]

Cotton plants will not develop if the temperature is too low. The lowest temperature at which cotton will continue to develop (also known as
the base temperature) is considered to be 60 degrees F. Temperatures lower than 60 degrees F will not reduce heat unit accumulations in the plant (unless the temperatures actually kill the plant), nor will they subtract from the plant’s physiological maturity. For calculation purposes, the upper temperature limit should be 95 degrees F.

Node development

Node development is a reliable indicator of plant maturity. Before bloom, node development depends primarily on temperature.

One way to estimate the number of DD60s a plant has accumulated is to count its nodes. A node is the site where a new true leaf arises from the main stem. A cotton plant develops a new node every 50 to 60 DD60s, whether the heat unit accumulation occurs in 2 days or 10 days.

To determine how many DD60s a plant has amassed, count the number of nodes along the main stem and multiply that number by 50 or 60.

Fruiting

Another way to determine a cotton plant’s development is to check the progression of fruiting on its branches. Flowers appear up the main stalk and along each fruiting branch at set intervals.

On adjacent branches, first-position flowers appear about every 3 days (at 50 to 60 DD60s). This is termed the vertical fruiting interval (VFI).

On a single branch, the flowers (first, second, third positions) appear 6 days apart (100 DD60s). This is called the horizontal fruiting interval (HFI).

Therefore, bolls set on the same fruiting branch are 6 days apart in age, while bolls set at similar positions on succeeding fruiting branch are 3 days apart in age.

Plant size

Two other indicators of crop development are plant height and internode length. Plant height reflects general growth conditions. The height can be affected by many factors, including early-season temperatures, wind, cotton variety, water, fertility, plant type, row spacing and plant density.

Internode length is also important. An internode is the part of the stem between two nodes. Because internodes are very sensitive to environmental conditions and plant health, their length is a very reliable indicator of growth conditions.

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Number of Days (range)</th>
<th>Heat Units (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting to seedling emergence</td>
<td>4-9</td>
<td>50-60</td>
</tr>
<tr>
<td>Emergence to first square</td>
<td>27-38</td>
<td>425-475</td>
</tr>
<tr>
<td>Square to white flower2</td>
<td>0-25</td>
<td>300-350</td>
</tr>
<tr>
<td>Planting to first flower</td>
<td>60-70</td>
<td>775-850</td>
</tr>
<tr>
<td>White flower to open boll</td>
<td>45-66</td>
<td>850</td>
</tr>
<tr>
<td>Planting to cutout</td>
<td>80-100</td>
<td>1,000-1,600</td>
</tr>
<tr>
<td>Planting to harvest</td>
<td>130-170</td>
<td>2,600</td>
</tr>
<tr>
<td>Between nodes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Up the main stem</td>
<td>2-34</td>
<td>0-60</td>
</tr>
<tr>
<td>Out the branch</td>
<td>5-7</td>
<td>80-120</td>
</tr>
</tbody>
</table>
A long internode (3 to 5 inches) indicates favorable growth and good potential for rank (excessive growth) plants to develop. A shorter internode (0.5 to 1 inch) tells us the plant was stressed while that node was developing, perhaps by a shortage of water or insects attacking the plant.

Using plant height and internode length, you can calculate the height-to-node ratio (HNR), which reflects the sum total of a particular plant’s experience – the availability of water, nutrients, heat, sunlight, etc.

A plant’s height is measured from its cotyledons (seedling leaves) to the terminal. Calculate the node number by counting the number of main stem nodes or true leaves. The uppermost node to count is the one with an unfurled leaf at least 1 inch in diameter (the size of a quarter).

To calculate the HNR, divide the height of the plant by the number of nodes. According to this formula, a plant 20 inches tall with 15 nodes would have a HNR of 1.33:

\[
\frac{20 \text{ inches}}{15 \text{ nodes}} = 1.33
\]

Height-to-node ratios should range from 1.3 to 2.0, especially during the bloom period.

This ratio will change as the season progresses. After emergence, the leaf area is small and temperatures are generally cooler. This limits both the development of nodes and the length of the internodes.

However, after bloom, the space between internodes should shorten as developing bolls progressively demand more of the plant’s carbohydrates and nutrients. At this point, the plant should be using its energy to develop bolls, not to produce excessive vegetative growth. If internode length increases after bloom, then the plant resources are not being fully used for boll development.

If the HNR increases above 2.0 after flowering starts, inspect the fields promptly to see if the cause is insect damage. If insects are not the problem, managers may need to reduce growth by applying plant growth regulators containing mepiquat chloride (Pix®, Pix Plus®, etc.).

**Fruit retention**

Once the plants start fruiting (setting flower buds), growers should start monitoring fruit retention (the percentage of fruit [squares] remaining on the plant) up to the appearance of the first bloom.

Divide the number of fruit by the number of fruiting sites. The number of fruiting sites should be equal to or greater than the number of fruit (squares and bolls).

For example, if you counted 10 plants and found 12 squares and 20 fruiting sites, the fruit retention would be 60 percent:

\[
\left( \frac{12 \text{ squares}}{20 \text{ fruiting sites}} \right) \times 100 = 60\% 
\]

**Nodes above white flower**

After flowering begins, you should start monitoring the number of nodes above white flower (NAWF). Find the white bloom at the highest first position (fruiting site closest to the main stem) on a plant and count the nodes above that bloom.

The NAWF number will give you an idea of how healthy the crop is and whether you need to irrigate or apply fertilizer to extend the boll-setting period.

**Interpreting crop information**

A number of computer models (GOSSYM, TEXCIM, PMAP, CALEX/Cotton, ICEMM, MEPRT, CROPMAN, etc.) have been developed to manage the information gathered during crop monitoring. Growers should evaluate these models based on the ease of use and information provided.

One of the most popular and widely evaluated crop models is COTMAN, which is being refined by the University of Arkansas and Cotton
Incorporated. COTMAN can help determine when to stop applying late-season insecticides and initiating harvest aids. COTMAN is available from Cotton Incorporated.

Another new technique for monitoring crop development is the combination of global positioning and remote sensing.

The most common type of remote sensing used in Texas is infrared photography, in which fields are photographed by satellite on different dates. Producers can compare the photos and note color changes in the fields from one date to the next. The color differences can indicate a change in the health of the crop.

To pinpoint exactly where crop health has been compromised (where the colors differ from one date to another), producers can use global positioning technology, which indicates the exact longitude and latitude of the areas in question.

This technology has helped farmers locate perennial weed infestations, nematode infestations and plant diseases in their crops.

Irrigation

Irrigation is another valuable cotton management tool that varies across the state. The irrigation systems used in Texas include furrow, sprinkler and subsurface drip irrigation systems.

**Furrow irrigation** is popular in areas where fields are level and which have predominantly clay loam soil textures and abundant supplies of relatively inexpensive water. These comparatively simple systems discharge water into an open earthen ditch with siphon tubes that apply water to the field from the ditch.

Producers have modified these systems by lining the ditches with concrete or plastic to limit water losses. They have also begun replacing the siphon tubes with gated pipe, and the more advanced systems have surge valves.

**Sprinkler systems** have been developed for land that is poorly suited to furrow irrigation. Most of them are now mobile, and the most common is the center pivot. These systems are being modified to improve water use efficiency.

