Crop Management Tools and Techniques

Chapter 2

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:

(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 degrees F + 75 degrees F)/2 – 60 = 22.5 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 2.1. Accumulated heat units (DD60s) required for different developmental stages of cotton.

Growth Stage	Number of Days (range)	Heat Units (range)
Planting to seedling emergence	4-9	50-60
Emergence to first square	27-38	425-475
Square to white flower2	0-25	300-350
Planting to first flower	60-70	775-850
White flower to open boll	45-66	850
Planting to cutout	80-100	1,000-1,600
Planting to harvest	130-170	2,600
Between nodes		
Up the main stem	2-34	0-60
Out the branch	5-7	80-120

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:

20 inches/15 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:

(12 squares/20 fruiting sites) x 100 = 60 percent

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 2.2. Irrigation system efficiencies.

System	Overall Efficiency
Surface	0.50-0.80
Average	0.50
Land leveling and delivery pipeline	0.70
Tail water recovery combined with above	0.80
Surge valves	0.60-0.90[1]
Sprinkler	0.55-0.73[2]
Center pivot	0.55-0.90[2]
LEPA	0.90-0.95
Drip	0.80-0.90[3]

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.*

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.

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

Growth Stage	K_c	Days after Planting
Seedling	0.07	0-10
First square	0.22	27-38
First bloom	0.44	60-70
Peak bloom	1.10	70-90
First open boll	1.10	105-115
25% open bolls	0.83	115-125
50% open bolls	0.44	135-145
95% open bolls	0.44	140-150
Harvest	0.10	140-150

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 inches x 1.10 = 1.65 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:

PET x Kc/Efficiency = 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 x 1.10)/0.73 = 2.26 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 causing significant losses is known as the economic injury level.

The first line of defense against pests is prevention through the use of good agronomic practices or cultural methods that are unfavorable to the development of a pest.

Producers should take control measures only when the cost of crop damage by the pests could become greater than the cost of treating them. This potentially harmful level of pests or plant damage is called economic damage.

The economic injury level is the lowest number of pests that will cause economic damage. The economic threshold precedes the economic injury level and is the pest density at which you should take action to prevent the pest population from reaching the economic injury level.

The economic injury level, and therefore the economic threshold, are not fixed numbers. The injury level is affected by the cost of the treatment, the value of the crop, the proportion of the crop destroyed by the insect and the yield or quality lost per proportion of the crop destroyed.

For example, if the value of the crop is high or yields are good, the economic injury level will be lower and treatment should occur sooner. Crop managers must have good information about the crop and the pests to be able to use the economic thresholds.

Finally, thresholds are guidelines to help crop managers make decisions. The thresholds are breakeven; that is, the amount of damage is equal to the treatment cost. Crop managers must be sure that pest infestations are at damaging levels before initiating treatment.

Disease management

Several species of fungi can infect cotton seeds and seedlings. The environmental conditions that are best for fungal development occur at the time of seed germination for early-planted cotton. The cool temperature and wet soils are generally marginal for the cotton seedling and provide an opportunity for the fungi to infect the plant.

As seedlings develop, they become naturally resistant to infection as their root systems become more extensive and as their root cells are lignified or hardened.

Because no one fungicide adequately controls all pathogens (disease-causing organisms), seeds should be treated with combinations of fungicides. There are two main types of fungicides:

- Systemic, which are chemicals absorbed by the plant and translocated within the plant.
- Protectant, which are chemicals that are not absorbed by the plant and that are active only in the vicinity where they are applied.

The two types of fungicides serve a complementary role in protecting the seed and the seedling. Generally, the more effective fungicides target a narrow group of fungi. These fungicides are usually systemic and can protect the seedling for a longer period than do contact fungicides.

Although contact fungicides such as captan and PCNB are very potent, they are not absorbed by the growing seedling, nor are they substantially leached into the soil. Systemic fungicides can compensate for these limitations.

Purchased seed is often pretreated with fungicides. Producers may apply additional fungicides at the time of planting as a planter box treatment or as in-furrow granules or spray. Several fungicides are approved for use as seed treatment against cotton pathogens (Table 2.4). When buying seed, growers can sometimes request a customized fungicide seed treatment.

