Chapter 27

CROP PHENOLOGY AND INSECT MANAGEMENT

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INTRODUCTION

The literature on the principles, concepts, mechanisms and theories of pest management is extensive. The serious reader is referred to publications by (Chant, 1964; Clark *et al.*, 1967; Geier, 1966; Hall and Norgaard, 1973; Knipling, 1966, 1979; Newsom, 1974; Pimentel *et al.*, 1965; Rabb and Guthrie, 1970; Rabb *et al.*, 1974; Stern, 1966; Webster, 1977) and many others. Book I, Cotton Physiology, (Mauney and Stewart, 1986) in The Cotton Foundation Reference Book Series may be equally helpful.

Simulation models have been employed to investigate the many phenomena which interact with the economics of treatment thresholds (For examples Baker *et al.*, 1986; Jones *et al.*, 1979; McClendon *et al.*, 1981; Spurlock and Parvin, 1988; and others). However, from a practical standpoint, little has been done to improve on Headley's (1971, 1972) original articles. Improvements in sampling techniques (Phillips, 1990) and refined estimates of economic threshold are needed (Harris, 1988; Parvin and Harris, 1986). Investigations of the temporal (of or relating to time) aspects of pests, especially multiple pests, have been constrained by their complexity but are needed. The interactions between broad spectrum chemical insecticides, parasites and predators, and economic thresholds require additional study.

Integrated pest management (IPM) system consists of several basic insect control tactics, two of which are: (a) conservation of naturally occurring parasites and predators for pest control, particularly during early season; and (b) judicious use of chemical insecticides (Harris, 1988; Parvin and Harris, 1986). Other control tactics include host plant resistance, cultural control, use of pheromones, diapause treatments, and crop termination tactics. It should be noted here that the relative importance of (or contributing) the various control tactics will vary among different areas in Cotton Belt and between areawide programs versus single farm programs.

The natural parasite and predator component of our current cotton IPM system [(a) above] is based on their efficiency (Ables *et al.*, 1983) and the knowledge that cotton can tolerate early season fruit loss (and other damage) by compensating with other fruit produced later in the season. Treatment thresholds have been established with the view that delayed corrective treatments were better than early preventive measures (Knipling, 1979). Judicious use of chemical insecticides [(b) above], can follow either of two basic but different approaches. From a broad standpoint, pest control procedures can be classed into two categories (Knipling, 1979)—preventive measures and corrective measures. Preventive measures are taken to suppress pests in anticipation of damage even though there is no absolute certainty that damage will occur in a localized area (farm) or selected field. Corrective measures more often are used and involve applying insecticides only where and when insects are causing damage.

Both approaches have merit. The corrective approach is where insecticide treatment is triggered by economic or treatment thresholds. With the prevention approach, insecticide/miticide treatments are used to manage pest populations before they reach threshold levels (Parvin and Smith, 1985).

Since preventive methods of control involve the application of broad spectrum chemical insecticides that can lead to side effects, more and more emphasis is being placed on pest control only where and when the need for the application is necessary. Integrated pest management (IPM) is based upon the close monitoring of plant and insect conditions and the use of control measures where and when necessary with emphasis on methods that permit natural control agents to have their maximum effect in regulating the pest population. However, when control measures are applied, they tend to involve chemical insecticides. Unfortunately, this approach has gained such prominence and has been emphasized in so many technical and popular publications that many people, scientists and nonscientists alike, have the impression that it is the only system having merit (Knipling, 1979). Their general perception is that it is economically unsound and wasteful of resources to develop or undertake preventive control measures (Knipling, 1979).

This chapter attempts to employ the principles of systems analysis (Conway, 1976; de NeuFville and Stafford, 1971; Optner, 1965; Parvin and Tyner, 1974; Watt, 1970) to investigate the interaction between crop phenology[1] and insect/ mite management on cotton.