Of the current sprinkler irrigation technologies, the low energy precision application (LEPA) system is considered the best to use in Texas. Instead of broadcasting water over the crop, this type of system delivers it directly to the ground via a drop hose with a nozzle or sock attached.

**Subsurface drip irrigation** is the newest development in irrigation technology in Texas. The main disadvantages of this technology are its high initial capital costs and inability to move water up to the surface of soils that have an appreciable sand content (sandy loams to loamy sands).

Producers are using this technology where water is limited and/or expensive to apply.

Because of limited water resources, producers have been forced to shift from furrow to other, more efficient irrigation methods (Table 2.2). These more efficient irrigation systems have

<table>
<thead>
<tr>
<th>System</th>
<th>Overall Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>0.50-0.80</td>
</tr>
<tr>
<td>Average</td>
<td>0.50</td>
</tr>
<tr>
<td>Land leveling and delivery pipeline</td>
<td>0.70</td>
</tr>
<tr>
<td>Tail water recovery combined with above</td>
<td>0.80</td>
</tr>
<tr>
<td>Surge valves</td>
<td>0.60-0.90&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>0.55-0.73&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Center pivot</td>
<td>0.55-0.90&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>LEPA</td>
<td>0.90-0.95</td>
</tr>
<tr>
<td>Drip</td>
<td>0.80-0.90&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

1. Surge has been found to increase efficiency 8 to 28 percent over non-surge furrow irrigation
2. Under low wind conditions
3. Drip systems are typically designed at 90 percent efficiency. Short laterals (less than 100 feet) or systems with pressure compensating emitters may have higher efficiencies.
enabled crop managers to reduce production costs as well as stretch their water resources.

Irrigation efficiencies can be increased with proper scheduling. Crop managers should know how much water the crop is using in order to supply adequate water for good growth.

Water is lost both by evaporation and by transpiration (the loss of water through plant tissues, primarily leaves). The combined water loss from these two processes is called evapotranspiration. For cotton, the standard method to estimate losses by evapotranspiration is to use potential evaporation (PET). PET depends on climate and varies from location to location. PET calculations are available from [http://texaset.tamu.edu](http://texaset.tamu.edu).

The water requirements of specific crops are calculated as a percentage of the PET. To determine how much water your crop needs, multiply the PET in your area at that time by the crop coefficient (Kc). Crop coefficients differ by crop and according to the various stages of plant development.

Crop coefficients for cotton in the Texas Northern High Plains are shown in Table 2.3. These values should be adequate for other production regions in Texas. However, crop managers in each production region should check them against their local conditions.

For example, if the 5-day PET is 1.5 inches and cotton is at peak bloom, the crop coefficient is 1.10 (Table 2.3).

$$1.5 \text{ inches} \times 1.10 = 1.65 \text{ inches}$$

The water requirement for this crop is 1.65 inches; that is, 1.65 inches of water needs to be applied to replace the water used by cotton in the previous 5 days.

When using PET, be sure to monitor soil moisture using gypsum blocks, watermark sensor tensiometer, the “feel” method or other devices for measuring the current water status in the root zone.

You may need to increase the amount of irrigation water in order to compensate for the efficiency rate of your irrigation system. To adjust for irrigation efficiency, use this equation:

$$\text{PET} \times Kc/\text{Efficiency} = \text{irrigation water requirements}$$

Using the above example, if 1.65 inches is needed by the crop and the irrigation system is a sprinkler system (Table 2.2), then the calculation would be

$$(1.5 \times 1.10)/0.73 = 2.26 \text{ inches}$$

The total water needed would be 2.26 inches. You would apply 2.26 inches of water to the crop if you wanted to replace 100 percent of the water lost to evapotranspiration.

### Pest management

Pest management is a system or strategy to control diseases, weeds and insect and mite pests. Many tools are available to use against cotton pests. To devise a pest management system, growers should use a combination of pest suppression techniques that are the most compatible and ecologically sound.

The pest management concept depends on the assumption that pests will be present to some degree in a production system and that at some levels, these pests may not lower production significantly. The level at which the pests begin

---

**Table 2.3. Cotton crop coefficients (Kc) for the Texas North High Plains.**

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Kc</th>
<th>Days after Planting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedling</td>
<td>0.07</td>
<td>0-10</td>
</tr>
<tr>
<td>First square</td>
<td>0.22</td>
<td>27-38</td>
</tr>
<tr>
<td>First bloom</td>
<td>0.44</td>
<td>60-70</td>
</tr>
<tr>
<td>Peak bloom</td>
<td>1.10</td>
<td>70-90</td>
</tr>
<tr>
<td>First open boll</td>
<td>1.10</td>
<td>105-115</td>
</tr>
<tr>
<td>25% open bolls</td>
<td>0.83</td>
<td>115-125</td>
</tr>
<tr>
<td>50% open bolls</td>
<td>0.44</td>
<td>135-145</td>
</tr>
<tr>
<td>95% open bolls</td>
<td>0.44</td>
<td>140-150</td>
</tr>
<tr>
<td>Harvest</td>
<td>0.10</td>
<td>140-150</td>
</tr>
</tbody>
</table>
Decisions made in the off-season are vital to cotton production. During this period, growers must make decisions on stalk destruction, tillage practices, fertility, crop rotation, variety selection and pest management.

**Stalk destruction**

The cotton plant can continue to grow even after harvest aid applications. Regrowth occurs when heat, soil moisture and nutrients are in excess of the developing fruit’s demands for carbohydrates.

Because of the potential for regrowth, stalk destruction is an important component of cotton production in Texas. After harvest, stalks must be destroyed to prevent the development of regrowth and fruiting structures (flower buds) for insects to feed upon.

Stalk destruction is more important in the south and eastern parts of the state, where higher rainfall and warmer temperatures occur. In West and North Texas, freezing temperatures often kill the stalk before new fruit is produced.

When field conditions and weather are favorable for tillage, stalks can be shredded and then disked or plowed to destroy the plant. Stubble stalk pullers can also be used to uproot stalks.

Although these mechanical methods are highly successful, many growers are implementing reduced tillage systems to conserve soil moisture and surface residues. Consequently, these producers are using chemicals to terminate plant regrowth. Two methods are being developed for chemical stalk destruction.

Several herbicides are approved for cotton stalk destruction and produce favorable results. Growers must consider these factors when using chemicals to destroy stalks:

- Good spray coverage is essential. You must use the proper spray volume and nozzle orientation over the row.
- The plants must have adequate regrowth so there is enough surface area to absorb the herbicide. This minimal surface area can range from 2 to 8 inches of new stem growth, which can occur within 2 to 3 weeks after stalk shredding.

Shred the cotton crop to a 4- to 8-inch height above the soil surface to allow uniform regrowth. The maximum regrowth allowable is 8 inches from the base of the stubble to the attachment of the last leaf present. At this point, new leaves should be big enough to receive treatment but not so big that they develop fruiting forms that could host boll weevils.

Recent research in the Rio Grande Valley indicates that if the bark is roughened at harvest, the percentage of dead plants increases after treatment with 2, 4-D. The 2, 4-D applications should be made as soon as possible after harvest.