Commercially available mixtures of seed-treatment fungicides (Table 2.5) may not protect against all fungi. For example, while all provide protection against *Rhizoctonia*, some mixtures do not affect *Pythium* or *Thielaviopsis*. These mixtures could also be mixed with the necessary fungicides shown in Table 2.4 to achieve a complete spectrum of control.

To decide what fungicides to choose, growers should first determine which pathogens are in their fields. This is easiest in the years when disease problems occur. To identify the pathogen in fields, send samples of seedlings with damping-off symptoms to a plant disease diagnostic clinic. It is particularly useful to know if either *Pythium* or *Thielaviopsis* is present.

If you have no specific information about the pathogens present in a field, choose a preventive seed fungicide mix that includes both systemic and protectant fungicides active against *Pythium* and *Rhizoctonia*. In the High Plains, cotton should also be treated with a fungicide that targets *Thielaviopsis*.

Several protectant seed treatment fungicides are available, some targeting a broad spectrum of different pathogen groups and some targeting a narrow spectrum. Thiram and mancozeb have a broad spectrum of activity. Captan helps protect against *Pythium* but not *Rhizoctonia*. PCNB has activity against *Rhizoctonia* but not other

Table 2.4. Chemicals applied to seed for seedling disease control.

Target Pathogen*	Chemical Name	Trade Name
T, R	triadimenol	Baytan® 30 Flowable
P, R, F, G	TCMTB (benzothiazole)	Ascend® 30, Nusan® 30 EC Nu-Flow® T
R	chloroneb	Nu-Flow® D, Demosan® 65 W
G	captan	Nu-Gro® Captan 4000 Captan 30-DD Captan 400
R	PCNB	PCNB Flowable, PCNB Seed-Coat PCNB 2-E, RTU-PCNB
G	mancozeb	Dithane® DF, Dithane® F-45 Dithane® M-45, Dithane® WSP Penncozeb® 75 DF Penncozeb® 80 WP
R, F, G	fludioxonil	Maxim® 4 FS
T, R	myclobutanil metalaxyl	Nu-Flow® M
P	mefenoxam (metalaxyl-m)	Allegiance®-LS, Allegiance® FL Allegiance® Dry Apron® Flowable, Apron® TL Apron® XL-LS
G	thiram	Thiram 42-S Thiram 50 WP
R	carboxin	Vitavax® 30 C Vitavax® 34
F, R, G	*Bacillus subtilis* (a bacterium)	Kodiak® Flowable Kodiak® Concentrate Kodiak® HB

*T = *Thielaviopsis basicola*; R = *Rhizoctonia solani*; P = *Pythium* spp.; F = *Fusarium* spp.; G = General damping-off pathogens

Table 2.5. Mixtures of chemicals applied to seed for seedling disease control.

Target Pathogen*	Chemical Name	Trade Name
T, R	triadimenol + thiram	RTU Baytan® Thiram
P, R, F, G	TCMTB (benzothiazole) + chloroneb	Nu-Flow® ND
R, P	carboxin + metalaxyl + PCNB	Prevail®
R, P	chloroneb + metalaxyl	Nu-Flow® AD
R, F, G, P	fludioxonil + mefenoxam	Maxim® XL
R, P	PCNB + metalaxyl + *Bacillus subtilis*	System® 3
R	carboxin + thiram carboxin + PCNB	RTU Vitavax® Thiram Vitavax®-PCNB Flowable Fungicide

*T = *Thielaviopsis basicola*; R = *Rhizoctonia solani*; P = *Pythium* spp.; F = *Fusarium* spp.; G = General damping-off pathogens.

seedling pathogens. Fludioxinil is effective against *Rhizoctonia* and *Fusarium*, as well as some of the seedling pathogens that occur less often. It also has long residual activity.

Metalaxyl is a systemic fungicide against *Pythium* but not other seedling pathogens. It should always be included as a seed treatment. Mefenoxam (also known as metalaxyl-M) contains only the active isomer of metalaxyl, allowing the grower to use about half as much chemical as is contained in metalaxyl, but achieving the same level of fungal control.