HISTORY

Scientists engaged in research on insect and mite control methods have been criticized for being too slow to recognize the limitations of the broad spectrum chemical pesticide approach as the solution of insect pest management problems and for the

[1]Phenology is a branch of science that deals with the relationship of climate and periodic biological pheromones on behavior of organisms.

long delay in devoting more of their research efforts to the study and development of alternatives and more acceptable methods (Knipling, 1979). The public sector research/extension community has been credited with entomological irresponsibility (Newsom, 1974) in the development of cotton insect control technology. It has been accused of promoting insect/ mite control techniques that resulted in "count and treat" methods and finally in "treating without counting", so that by the mid 1950s much of the cotton was treated on a "womb to tomb" schedule. This umbrella of protection stimulated several changes in production practices. Varieties were introduced that extended the fruiting season; and other inputs, such as herbicides, fertilizers and water, were increased to take advantage of the protection granted by the insecticides/miticides.

By the early 1970s, it was apparent that we were on another crisis course due to insecticide resistance. The crisis occurred during the mid 70s (especially in 1976 and 1977) and field populations of tobacco budworm, *Heliothis virescens* (F.) on cotton were not controlled despite higher rates of materials and shorter intervals of applications. If new materials had not become available in 1978, the crisis would have been much worse[2]. The introduction of synthetic pyrethroids gave us several years of excellent control.

ATTITUDE OF PUBLIC SECTOR RESEARCHERS/EXTENSION WORKERS

Public sector researchers and extension workers are concerned about the charge of irresponsibility. Many researchers reacted by excluding most preventive measures of insect pest suppression from "acceptable" methods of pest management, i.e., IPM should be comprised only of corrective techniques. However, both corrective and preventive approaches are needed (Knipling, 1979).

Researchers were not irresponsible during the 1950s, 60s and 70s. Once the insecticide technology developed during (and after) World War II was available, there were strong economic incentives (larger and more stable yields, low insecticide costs and increased net returns) to put it into place. Positions by public researchers in the future will have little impact on the next crisis if economic incentives for their positions are not strong. And, as long as insect/mite control is based primarily on chemical pesticides, failures or crises will occur from time to time.

COST-PRICE SQUEEZE OF THE 1980s

In the 1980s growers were caught in a cost-price squeeze. Production costs were up as prices for most inputs increased. Cotton price declined and net returns were drastically reduced. Because of very limited success with increasing cotton net returns by reducing costs, growers were forced to increase yield. Increased yield requires additional inputs (A notable exception is the work reported by Sterling and Haney [1973]).

With the use of additional inputs, growers were forced to lower their treatment thresholds for insect/mite pests so that these pests did not limit yields. From an eco-

[2]Pyrethroids and new organophosphates were available in 1977-78 on a limited basis under a FIFRA Section 18 (Emergency Use) program. They were conditionally registered for use in 1979.

nomic efficiency standpoint, as other inputs are increased, insect/mite treatment thresholds must be reduced or inputs are not being employed correctly (Leftwich and Eckert, 1982; Samuelson, 1961).

CRISIS FOR THE 1990s

Are we on course for another crisis in cotton insect control? Producers are more aware of the benefits of early-season insect control (Anderson *et al.*, 1976; Carter, 1990; Kerby, 1988; Jenkins, 1990; Mauney, 1988: Parvin, 1990a-e; Parvin and Miller, 1986; Smith, 1990). Economic incentives for increased, realized yield and larger net returns through earlier maturity are strong at this time.

Another insect control crisis will occur unless new insecticides/miticides are developed and/or improved strategies for insect/mite management become available soon. And, quite frankly, cotton insect/mite control technology in most of the United States Cotton Belt, into the foreseeable future, will probably depend almost entirely on chemical pesticides.

When the crisis occurs, biological and economic conditions will force the producer to modify his approach to insect/mite management. In the meantime, the increased use of insecticides during early season is sending strong economic messages to the chemical industry to develop new insecticides and sending strong biological messages to the public sector extension/research community to develop improved management strategies.