- Apply the chemicals only when environmental conditions are favorable. Conditions should encourage rapid growth so that the cotton plants are more susceptible to treatment. Conditions should also be favorable to discourage off-target spray drift.
- The product must not cause problems with successive crops in a crop rotation system. Although many approved chemicals have relatively short soil residuals, others may last for months. This is especially true if the soil stays cool and dry after the herbicide application.
- Because pesticide application is regulated in certain counties, you may need to obtain a permit from the Texas Department of
Agriculture before applying 2,4-D or dicamba to a field during harvest.

The Texas Department of Agriculture currently approves only 2,4-D (Barrage®, Salvo® and Savage®) dicamba (Banvel®, Clarity® and Weedmaster®) and Harmony® Extra for cotton chemical stalk destruction. This was the approved list in 2001 and may change in the future. Producers should be sure to have the most current labels before applying any pesticide.

Tillage practices

Three types of tillage systems are used in Texas: conventional, reduced and conservation. Each system offers advantages and disadvantages. The best system for a particular site depends on soil type, environmental conditions, weed pressure and availability of specialized equipment.

In conventional tillage systems, stalks are usually shredded and then plowed under. In the southern production regions, bolls and squares that are shredded should remain on the ground for 2 to 3 days to dry out. Daytime heating will desiccate (dry out) squares, limiting the survival of developing boll weevils, especially the early instars (immature stages).

The advantages of conventional (clean) tillage systems are that they:

- Provide for good seedbed conditions and allow the use of mechanical tillage to help control weeds.
- Help with disease and insect management at post harvest.
- Destroy food sources and reproduction sites for microorganisms responsible for cotton diseases as the residue is incorporated and decomposed.
- Reduce populations of tobacco budworm, bollworm and pink bollworm. These insects overwinter as pupae (the stage between larva and adult) underground. Disturbing the soil can reduce winter survival and insect emergence in the spring.

A disadvantage of conventional tillage systems is that the residue may encourage the growth of the seedling pathogen *Rhizoctonia solani*. This pathogen is a strong saprophytic (dead plants) colonizer of crop debris, so that in some environments, the presence of cotton crop residue could increase seedling disease in later crops.

Even though conventional tillage approaches have been used for years, economic conditions are causing many producers to shift to reduced tillage systems. Reduced tillage systems allow producers to farm large acreage while minimizing equipment and labor costs. Reduced tillage in this book refers to making fewer trips with tillage tools (moldboard plows, chisel plows, cultivators, etc.) than in a conventional system.

The benefits of reduced tillage systems include protection of the soil from wind and water erosion, reduced fuel and labor inputs, fewer equipment requirements and increased soil moisture retention.

On the other hand, reduced tillage systems may increase the risk of seedling disease in fields where residues do not decompose. Growers can minimize this risk by applying in-furrow granular or liquid fungicides to supplement fungicide treatment on seed.

Conservation tillage is similar to reduced tillage, but the goal is to have 30 percent or more of the field surface covered with crop residue.

One conservation tillage approach used in many irrigated farms in the High Plains is called the terminated small grain system. Rye or wheat is drilled into prepared seedbeds after cotton harvest, and the small grain is terminated with herbicide 2 to 4 weeks before planting the cotton. The standing small grain stubble reduces wind and water erosion and protects the young cotton from wind and sandblasting.

Fertility

A strong cotton fertility program provides the foundation for high yields and good fiber quality. Without adequate nutrients, plant performance will suffer.
Compared to many other crops, cotton has a lower nutrient demand, which generally results in lower annual fertilizer expenditures. Relatively small amounts of nutrients are removed from the field at harvest. However, during the reproductive stages of development, proper fertility is extremely important. Once cotton begins fruiting, nutrient needs increase dramatically.

The primary goal of a cotton fertility program should be to achieve optimum fertilizer use efficiency (FUE), which is the conversion of applied nutrients into harvestable yield.

The first step in attaining a high FUE is to determine what nutrients the plants need to achieve the production level desired. The key to nutrient management and a high FUE is soil testing.

A soil test is an estimate of the nutrient-supplying power of a soil. The test identifies the degree of deficiency or sufficiency of a given nutrient. Although soil testing is not an exact science, it is the best tool available for determining the proper amounts of nutrients necessary to attain a given yield.

However, the information and recommendations provided by any laboratory are only as good as the samples collected. Consequently, good sampling techniques are critical.

The best method for taking soil samples is to collect soil from 12 to 15 locations in each field, mix them together thoroughly and ship the mixture immediately to a soil-testing laboratory.

In conventional tillage systems, collect a standard 0- to 6-inch soil sample. However, in reduced and no-tillage fields, some plant nutrients can become stratified (accumulate in the upper 1 to 3 inches of soil).

For instance, phosphorus (P) is highly subject to stratification in these systems because:

- P is a very immobile, especially in clay soils.
- Reduced tillage limits soil mixing and nutrient incorporation.

Fertilizer is often applied at or near the surface.

Crop residues and the nutrients they contain (which have been mined from throughout the rooting zone) are placed on the surface rather than incorporated back into the soil.

Conventional soil sampling techniques (0- to 6-inch depth) do not account for stratification. They may indicate that enough P is available for production, when in fact it may be located in a position in the soil that makes it inaccessible to the plant.

Consequently, to determine if the nutrients have become stratified, take two soil samples. Collect one sample from the 0- to 3-inch depth and another from the 3- to 9-inch zone. Test the soil layers every 3 to 5 years to track nutrient placement in the field.

Growers can eliminate stratification by deep tillage operations and subsurface banding of fertilizer.

The primary nutrients of interest in cotton production are nitrogen (N), P and potassium (K). Secondary nutrients include calcium, magnesium, sulfur and the micronutrients iron, zinc, manganese and copper.

The production of one bale of cotton removes about 50 pounds N, 40 pounds P, 30 pounds K, 2 pounds calcium, 4 pounds magnesium and 3 pounds of sulfur (Table 3.1). Only very small amounts of the micronutrients are required.

Nitrogen is, by far, the most important nutrient for cotton production. If the soil lacks nitrogen, the crop may suffer reduced growth and development, early cutout, lower fruit retention, reduced root health and limited water and nutrient uptake.

Excess N also causes problems, such as delayed maturity, excessive growth, reduced boll retention, greater incidence of boll rot, higher pest insect populations and reduced fiber quality.

When calculating the amount of nitrogen to apply to a field, base your estimates on realistic yield goals. Test the soil every year, and collect
deep samples (0 to 12 inches and/or 12 to 24 inches) when possible to account for N that has accumulated deeper in the soil profile.

Although the deep-sampling approach is uncommon, recent research indicates that N can accumulate with depth. Crediting this N to the total for the field could reduce overall N fertilization needs.

Apply nitrogen fertilizer in a tandem approach by applying 20 to 30 percent of the total N required at preplant and the rest side-dressed at squaring. If the crop is irrigated, you can apply N through the pivot.

In addition to commercial fertilizer, producers can use manures, municipal sludges and other organic amendments to supply nutrients for crop production (Table 3.2).

Along with nutrients, these manures supply valuable organic matter that helps improve soil structure, tilth and workability, as well as water- and nutrient-holding capacities. Manures also increase the activity of beneficial soil microbes (microorganisms).