Other systemic seed treatment fungicides include TCMTB for *Rhizoctonia, Pythium* and *Fusarium*; chloroneb for *Rhizoctonia* and *Pythium*; and carboxin for *Rhizoctoni*a. Triadimenol and myclobutanil are systemic fungicides for *Rhizoctonia solani* and, at higher label rates, for *Thielaviopsis basicola*. Triadimenol has been reported to delay seedling emergence under cool, wet growing conditions.

A living bacterium, *Bacillus subtilis*, is available as a seed treatment. The bacterium should be used in conjunction with and not as a substitute for chemical fungicides. It will extend the length of control beyond the point where the chemicals lose their effectiveness. The bacterium acts against *Rhizoctonia* and *Fusarium* but not *Pythium* or *Thielaviopsis*.

No particular combination of the aforementioned fungicides is a better seed treatment than others. Studies of various combinations of fungicides suggest that the key to seedling disease control is to use a mixture of systemic and protectant fungicides targeting at least *Pythium* and *Rhizoctonia*.

When *Thielaviopsis* is also present, add triadimenol or myclobutanil (at the appropriate rate). The aim in using seed treatments is not to eliminate damping-off but to suppress the disease enough to produce a good, uniform stand. The seed treatment is successful if no large gaps are left within rows. In many cases, using a seed treatment is sufficient for disease control.

When there is a greater risk of seedling disease, augment seed treatments with other treatments. Use fungicides applied as a planter box treatment or as granules or liquid sprays applied to the soil surrounding the planted seed.

The risk of disease increases by:

- Planting early in soils with a frequent history of seedling disease problems

- Replanting a field where a stand failure occurs
- Planting into a field previously cropped to cotton
- Or, in some growing areas, planting into a no-till or reduced tillage field

Planter box fungicide treatments (Table 2.6) are, with one exception, mixtures of chemical fungicides that offer protection against *Rhizoctonia* and *Pythium* and are the same fungicides as those used in seed treatments.

The exception is a formulation of a living fungus, *Trichoderma harzianum*, which is used for general damping-off fungi and is compatible with chemical fungicides. Like the *Bacillus subtilis* bacterium, this fungus is used to supplement and extend the activity of chemical fungicides. However, its benefits have not been demonstrated consistently.

Planter box dusts stick to fuzzy cottonseed but may settle to the bottom of the planter box when acid-delinted seed is used. If you plant seed deeper than 1.5 inches when applying chemicals in a planter box, the chemicals may not be distributed uniformly.

In-furrow granules distribute fungicide into the soil around the seed better than do planter box applications. In-furrow granular treatments (Table 2.7) include PCNB and mefenoxam formulations, which target *Rhizoctonia* and *Pythium*, respectively.

Another fungicide, not registered as a seed treatment, is etridiazole. This is a systemic fungicide that has good activity against *Pythium* and *Fusarium* but is not as effective against *Rhizoctonia*.

Table 2.6. Hopper (Planter) box treatments applied for seedling disease control.

Target Pathogen*	Chemical Name	Trade Name
R, P	PCNB + metalaxyl + *Bacillus subtilis*	System 3®
R, P	carboxin + metalaxyl + PCNB	Prevail®
R, P	chloroneb + metalaxyl	Delta-Coat AD®
R, P, G	chloroneb + TCMB	Nu-Coat®
G	*Trichoderma harzianum* (a fungus)	T-22® Planter Box

*R = *Rhizoctonia solani*; P = *Pythium* spp.; G = general damping-off pathogens.

Table 2.7. In-furrow granular applied for seedling disease control.

Target Pathogen*	Chemical Name	Trade Name
R	PCNB	PCNB 10 Granular Terraclor® 15 G Terraclor® 6.5% plus Di-Syston® 6.5%
P	mefenoxam (metalaxyl-m)	Ridomil® Gold GR
R, P	PCNB + etridiazole	Terraclor® Super X 18.8 G Terraclor® Super X with Di-Syston
R, P	PCNB + mefenoxam	Ridomil® Gold PC GR

*R = *Rhizoctonia solani*; P = *Pythium* spp.

The best way to distribute fungicide into the soil around seed is through in-furrow liquid applications. These applications (Table 2.8) include the same fungicides used for in-furrow granular treatments.

Two additional fungicides are both systemic – iprodione, which acts against *Rhizoctonia* and *Fusarium*, but not *Pythium*; and azoxystrobin, which acts against *Rhizoctonia* and *Pythium*.

Weed management

To have a successful crop, cotton growers must control weeds. Early in the season, cotton grows slowly and does not compete well with weeds. Consequently, cotton fields must be fairly weed-free for a long period – up to 8 weeks, depending on the species of weeds present.

Weeds reduce the amount and quality of the lint by competing for nutrients, water, sunlight and space. At the end of the season, weeds interfere with harvest and reduce harvest efficiency. Heavy weed populations can force strippers/pickers to travel more slowly, and dense morning glory vines can clog machinery, resulting in considerable downtime.

Lint quality can be compromised because of staining, foreign material, etc. Weeds can also serve as alternate hosts for insects, diseases and nematodes that attack cotton.

A good weed management strategy depends on several factors:

- Weed species in the field
- Crop rotation
- Tillage system (conventional vs. reduced vs. no-till)
- Mechanical cultivation
- Herbicides
- Transgenic cotton varieties

Growers must consider these factors when devising weed management systems that best fit their needs, often on a field-by-field basis.

Herbicides

One way to control weeds is by applying herbicides. Herbicides are classified according to the timing of application, selectivity, uptake and their mode of action.

Table 2.8. In-furrow liquid chemicals applied for seedling disease control.

Target Pathogen*	Chemical Name	Trade Name
R	PCNB	Terraclor® 75 WP Terraclor® 2E Terraclor® Flowable
R	iprodione	Rovral® Brand 4 Rovral® Brand 75 WG Rovral® Fungicide
P	mefenoxam (metalaxyl-m)	Ridomil® Gold EC
R, P	azoxystrobin	Quadris® Flowable
R, P	PCNB + etridiazole	Terraclor® Super X EC Terraclor® Super X plus Di-Syston® EC
R, P	PCNB + mefenoxam	Ridomil® Gold PC Liquid

*R = *Rhizoctonia solani;* P = *Pythium* spp.

Timing: Products are generally applied before planting (preplant); after the crop is planted but before it emerges (preemergence); or after the crop has emerged (postemergence).

Preplant and preemergence herbicides are applied to the soil to control annual grasses and small-seeded broadleaf weeds before the weeds appear. They generally provide some level of residual control.

Postemergence products are used on observed rather than anticipated weed problems. To be effective, they must be applied when the crop and the weed are at the proper growth stages. Generally, postemergence treatments are most effective on small weeds.

Selectivity: The susceptibility or tolerance of different plants to a herbicide is called herbicide selectivity. Many plant characteristics interact to affect herbicide selectivity.

Several herbicides are selective only for grass or broadleaf plants. Many newer generation herbicides have very complex selectivity that differentiates among several broadleaf and/or grass plants.

Uptake: Herbicides are also categorized by their ability to move within the plant. Systemic or translocated herbicides can enter plants through the leaves, roots, or both. Herbicides that do not move within the plant are termed contact herbicides. Some products can have both systemic and contact activity, depending on how they are applied.

Mode of action: The effects that a herbicide has on plant growth and development are known as the mode of action (MOA). For example, some herbicides inhibit seedling growth, others disrupt photosynthesis and still others destroy cell membranes (Table 2.9).

Many herbicides of differing chemistry may have similar modes of action. That is, they affect the same biochemical processes in the plant. Consequently, products in the same mode-of-action class produce similar symptoms on susceptible plants.

There are eight primary modes of action for herbicides:

- **Growth regulators** – Known as the "hormone herbicides," these control broadleaf weeds in grass crops by affecting their hormonal balance, causing abnormal cell division, cell enlargement, etc. These herbicides are volatile (will vaporize) and can drift onto susceptible plants. They are primarily applied postemergence.