### Table 3.1. Typical nutrient content of a bale of cotton.

<table>
<thead>
<tr>
<th></th>
<th>Above-Ground Plant (leaves, stems, fruit)</th>
<th>Seed Cotton</th>
<th>Lint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pounds per Bale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>2,100</td>
<td>700</td>
<td>250</td>
</tr>
<tr>
<td>Carbon</td>
<td>1,650</td>
<td>550</td>
<td>190</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>360</td>
<td>120</td>
<td>35</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>62</td>
<td>35-40</td>
<td>1</td>
</tr>
<tr>
<td>Potash (K₂O)</td>
<td>61</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Phosphate (P₂O₅)</td>
<td>22</td>
<td>13-20</td>
<td>0.3</td>
</tr>
<tr>
<td>Calcium</td>
<td>27-62</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Magnesium</td>
<td>11-27</td>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>Sulfur</td>
<td>8-16</td>
<td>1-2</td>
<td>trace</td>
</tr>
</tbody>
</table>


### Table 3.2. Average nutrient values for manure at the time of land application

<table>
<thead>
<tr>
<th>Source</th>
<th>Dry Matter</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Pounds per Ton</td>
<td>Pounds per Ton</td>
<td>Pounds per Ton</td>
</tr>
<tr>
<td>Cow (fresh)</td>
<td>25</td>
<td>15</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Beef (feedlot)</td>
<td>65</td>
<td>27</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>Dairy (corrals)</td>
<td>65</td>
<td>28</td>
<td>11</td>
<td>26</td>
</tr>
<tr>
<td>Dairy (stockpile)</td>
<td>80</td>
<td>28</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>Broiler (litter)</td>
<td>65</td>
<td>58</td>
<td>51</td>
<td>40</td>
</tr>
<tr>
<td>Layer</td>
<td>35</td>
<td>30</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Swine</td>
<td>18</td>
<td>10</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

Cotton plants grow in an orderly manner, producing new nodes, internodes, leaves and squares from meristems (growing points) over the course of the season. The plant growth stage of cotton from emergence to first bloom requires 7 to 9 weeks.

The growth rate of cotton vegetation follows an S-shaped curve pattern (Figure 5.1). Recently emerged seedlings grow slowly until the squares (flower buds) reach the match-head stage (3/16 inch in diameter). Then the growth speeds up substantially.

During this period, growers need to continue monitoring plant development; control insects, weeds and diseases; and make decisions on the use of water, fertilizers and plant growth regulators.

![Vegetative Growth Curve](image)

**Figure 5.1. Vegetative growth curve for cotton.**

**Plant development**

Cotton plants grow slowly at emergence (the lag phase) because of the plants’ limited leaf area, cooler temperatures early in the season and pests.

The first leaves that emerge are the cotyledon or seed leaves, the only leaves on the plant that grow directly opposite each other. Cotyledon leaves are primarily storage tissues; they have minimal ability to produce photosynthates (food).

If both cotyledons are lost within the first week after emergence, plant maturity will be delayed because the leaves do not have time to transfer their stored nutrients to other plant parts. After the cotyledons emerge, the plant develops main-stem or true leaves. Later in the season, subtending leaves develop on fruiting branches, which are critical to boll set and boll fill.

Through the process of photosynthesis, leaves produce carbohydrates that the plant uses to survive, grow and produce fruit. A leaf’s ability to produce carbohydrates is closely related to its age. Leaves that are 16 to 25 days old are prime producers and exporters of carbohydrates to other parts of the plant. After this age, they become less able to supply photosynthates. A 60-day-old leaf is unable to supply food reserves for developing fruit.

During the early stages of plant development, the roots grow faster than the plant parts above-ground. A young taproot may extend 6 inches into the soil by the time the first true leaf is visible. Soon after the first true leaf appears, the roots begin developing an extensive lateral system.

Roots grow where moisture, oxygen and temperature are optimum. As these three factors decline, root growth slows and, as a consequence, the plant takes up less water and nutrients.

To provide more oxygen to the roots, producers using conventional tillage systems (clean tillage) can aerate the soil with shallow cultivation. This can break up any crusting that has developed and speed surface drying. Because drier soils are usually warmer, aeration can also warm the soil.

Minimum or conservation tillage systems do not offer this option, but the surface residue left by these systems usually minimizes soil crust formation. Root channels and increased organic matter in minimum tillage systems also promote better soil aeration.
Plant development

Growers must begin monitoring the crop early and continue throughout the growing season until harvest. Before bloom, plant development depends primarily on temperature.

**Node development:** A new node, which is the point along the main stem at which a vegetative or fruiting branch arises, develops every 50 DD60s. Early in the season, a cotton plant can accumulate 50 DD60s in 3 to 10 days, depending on the temperature.

Through early bloom, the number of nodes on a plant is a good indicator of its age. Node development is not affected by environmental stresses at this stage, making it a valuable index to the plant’s development.

At the base of each node are two buds designated the first and second axillary buds. At the first five to seven nodes, the first axillary buds are vegetative (producing leaves and stems). The cotton plant will establish a root system and an adequate vegetative structure before it starts fruiting.

The plant usually starts to flower at the seventh node. At that time, the first axillary bud starts to produce fruit. The second axillary bud remains dormant. Fruit initiation (development of the first flower buds) can be delayed by cool temperatures, high plant populations and high pest densities. Plants very rarely revert to producing vegetative branches after a plant starts to produce fruiting branches. Hormones (plant chemicals) prevent other vegetative meristems from growing below nodes six or seven.

If insects or hail damages the plant terminal, one or more of the lower vegetative meristems will begin growing to produce new main stems. This is how plants damaged early in the season recover to produce a crop, even though it will mature late. Table 5.1 shows a time line of square progression to open flower.

Unlike nodes, the internode (the portion of stem between the nodes) is very sensitive to environmental and plant conditions, making the length of the internodes a reliable indicator of plant growth. A long internode (more than 3 inches) indicates favorable growth conditions and

<table>
<thead>
<tr>
<th>Days Before Bloom</th>
<th>Bud Height (25 mm=1 inch)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>Microscopic</td>
<td>Square initiation can occur, as early as the 2nd true leaf expansion. Hot, spring weather induces 4-bract squares. Cool or very hot weather delays square initiation.</td>
</tr>
<tr>
<td>32</td>
<td>Microscopic</td>
<td>Lock number determined, carbohydrate stress decreases number of locks from 5 to 4.</td>
</tr>
<tr>
<td>23</td>
<td>2 mm, Pinhead</td>
<td>Ovule number determined, carbohydrate stress decreases potential seed number</td>
</tr>
<tr>
<td>22</td>
<td>2 mm, Pinhead</td>
<td>Pollen cells divide</td>
</tr>
<tr>
<td>19</td>
<td>3 mm, Matchhead</td>
<td>Pollen viability reduced by night temperatures &gt; 80 °F</td>
</tr>
<tr>
<td>5</td>
<td>13 mm</td>
<td>Square starts to expand rapidly</td>
</tr>
<tr>
<td>3</td>
<td>17 mm</td>
<td>Fibers begin to form</td>
</tr>
<tr>
<td>0</td>
<td>Flower opens</td>
<td>Pollen sheds and fibers start to elongate. Extremes of humidity or water disrupt pollen function.</td>
</tr>
<tr>
<td>+1</td>
<td>Fertilization of ovule</td>
<td>Ovule now called seed</td>
</tr>
</tbody>
</table>
the potential for excessive growth. A short internode (less than 1.5 inches) shows that the plant was stressed when that internode was developing.

Cells in a developing internode stop elongating between the fourth and fifth node from the terminal (the dominant, upper main stem part of the plant). The fifth internode from the terminal is the last fully mature internode and is the best indicator of plant vigor.

**Fruiting:** Once fruiting begins, growers have to make many more management decisions. Squares form at the first axillary bud after the first fruiting branch develops. The location of the node is determined by the cotton variety and environmental conditions during the first weeks after emergence.

After the first 3 weeks of plant growth, the only way to increase the number of squares is to protect against pests and to sustain plant growth, which produces sites for additional fruiting branches and adds fruiting sites to existing branches. Under optimum growing conditions, a new fruiting site will develop every 3 to 5 days moving up the plant (vertical fruiting interval) and every 5 to 7 days moving horizontally along the fruiting branch (horizontal fruiting interval).

The objective at early fruiting is to retain the most squares possible. Because of the different weather characteristics and pest problems across Texas, the optimum number of squares retained differs by region.

In West Texas, fruit initiation usually occurs during warm temperatures and sunny days. The goal in that region is to have 90 percent square set in the first week of squaring, 85 percent in the second week and 75 percent in the third week up to first bloom.

This goal is more difficult to reach in the eastern part of the state because of pest problems and environmental stresses (cool temperatures and cloudy conditions).

**Fruit shed**

Fruit shed is unavoidable in the life of a cotton plant (Figure 5.3). It is caused by environmental, physiological and pest influences. Although growers generally view it as detrimental, some fruit shed is necessary, especially when the plant is adjusting its fruit load to accommodate growing conditions.

Fruit shed is most harmful when cotton is planted late or during short growing seasons. Nonirrigated cotton has a higher risk of shedding because mid-season drought substantially reduces boll set.

A plant’s response to fruit shed varies with local conditions and can vary from field to field. The most obvious symptoms are delayed flowering and increased vegetative growth. If fruit loss occurs early, more mid- and late-season bolls are often retained, but crop maturity will be delayed.

Under certain conditions, these plant responses can be favorable because they produce larger plants that are less prone to premature cutout during longer growing seasons. However, time is lost with delayed squaring, and the weather is unfavorable in most growing regions in Texas at the end of the bloom period. Consequently, in Texas, early fruit set is critical to successful production of high-quality cotton.
Several insecticide applications may be needed if traps show continued movement into the field from overwintered sites (wooded or brushy areas).

Natural enemies play a limited role in controlling boll weevils. Parasites of third-instar larvae also play a minor role. Although effective parasites are present in Mexico, they cannot survive Texas winters. Therefore, annual periodic releases are necessary. Rearing these boll weevil parasites is costly and so releasing parasites is cost prohibitive for producers.

Predators such as the red imported fire ant have a greater effect than do parasites, but these are limited to the eastern production region. In the west, the main reason for boll weevil deaths is the desiccation of larvae in aborted squares. This is important in nonirrigated acres but less important where irrigation is available.

Plant breeders and entomologists have identified plant characteristics that provide some protection of the fruit from boll weevils. Cotton characteristics such as frego bracts (small, twisted bracts that expose the flower bud), red plant color, okra leaf characteristics and leaf hairiness provide a level of resistance or tolerance to the boll weevil. Problems with adequate yield (red color), susceptibility to other insects (okra leaf and frego bract) and harvesting concerns (leaf hairiness) have limited the use of these characteristics in new varieties.

Other potential fruit-feeders in cotton before bloom are the bollworm/tobacco budworm complex and beet armyworms. These rarely cause economic damage before blooming. The thresholds for these pests are high early in the season because few of them survive to feed on developing fruit.

Treatment decisions for caterpillar pests are made when 15 to 25 percent of the squares are damaged. To determine this, pull 100 green squares from different areas of the field and count the damaged ones.

When making insect management decisions early in the season, also consider natural enemies. Conserving natural enemies is the most cost-effective way to control insects. Start managing the natural enemy populations early so that enough remain later in the season to attack pest populations.

Multiple applications of insecticides reduce natural enemy populations. Try to maintain an adequate square set while limiting the effects of insecticide use on natural enemies.

The importance of setting early squares cannot be overemphasized. As cotton moves closer to first bloom, producers should place more emphasis on maintaining natural enemies. Table 5.3 shows how reducing insecticide rates can provide control of pests and still conserve natural enemies.

### Water, fertilizers and plant growth regulators

During this growth stage, decisions on water, fertilizers and plant growth regulators become important. Water use increases dramatically, from less than 1 inch per week to 2 inches per week at first bloom (Figure 5.4).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate (oz/ac)</th>
<th>% Fleahopper Control</th>
<th>% Square Set</th>
<th>Predators/Acre</th>
<th>Bollworm Larvae/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>0</td>
<td>68</td>
<td>52,500</td>
<td>4,000</td>
<td></td>
</tr>
<tr>
<td>Orthene® 75 S</td>
<td>2</td>
<td>93</td>
<td>81</td>
<td>47,750</td>
<td>3,750</td>
</tr>
<tr>
<td>Orthene® 75 S</td>
<td>4</td>
<td>94</td>
<td>79</td>
<td>16,500</td>
<td>13,250</td>
</tr>
</tbody>
</table>
Producers with adequate water should start making management decisions soon after the first bloom appears. The goal is to avoid any water stress early in the season and to have a full soil water profile as the plant reaches peak bloom (usually 3 weeks after bloom for most regions of Texas).

Nitrogen

Fertilizer requirements at this stage are much like water requirements. In much of Texas, residual nitrogen from previous crops is adequate for early-season growth until the squares appear. Research indicates that the vegetative stage requires less than 25 percent of the plant’s nitrogen needs for the season.

Figure 5.5 shows that the plant has used 50 percent of the nitrogen by first bloom. After first bloom, nitrogen uptake increases dramatically. The goal for producers is to have all the nitrogen applied before peak bloom.

Early in the growing season, nitrogen deficiency symptoms include lighter green foliage, slowed growth rate and smaller overall leaf area. In mid to late season, the symptoms are discolored, yellow to red leaves, smaller plants and reduced boll set.

Excess nitrogen also presents problems for cotton production. If there is too much nitrogen, the plant develops too much vegetative growth and becomes rank (excessively vigorous). This reduces its ability to cope with dry conditions, delays maturity, increases the incidence of boll rot and creates difficult defoliation conditions. Excess nitrogen also increases the risk of problems from cotton aphids.

If nitrogen is needed, apply it as a side-dress before the first white blooms appear. If more nitrogen is needed later, apply it without disturbing the root system (through irrigation or foliar sprays).

Plant growth regulators

Cotton producers use plant growth regulators to slow plant growth and, therefore, improve harvest efficiency. In some parts of Texas, growth regulators also reduce boll rot.

One plant growth regulator used in cotton is mepiquat chloride (Pix® Plus, etc.). In cotton, it reduces the production of gibberellic acid, a plant hormone that promotes cell expansion.