  Plant symptomology includes curling, twisting and bending of stems, and cupping and strapping of leaves. Example: 2,4-D.

- **Photosynthesis inhibitors** – Herbicides that inhibit photosynthesis are used primarily on broadleaf plants, but they do control some grasses. Many products have this MOA. Although they are applied mainly to the soil, several are used postemergence on the plants.

  Effects include yellowing of leaves between the veins, yellow veins and yellowing leaf margins. Examples: Caparol® (prometryn) and Cotoran® (fluometuron).

- **Pigment inhibitors** – These herbicides are absorbed by the roots and then move to a plant's growing points, where they inhibit carotenoid (yellow to red pigments) formation and the subsequent development of chlorophyll.

  These cause new growth to be pale yellow to white, appearing bleached. Example: Command® (clomazone).

- **Seedling growth inhibitors** – Applied to the soil, these products kill seedlings shortly after germination. They are divided into two categories: root inhibitors and shoot inhibitors.

  Root inhibitors prevent root growth and are most effective on small-seeded broadleaf and grass weeds. Shoot inhibitors prevent cell growth and are most effective on small-seeded grasses and some broadleaf weeds.

Table 2.9. A partial list of cotton herbicides and their modes of action.

Mode of Action	Example	Pests Controlled
Growth regulator	2, 4-D, dicamba (Banvel®, Clarity®)	Cotton stalk destruction, broadleaves
Amino acid synthesis inhibitors	Thifensulfuron-methyl + tribenuron-methyl (Harmony Extra®), pyrithiobac-sodium (Staple®)	Cotton stalk destruction, grasses and broadleaves
Other amino acid inhibitors	Glyphosate (Roundup® Ultra, Glyphomax®, Rattler®), glufosinate-ammonium (Liberty®), sulfosate (Touchdown®),	Annual and perennial grasses and broadleaves
Lipid synthesis inhibitors	Quizalofop-P-ethyl (Assure® II), fluazifop-P-butyl (Fusilade® DX), fluazifop-P-butyl + fenoxaprop-P-ethyl (Fusion®), sethoxydim (Poast®, Poast® Plus), clethodim (Prism®, Select®),	Annual and perennial grasses
Seedling growth inhibitors	Metolachlor (Dual Magnum®, Dual II Magnum®), S-ethyl dipropylthiocarbamate (Eptam®), pendimethalin (Pentagon®, Prowl®), trifluralin (Treflan®, Tri-4®)	Small seeded grasses and broadleaves
Photosynthesis inhibitors	Cyanazine (Bladex®), bromoxynil (Buctril®), prometryn (Caparol®, Cotton-Pro®), fluometuron (Cotoran®), diuron (Direx®, Karmex®)	Primarily broadleaves, some grasses
Contact	Carfentrazone-ethy (Aim®), DSMA, MSMA, lactofen (Cobra®), paraquat (Cyclone® Max), oxyfluorfen (Goal®)	Non-selective, grasses and broadleaves
Pigment inhibitors	Clomazone (Command®), norflurazon (Zorial® Rapid 80)	Grasses and broadleaves

Examples: Treflan® (trifluralin) and Dual Magnum® (metolachlor).

- **Contact** – These postemergence herbicides destroy cell membranes, causing the cell contents to leak. They affect both grasses and broadleaf plants.

  Treated plants turn yellow or pale and may appear water-soaked. Activity is fairly rapid. Example: Cyclone® Max (paraquat).

- **Lipid synthesis inhibitors** – These postemergence herbicides affect annual and perennial grasses only. They disrupt lipid formation and, therefore, damage cell membranes.

  These products act relatively slowly, requiring 7 to 14 days before symptoms appear. The youngest leaves turn yellow and die, and the stem may turn reddish-blue. Example: Select® (clethodim).

- **Amino acid synthesis inhibitors** – Active both in the soil and on leaves, these herbicides. control grasses and broadleaf plants. Known as ALS inhibitors, they prevent key amino acids from forming. Several different chemistries have this same MOA.

  Effects include stunting and purple coloration of the plants and a bottlebrush appearance on the roots and blackened terminals on the roots. Example: Staple® (pyrithiobac-sodium).

- **Other amino acid inhibitors** – These herbicides are used postemergence. They are nonselective, meaning they control a broad range of grass and broadleaf plants (annual and perennial).

  Treated plants turn yellow within 5 to 7 days, then turn brown and die within 10 to 14 days. Examples: Roundup® Ultra (glyphosate) and Touchdown® (sulfosate).

Insect management

To control insects, growers need to monitor their fields throughout the season and use a combination of control methods. The methods available include natural control, insecticide applications and transgenic cotton varieties.

Monitoring

Because insecticide use varies from season to season in Texas more than any other input, it is critical that you monitor or scout for insects. A good insect-scouting program can help you increase profit margins by either preventing unnecessary use of insecticides and thus unnecessary costs or by preventing economic loss from insects.

Cotton is affected by three main categories of insect pests: key pests, occasional pests and secondary pests.

- A **key pest** is a perennial, severe pest that dominates cultural practices. For many years, the dominant key pest in Texas has been the boll weevil. As boll weevils are being eradicated across the state, other insects are becoming the dominant key pests.

  In the eastern part of the state, a key pest is the cotton fleahopper. In the west, it is the cotton aphid. As boll weevil eradication continues, stink bugs and Lygus bugs (plant bugs) may also develop as key pests.

- **Occasional pests** generally stay below the economic injury level but can sporadically cause problems. Beet armyworms, whiteflies and the defoliators (salt marsh caterpillars, grasshoppers, cabbage loopers) fit in this category.

- **Secondary pests** typically are present at low levels throughout the season; natural enemies keep them below damaging levels.

If they become a problem, it is usually because of a management tactic such as an insecticide application that disturbs the system. Bollworms and tobacco budworms fit in this category, although an argument could be made that these two pests are also occasional pests.

Natural control

Insect and mite infestations are often held below damaging levels by natural control factors such as weather, inadequate food sources and natural enemies such as disease, predators and parasites. Crop managers should understand the effects of these natural control factors and encourage their action.

The use of predators, parasites and disease-causing organisms to control pests is known as biological control. Texas has a wide variety of these natural enemies, and producers should be able to recognize them. (See Extension publication B-6046, “Guide to the Predators, Parasites and Pathogens Attacking Insect and Mite Pests of Cotton.”)

Biological control tactics include importation, augmentation and conservation of natural enemies.

Importation is the transfer of a pest’s natural enemies from their places of origin to an area where they are needed. Once established, a natural enemy provides long-term benefits by keeping the pest below damaging levels.

In Texas cotton, importation has been unsuccessful because the natural enemies brought in have been unable to adapt to local conditions.

Augmentation involves periodically buying and releasing natural enemies. Although this practice has proven effective at the small-scale level in Texas, entomologists with Texas Cooperative Extension cannot provide guidelines for cotton producers because there is not enough information available on timing of application and numbers to be released. Also, the numbers of natural enemies that were released in successful small-scale trials are currently cost prohibitive.

Augmentation provides no long-term benefits. Unlike a successful importation program where the natural enemy establishes, and releases are no longer required, an augmentation program requires the release of natural enemies year after year.

Conservation is the least expensive and most effective method of biological control available to Texas cotton producers. To conserve natural enemies of cotton pests, growers should minimize the effects of insecticides by applying the insecticides at reduced rates when feasible, using chemicals with less persistence, applying the insecticides at times when natural enemies are not present and using insecticides with different formulations.

Insecticides

Insecticides have long been used in cotton. Although they still play an important role in cotton production, crop managers should remember that the main reason that integrated pest management (IPM) programs were developed in Texas was that the tobacco budworm became resistant to DDT and methyl parathion.

Pesticides will always be important to growers because they can control a pest immediately and prevent crop losses. But crop managers must manage pests with as many control tactics as possible to avoid the pests’ developing resistance to one method.