Applications of mepiquat chloride suppress cell enlargement and promote shorter internodes; smaller, thicker, darker-green leaves; and ultimately shorter plants. This overall reduction in plant growth makes harvest more efficient and reduces boll rot in the eastern part of the state.

Because environments and management levels vary across Texas, no one approach to using plant growth regulators will work in all regions. However, for best results, make the first applica-
tion of mepiquat chloride early (at the matchhead square stage) and then let growing conditions and fruit retention dictate the strategy for the remainder of the season, especially in fields that historically produce rank growth.

The strategy of making early applications of a plant growth regulator provides the best chance of success. Once a cotton plant has begun to grow rapidly, especially under irrigated or good rainfall conditions, it is difficult to slow it down. Reducing growth is difficult, costly and usually unsuccessful.

Use mepiquat chloride if the plants undergo excessive early growth caused by early-season square loss, good growing conditions and ample nitrogen fertilization. Mepiquat chloride treatments are also used on varieties that tend to produce larger, ranker plants.

Because mepiquat chloride reduces plant growth, do not apply it if the plants are already under stress. Low heat unit accumulation and water stress can reduce plant growth, and applications of mepiquat chloride during these periods can be harmful.

Once good growing conditions return, monitor plant growth to determine future use of the chemical.
Management decisions and weather conditions early in the growing season have a direct influence on boll set and yield potential. Because the eastern part of Texas has a long growing season, the cotton plant may be able to recover if fruit set is below average. In the west, however, the first 3 weeks of fruiting determine 80 percent or more of the final yield.

During this period, cotton producers need to monitor and make decisions on plant development, fruit shed, water use, nutrients, insect management and late-season disease control.

Plant development

The period of first bloom to open boll places the greatest demands on the plant. Any shortage of carbohydrates, water or nutrients at this time will reduce yield.

Through photosynthesis, plants produce the carbohydrates (sugars) that provide the energy for plant growth and development. Cotton leaves that produce more carbohydrates than they need are called “sources.” These source leaves supply the carbohydrates for other plant parts, termed “sinks.” Sinks include developing fruit, leaves, stems and roots.

During the first 16 days after a leaf unfurls, the carbohydrates produced by that leaf are used for its own growth. Between days 16 to 25, the leaf reaches its prime as a source and exports its carbohydrates to other developing plant parts, such as bolls. At 4 weeks old, a leaf’s carbohydrate production begins to slow until about day 60, when the leaf can no longer export sugars.

During the bloom period, the most active main stem leaf is five nodes below the terminal. At this time, the leaf 13 nodes below the terminal is non-functional.

Young squares can support themselves with carbohydrates from the bracts (triangular leaves immediately surrounding the flower bud). However, once the boll reaches 10 days old, it demands a tremendous amount of nutrients and carbohydrates. It becomes a very strong sink.

A young boll derives most of its food from the leaf immediately below it, which is termed the subtending leaf (Table 6.1). If the subtending leaf of a 4- to 7-day-old boll is shaded – for example, because of cloudy weather or a thick stand – the boll may shed from lack of carbohydrate supply.

Of the final weight of the boll, the subtending leaf contributes 50 percent and the nearest main stem leaf 35 percent. The remaining 15 percent comes from leaves elsewhere on the plant.

By the time a boll reaches peak carbohydrate demand, it is usually buried in the canopy and

<table>
<thead>
<tr>
<th>1st Position Fruit Stage</th>
<th>Major Food Sources</th>
<th>Function of Stem Leaf</th>
<th>Function of Main Subtending Leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinhead Square</td>
<td>Bracts</td>
<td>Unfurling</td>
<td>Microscopic</td>
</tr>
<tr>
<td>Large Square</td>
<td>Bracts + Main stem leaf</td>
<td>Source</td>
<td>Unfurling</td>
</tr>
<tr>
<td>Small Boll</td>
<td>Bracts + Main stem leaf + Subtending leaf</td>
<td>Source</td>
<td>Source</td>
</tr>
<tr>
<td>Medium Boll</td>
<td>Bracts + Subtending leaf</td>
<td>Declining</td>
<td>Source</td>
</tr>
<tr>
<td>Large Boll</td>
<td>Leaves at top of plant + Subtending leaf</td>
<td>Declining</td>
<td>Declining</td>
</tr>
</tbody>
</table>

the leaves surrounding it are in dense shade. Bolls in this position must rely on leaves farther away at the top of the plant for carbohydrates.

Water stress, cloudy weather and nutrient deficiencies can all decrease photosynthesis and therefore reduce the carbohydrate-supplying power of the plant.

First bloom is a good time to evaluate the overall status of the plant. At 7 to 14 days after first bloom, check square retention and the number of nodes above white flower (NAWF). NAWF at early bloom will vary, depending on management and the level of stress encountered by the crop. NAWF provides a good estimate of the potential boll sites.

Studies conducted in the Coastal Bend indicate that crops produce average yields if they retain 60 to 70 percent of first- and second-position fruit (squares, flowers and bolls). Table 6.2 shows potential management guidelines for cotton production in the Coastal Bend based on fruit retention.

Drought, disease and pests can reduce terminal growth and NAWF at early bloom. Insects that remove squares, such as cotton fleahoppers and Lygus bugs, may actually increase NAWF at early bloom.

To determine NAWF, count the nodes above a first-position white flower. If the NAWF count at early bloom is below seven, the plant may reach cutout prematurely unless the plant stress is relieved. Much of the dryland production in the western part of Texas enters early bloom at this stage.

To maintain growth, producers must carefully manage inputs. An NAWF count above 10 at early bloom may indicate reduced fruit retention or rank growth. You will need to monitor the fields continually to determine the proper management strategies.

A rapid decline in NAWF can be good or bad. It may signify excellent boll retention and high demands for nutrients and water. However, it may also indicate severe drought stress, which should be alleviated with irrigation where possible.

If NAWF remains above 10 or increases rapidly, a more significant problem may exist. This indicates that there are not enough bolls to prevent additional terminal growth. You will need to respond immediately to avoid rank growth and delayed maturity.

The plant continues to add squares and develop bolls at early bloom. The ovary (where the seed develops) is compound in domesticated cotton. A Pima cotton ovary averages three to four carpels (sections) or locules (locs) per boll. An upland cotton ovary averages four to five locs per boll.

The number of locs is determined early in square formation (3 weeks before flower opening). Although the number is strongly influenced by genetics, environment also plays a role. Most studies indicate that the carbohydrate status of

<table>
<thead>
<tr>
<th>Factors Affected</th>
<th>Below 60%</th>
<th>Above 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield potential</td>
<td>Below average</td>
<td>Above average</td>
</tr>
<tr>
<td>Potential for rank growth</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Need for Pix®</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Need for nutrients</td>
<td>Lower</td>
<td>Higher</td>
</tr>
</tbody>
</table>

the plant influences the relative formation of four or five loc bolls. Moisture stress plays a relatively minor role. Factors such as shading and limiting resources produce bolls with fewer locs.

A cotton flower opens in the morning and then sheds its pollen. Cotton is generally considered a self-pollinating plant (if there are no insects, 95 to 99 percent of the flowers are self-pollinated). Cotton pollen is sensitive to moisture and can rupture upon contact with water (rainfall or irrigation) within 30 to 60 seconds.

The cotton fibers begin to elongate from the surface of the ovule (unfertilized seed) and can elongate for a few days even if the ovule is not fertilized. The unfertilized ovules are called motes.

Fiber initiation is sensitive to temperature. Hot weather during initiation produces shorter fibers, fewer seeds per boll, smaller seeds and smaller bolls. An average seed has 13,000 to 21,000 lint fibers, and the average loc has six to nine seeds.

Young seeds produce hormones that increase the flow of nutrients and carbohydrates to them. Bolls that produce fewer than 10 to 15 seeds are not strong sinks and are ultimately shed. High temperatures are the major cause of low seed counts.

As the fiber is lengthening and the seed expanding, the boll wall enlarges. The boll reaches maximum size and fiber reaches its maximum length in about 20 days. A lack of potassium or water can limit boll size, seed size and fiber length.

During the remainder of boll development, micronaire, maturity and strength are determined. Cellulose is laid down in winding sheets around the inside of the cotton fiber. Warm weather favors cellulose deposition and may increase micronaire values. Cool weather reduces cellulose deposition and can reduce micronaire values.

Fiber strength is related to the average length of the cellulose molecules deposited inside the cotton fiber. The longer the cellulose chains, the stronger the fiber. Genetics controls about 80 percent of strength development, although environment does have some influence. Excessive weathering and over-ginning can weaken fiber.

Seed quality is determined in the later stages of development. Seeds reach maximum size 4 weeks after pollination. After day 25, the embryo begins to accumulate protein and oil. The same factors that decrease the maturity of the fibers also lower seed quality.

**Fruit shed**

Square and boll shed are common and can be attributed to numerous factors. Large squares, blooms and medium to large bolls are generally resistant to environmental shed. Small boll shed may be an important natural process by which the plant adjusts its fruit load to match the supply of inorganic and organic nutrients.

Shedding is controlled by a series of plant hormones that regulate growth, fruiting, flowering and abscission. Boll retention declines throughout the boll-loading period as the overall nutrient “sink” demand increases.

Boll position also influences boll retention. First-position sites (bolls closest to the main stem) have a higher retention rate. Because of shading, pest pressure, light, water and nutrient availability, bolls located at second and third positions are less likely to be retained.

Although these second- and third-position bolls contribute more to yield in the eastern part of Texas because of the longer growing season, the first-position bolls generally contribute the most to the overall yield.

**Water**

The plant’s water use increases dramatically during the stage from first bloom to open boll. Measured as evapotranspiration (water lost from the soil and the plant), water use can be as high 0.4 inches per day or 2.8 inches per week (Figure 6.1).
Because the soil is the storage site for water available to the plant, the primary factor in determining water-holding capacity is soil texture. The more surface area per unit volume of soil, the more water it can hold (Table 6.3). Sand particles have the largest diameter and the least surface area per unit weight. Therefore, sand retains the least water. Clay particles have the most surface area and thus retain the most water.

The total amount of water available to the growing crop is determined by the texture of each soil zone in the effective rooting depth. Rooting depth is affected by both chemical and physical soil characteristics.

Once blooming starts, cotton prefers frequent, low-volume applications of water rather than large, less frequent amounts. This strategy minimizes the degree of water stress between rain or irrigation and thus increases fruit retention.

In the western part of Texas, very few producers have the irrigation capacity to satisfy crop demands (0.3 to 0.4 inches per day). Table 6.4 shows the relationship between irrigation water supply and a crop water demand of 0.3 inches per day.

Because center pivot irrigation systems are so prevalent in west Texas, irrigation studies have focused on making these systems more efficient and on optimizing production with limited irrigation. Low energy precision application (LEPA) irrigation systems (circle rows, dragging socks in alternate furrows, furrow diked) will extend water because of increased application efficiency.

Research indicates that cotton responds very well to high-frequency deficit irrigations, even with amounts as low as 0.20 to 0.25 inch applied every 2 days (Table 6.5). When irrigation capacities are above 0.2 inch per day, the frequency of irrigation is not as critical.

![Figure 6.1. Water use for cotton up to first open boll.](image)

Table 6.3. Inches of water held per foot of soil depth.

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>Clay loam</th>
<th>Loam</th>
<th>Sandy loam</th>
<th>Loamy sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field capacity</td>
<td>4.8</td>
<td>4.2</td>
<td>3.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Permanent wilting point</td>
<td>2.4</td>
<td>2.1</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Plant available water</td>
<td>2.4</td>
<td>2.1</td>
<td>1.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 6.4. Relationship between irrigation water supply and crop water replacement when water use is an average of 0.3 inches per day. GPMA is gallons per minute per acre.

<table>
<thead>
<tr>
<th>Irrigation, GPMA</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation, inches/acre/day</td>
<td>0.052</td>
<td>0.104</td>
<td>0.155</td>
<td>0.207</td>
<td>0.259</td>
<td>0.311</td>
</tr>
<tr>
<td>% water replacement</td>
<td>17</td>
<td>34</td>
<td>52</td>
<td>69</td>
<td>86</td>
<td>104</td>
</tr>
</tbody>
</table>
Nutrient management

Cotton requires most of its nutrients during the fruiting stage. During this time, bolls are heavy consumers of nutrients, and any shortage will reduce yield (Figure 6.2). Nitrogen fertilizer should be applied before first bloom.

Growers can use irrigation systems to deliver nitrogen and other nutrients to the crop. This method is used extensively in west Texas, where center pivot irrigation comprises 50 percent of the acreage, and soils are very sandy.

Under most conditions, soil-applied nutrients are adequate to meet crop demands. However, in some situations, foliar fertilization can increase yields. Foliar feeding may be useful in exception-
This period reflects the results of weather conditions and management steps taken throughout the season. During this stage, growers should focus primarily on water and insect management. You will also need to manage disease and make decisions about harvest aids.

**Water use**

At peak bloom, cotton requires about 0.3 inch of water per day. By harvest, the rate will drop considerably, to less than 0.1 inch per day (Figure 7.1).

In a “perfect environment,” dryland producers would have a full profile of moisture at the third week of bloom, followed by a couple of timely rain showers. Producers with furrow irrigation have more control than dryland producers but still must make the last irrigation before bolls open.

Late applications of excessive water can lead to many problems, including boll rot, late season regrowth, an increase in late-season insect pests, added harvest aid inputs and possible grade reductions from late-season regrowth.

In West Texas, furrow irrigation should be terminated before September 1. Sprinkler or drip irrigation should be continued for 1 to 2 weeks after open boll or until 20 percent of the bolls are open. The goal is to provide adequate moisture for the last harvestable bolls to mature.

**Nitrogen use**

After boll opening, nitrogen uptake plummets (Figure 7.2). Although nutrient deficiencies are common during this period, it is too late to take corrective action. When boll growth peaks, so does demand for several nutrients, especially potassium.

The root system is no longer functioning at full capacity because of demands from developing bolls. Soil nitrogen needs to be in short supply by harvest. If there is too much nitrogen, regrowth problems will increase, as will harvest aid costs and potential late-season insect problems. Excessive nitrogen can also reduce lint quality.

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**Figure 7.1.** Water use for cotton up to harvest.