A number of disadvantages are associated with the use of insecticides:

- Excessive use in cotton can cause outbreaks of secondary pests.
- Pest resurgence can result. Sometimes the insecticide application does a good job of reducing the population but also kills the insect’s natural enemies. The pests then rebound to higher levels than before the initial application.
- Insecticide resistance is an important issue in Texas cotton. Resistance in this book refers to insects that can tolerate rates of

insecticides that were effective within a normally susceptible species. In Texas, tobacco budworms and cotton aphids have both become resistant (tolerant) to commonly used products. Although insecticide use can be managed to extend the usefulness of insecticides, some classes of insecticides will eventually become ineffective. The most recent example is the development of resistance (tolerance) to the pyrethroids by tobacco budworms. Field failures were first noted in 1985; by 1998, pyrethroids were rarely used for tobacco budworm control.

Insecticides can be classified by their chemical type. Most insecticides used in cotton attack the insect's nervous system:

- **Axonic poisons** disrupt the conduction of nerve impulses along nerves.
- **Synaptic poisons** affect the nerve synapse, which is the space between two nerve cells or the space between a nerve and muscles or organs. Chemical messengers carry the nerve impulse across this space. Insecticides can affect either the production of these chemical messengers or the way they send the impulse across the synapse.
- **Metabolic inhibitors** prevent the insect from converting food to energy.
- **Insect growth regulators** affect how insects molt.

Sometimes the mode of action can be confused with the uptake of an insecticide. Mode of action is the way the insecticide affects the insect. Uptake is the way the insecticide enters the insect's or plant's system.

Systemic insecticides are able to move into plant tissue. These insecticides are useful against pests with sucking mouthparts.

Contact insecticides are taken up through the cuticle or "skin" of the insect.

Stomach insecticides are those insecticides whose main uptake is by insect feeding. These insecticides are more effective against insects with chewing mouthparts.

Insecticide recommendations in Texas cotton are reviewed by Extension and research entomologists every year and published on the Internet at *http://texaserc.tamu.edu* or *http://insects.tamu.edu*. Table 2.10 provides a list of cotton insecticides, their chemical class, mode of action and impact on natural enemies.

Transgenic varieties

Another tool that crop managers have to use for pest control is transgenic technology. The term transgenic refers to the transfer of genes from other species into cotton. The new genes help the plant tolerate herbicides or produce toxins that kill pests.

One transgenic cotton product is BXN®. The cotton contains a gene that enables it to metabolize the herbicide bromoxynil (Buctril®, etc.) when applied over the top to emerged cotton. Bromoxynil controls morning glory, cocklebur, spurred anoda, common ragweed and devil's claw but does not harm the BXN® cotton. Because bromoxynil does not affect grass, producers evaluating whether to plant BXN® cotton should factor in the additional cost of grass control.

No more than three applications of BXN®, with a total of 3 pints per acre, can be made per growing season. The last application can be made no later than 75 days before harvest.

Another transgenic product, Roundup Ready™ cotton, contains a gene that makes the plant tolerant to glyphosate (Roundup® Ultra, etc.). Glyphosate controls a wider spectrum of weeds than does bromoxynil, but the timing of the application is more critical. Glyphosate can be applied over the top of Roundup Ready™ until the fourth true-leaf stage. After that time, glyphosate should be applied as a directed spray, avoiding the plant terminal.

Table 2.10. A partial list of cotton insecticides and their modes of action.