**Figure 7.2.** Percentage of nitrogen in the plant up to harvest.
Plant development

During this period, it is still wise to monitor nodes above white flower (NAWF) by counting the nodes above the uppermost first position white flower (Figure 7.3). The terminal node is the one with an unfurled main stem leaf larger than a quarter (more than 1 inch in diameter).

NAWF measures the potential boll loading sites remaining. At this point in the season, all carbohydrates produced by the plant are committed to boll development. Monitoring NAWF is critical at this time because pest managers need to know when the last harvestable boll has been set.

Research indicates that the last effective flow- ers that need to be protected appear when NAWF is equal to five. This changes somewhat in the western part of the state, where NAWF equal to four is a more reliable estimate.

Cotton physiologists define cutout to be when NAWF is equal to four or five. Before then, approximately 100 flowers will produce 1 pound of seed cotton. After cotton reaches cutout, the number of flowers needed to produce 1 pound of seed cotton increases dramatically.

In estimating when the plant has reached cutout, NAWF is a more reliable indicator than calendar dates. Table 7.1 provides calendar dates for the last effective bloom period for some of the production regions in Texas.

The dates vary widely because of weather and location. Dates for the South, Central and Lower Rio Grande Valley are due to the effect of weather on harvest. The dates for the Rolling Plains

![Diagram of cotton plant with labeled nodes and terms]

Figure 7.3. Nodes above white flower (NAWF) equal to five.
and High Plains are due to limited heat units. Although boll set can occur after these dates, bolls that set later generally have lower fiber quality.

Insect control

Monitoring NAWF is also a key to making late-season insect decisions. The same fruit-feeding complex that causes problems during peak bloom will also lower yields later in the season. Although thresholds change little from peak bloom, the emphasis shifts from protecting squares and bolls to protecting developing bolls.

Recent studies using the computer model COTMAN have verified treatment termination rules for fruit-feeding insects. Once bolls accumulate 350 to 450 heat units, they suffer less damage from bollworms and boll weevils (Figure 7.4).

NAWF, heat units and historical weather data can be used for more than predicting cutout. Table 7.2 is an example of using NAWF and historical weather to predict the dates when bolls are safe from insect damage in the High Plains.

In the above example, a bloom on August 1 would be safe from boll weevils on August 18 and would be a mature boll on September 19. A bloom on August 5 would mature 10 days later than a bloom on August 1.

The extra time is needed because fewer heat units accumulate later in the season. The reduced heat unit accumulation is also the reason that blooms on August 20 have a negligible impact on yield, because the chances of the bolls reaching maturity (750 DD60) are reduced in West Texas.

Blooms that accumulate 350 DD60 are safe from Lygus spp. feeding. Those that accumulate 450 DD60 are safe from newly hatched larvae, but larger larvae could penetrate bolls (Figure 7.4).

Insects with stronger mouthparts, such as stink bugs, can penetrate older bolls, so heat unit accumulations should reach 600 DD60 after cutout (NAWF = 5).

### Table 7.1. Estimate of effective bloom period for some growing regions of Texas.

<table>
<thead>
<tr>
<th>Region</th>
<th>Bloom Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Rio Grande Valley</td>
<td>June 1 to June 20</td>
</tr>
<tr>
<td>Coastal Bend</td>
<td>June 10 to July 5</td>
</tr>
<tr>
<td>Blacklands, Winter Garden</td>
<td>July 5 to July 15</td>
</tr>
<tr>
<td>Rolling Plains</td>
<td>August 20 to September 5</td>
</tr>
<tr>
<td>High Plains</td>
<td>August 15 to September 1</td>
</tr>
</tbody>
</table>

Table 7.2. Heat unit (HU) events based on date of cutout (NAWF=4) and actual Lubbock, TX temperatures (August 1-29). Focus on Entomology, 2001.

<table>
<thead>
<tr>
<th>Heat Unit Accumulation</th>
<th>August 1</th>
<th>August 5</th>
<th>August 10</th>
<th>August 15</th>
<th>August 20</th>
<th>August 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>+350 HU (safe from weevils)</td>
<td>Aug. 18</td>
<td>Aug. 22</td>
<td>Aug. 27</td>
<td>Sept. 2</td>
<td>Sept. 11</td>
<td>Sept. 19</td>
</tr>
<tr>
<td>+450 HU (safe from worm egg lay)</td>
<td>Aug. 22</td>
<td>Aug. 26</td>
<td>Sept. 3</td>
<td>Sept. 10</td>
<td>Sept. 20</td>
<td>Oct. 1</td>
</tr>
<tr>
<td>+750 HU (near mature boll)</td>
<td>Sept. 10</td>
<td>Sept. 18</td>
<td>Sept. 30</td>
<td>Oct. 16</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>+850 HU (fully mature boll)</td>
<td>Sept. 19</td>
<td>Sept. 29</td>
<td>Oct. 18</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
For More Information

Web sites

Diseases in Texas cotton
http://plantpathology.tamu.edu/Texlab/Fiber/Cotton/cottop.html

High Plains cotton information
http://lubbock.tamu.edu/ipm/AgWeb/cotton/insect/cotindex.htm

Links to cotton industry sites
http://sanangelo.tamu.edu/agronomy/cotton.html

National Cotton Council
http://www.cotton.org

Cotton Incorporated and links to COTMAN information
http://www.cottoninc.com

Texas Cooperative Extension:
Cotton information
http://insects.tamu.edu/cotton/
Entomology publications
http://insects.tamu.edu/extension/ag_and_field.html
Ordering and accessing publications
http://texaserc.tamu.edu
Soil and crop sciences cotton information
http://soil-testing.tamu.edu/topics/Cotton/cotton_index.html

Irrigation information and moisture evaluation (University of Nebraska)
http://www.ianr.unl.edu/pubs/irrigation/

Potential evapotranspiration (PET) for Texas North Plains
http://amarillo2.tamu.edu/nppet/petnet1.htm

Pesticide applicator training
http://www-aes.tamu.edu

Texas Evapotranspiration Network
http://texaset.tamu.edu

Texas Plant Disease Diagnostic Laboratory
http://plantpathology.tamu.edu/index4.html

Texas Tech information on thrips and Lygus spp. in the High Plains
http://www.pssc.ttu.edu/entomology

Texas Department of Agriculture
http://www.agr.state.tx.us/

Texas Pest Management Association
http://www.tpma.org

Publications

Texas Cooperative Extension publications
B-933, “Identification, Biology and Sampling of Cotton Insects”
B-1593, “Cotton Harvest-Aid Chemicals”
B-6046, “Guide to the Predators, Parasites and Pathogens Attacking Insect and Mite Pests of Cotton” ($5.00)
B-6107, “Bt Cotton Technology in Texas: A Practical View”
E-5, “Managing Cotton Insects in the Southern, Eastern and Blackland Areas of Texas”
E-6, “Managing Cotton Insects in the High Plains, Rolling Plains and Trans Pecos Areas of Texas”
E-7, “Managing Cotton Insects in the Lower Rio Grande Valley of Texas”
E-5A, “Suggested Insecticides for Managing Cotton Insects in the Southern, Eastern and Blackland Areas of Texas”

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Other


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Texas Plant Disease Diagnostic Laboratory, Texas Cooperative Extension, 1500 Research Parkway, Room 130, TAMU 2119, College Station, TX 77843-2119.

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