Chemical Type	Example	Pests Controlled	Mode of Action	Impact on Natural Enemies
Organophosphate	Acephate (Orthene®), disulfoton (Di-Syston®), phorate (Thimet®), dicrotophos (Bidrin®), dimethoate, methyl parathion, parathion, chlorpyrifos (Lorsban®), azinphosmethyl (Guthion®), malathion, profenofos (Curacron®) Aldicarb (Temik®), carbaryl (Sevin®),	Thrips, cotton fleahoppers, boll weevils, aphids, tobacco budworms, grasshoppers, beet armyworms, *Lygus* bugs, stink bugs, pink bollworm, spider mites, whiteflies	Central nervous system Synaptic poison	High
Carbamate	methomyl (Lannate®), oxamyl (Vydate®), thiodicarb (Larvin®), carbofuran (Furadan®)	Cutworms, thrips, cotton fleahoppers, boll weevils, aphids, tobacco budworms, grasshoppers, beet armyworms, *Lygus* bugs, stink bugs, pink bollworm, spider mites	Central nervous system Synaptic poison	High (Rate dependent)
Neonicotinoid	Thiamethoxam (Cruiser®, Centric®), imidacloprid (Provado®), acetamiprid, thiacloprid	Thrips, cotton fleahoppers, aphids, *Lygus* bugs, stink bugs,	Central nervous system Synaptic poison	Medium
Indeno-oxadiazine	Indoxacarb (Steward®)	Cotton fleahopper, beet armyworm, bollworm, tobacco bollworm, cabbage looper	Axonic poison	Low (rate dependent)
Cyclodiene	Endosulfan (Phaser®, Thiodan®), propargite (Comite®),	Boll weevil, spider mites, whiteflies	Central nervous system Synaptic poison	Medium
Chlorinated hydrocarbon	Dicofol (Kelthane®)	Spider mites	Axonic poison	Low

Some of the materials listed in this table may no longer be registered for use in cotton. Ratings for natural enemies based on Low=0-30% mortality, Medium=31-70% mortality and High=>70% mortality.

Continued on next page

Table 2.10. A partial list of cotton insecticides and their modes of action. (continued)

Chemical Type	Example	Pests Controlled	Mode of Action	Impact on Natural Enemies
Pyrethroids	Bifenthrin (Capture®), cyfluthrin (Baythroid®), cyhalothrin (Karate®), cypermethrin (Ammo®, deltamethrin (Decis®), esfenvalerate (Asana®), fenpropathrin (Danitol®), tralomethrin (Scout®), zeta-cypermethrin (Fury®)	*Lygus* bugs, boll weevils, bollworm, spider mites, stink bugs, cutworms	Axonic poison	High
Formamidine	Amitraz (Ovasyn®)	Bollworm eggs, spider mites	Insect hormone system	High
Insect growth regulator	Methoxyfenozide (Intrepid®), diflubenzuron (Dimilin®), tebufenozide (Confirm®), pyriproxyfen (Knack®)	Bollworm, beet armyworm, tobacco budworm, cabbage looper	Affects molting Insect hormone system	Low
Naturalyte	Spinosad (Tracer®)	Bollworm, tobacco budworm, beet armyworm, cabbage looper	Axonic poison	Low
Avermectins	Avermectin (Zephyr®), emmamectin benzoate (Denim®)	Spider mites, bollworm, tobacco budworm, beet armyworm	Axonic poison	Medium to High

Some of the materials listed in this table may no longer be registered for use in cotton. Ratings for natural enemies based on Low=0-30% mortality, Medium=31-70% mortality and High=>70% mortality.

Transgenic products are also being developed for insect control. The first product is Bollgard®, which is a gene from the soil bacterium, *Bacillus thuringiensis*, that produces a crystal insecticidal protein, often referred to as Cry-proteins. This product was developed to control lepidopteran or caterpillar pests of cotton.

For Bollgard® technology to be useful, it is critical that growers manage resistance. Producers must create refuge areas where non-transgenic varieties are planted in close proximity to the transgenic varieties.

These refuges help ensure that some susceptible insects will be produced and available to mate with more-tolerant insects. Their offspring will be more likely to be susceptible to the technology.

Cotton varieties are currently being developed with several genes that make it more difficult for insects to develop resistance to insecticides.

When using the transgenic technology, crop managers must also be aware of developing pest problems. In weed control, managers must know the proper timing of the herbicide applications as well as the species of weeds that are tolerant to the herbicide being used in conjunction with the technology.

In planning insect control, managers using transgenic varieties must consider the development of resistance as well as developing pest problems. As the boll weevil has been eradicated and transgenic technology has been adopted, cotton producers have reduced the number of insecticide applications on their crops.

However, many of these applications also controlled minor pests. As these applications have been discontinued, the minor pests have become a concern. One example is in the Upper Coastal Bend of Texas, where the stink bug complex has risen from an occasional to a key pest.

When evaluating transgenic cotton as another control tactic in pest management, crop managers must consider all the implications before adopting any technology.