COMPLEXITY OF PEST CONTROL DECISIONS

Insect and mite pest control decisions are very complex. When long range considerations are included, as most researchers insist they should be, the decisions are more complex.

Clearly all costs should be considered. Early season foliar applications can result in increased numbers of late season applications by inducing secondary pests to major pest status and/or by eliminating beneficial predators and parasites which may result in additional treatments directed toward mid and/or late season bollworm/tobacco budworm. In such cases, the increased cost of the late season program should be considered. Additionally, if the insect control program selected increases the rate of insecticide resistance, a cost should be charged for the change in the level of resistance.

THRESHOLD LEVELS

Generally, the application of chemicals to control cotton insect/mite pests is recommended only if they attain threshold levels. Recommended thresholds are treatment guidelines, not necessarily "true" thresholds. The need to lower or raise a threshold level is influenced by individual conditions on a farm-by-farm or field-by-field basis.

Conceptually, the term, "economic threshold," has meaning to both growers and professional agriculturists. While we may know how to estimate treatment thresholds, we still lack satisfactory estimates of most of the key parameters required (Harris, 1988; Phillips, 1990). Hence, we do not know if our recommended thresholds are correct. And, while individual populations of multiple pests may be at sub-economic levels, indicating no treatment, the combination of all the pests may result in economic damage.

Finally, thresholds should include a temporal aspect. Currently, sub-threshold levels for an extended period of time do not trigger insecticide/ miticide treatment. However, it is known that sub-treatment levels that persist over a period of time may do considerably more damage than a few days with populations slightly above the treatment thresholds.

LONG TERM VS. SHORT TERM CONSIDERATIONS

Public sector agricultural workers tend to be conservative and place more emphasis on long term costs (such as the cost of resistance) than do growers. Many growers mainly are concerned with year-to-year economic survival of their farms. They discount long term considerations. In fact, many growers ignore costs that do not move through the current marketing year. There is no market for resistance. For example, a grower is charged the same unit price for a needed application as for an unnecessary application of the same material that only contributes to resistance. Consequently, growers with considerable funds at risk and the many uncertainties for future years often arrive at different decisions relative to the use of insecticides/miticides than do public sector researchers.

The agricultural research community is beginning to investigate and partially understand the complex interrelationship between early season/mid season insect feeding, the plant's ability to compensate for that feeding, and harvesting economics. With improved and expanded educational activities concerning all aspects of this complex interrelationship, growers will be able to make improved decisions with regard to insect management.

CONSIDERATION OF THE COTTON PLANT

SYSTEMATIC AND PREDICTABLE MANNER OF COTTON GROWTH AND DEVELOPMENT

The cotton plant itself must be considered in insect/mite management decisions. Physiologically, cotton grows and fruits in a systematic and predictable manner. Because it is systematic and predictable, the fruiting sites can be accurately numbered. The main axis and branches have nodes. The first three to nine (usually six) modes of the main axis above the cotyledon leaves usually produce vegetative branches (or no branches). Once fruiting (flowering) begins, each node out each fruiting branch contains a fruiting site (exceptions are extremely rare). Familiarity with the mechanics of plant mapping has increased significantly among growers and others in the last several years. Educational activities of state extension cotton specialists and the Cotton Physiology Education Program sponsored through The Cotton Foundation have made major contributions in this respect.

Because fruiting occurs in a systematic manner, several important fruiting events move up and out the plant in a systematic and predictable manner. In order of occurrence, they are: squares, blooms, green bolls (young green bolls that are subject to insect damage, older green bolls that are generally "safe" from insect damage, and green bolls that are mature in terms of seed and fiber development), and open bolls.

All of these events are important, but the interactions between the events is more important. The research community is just beginning to investigate the relationship between safe/mature green bolls and defoliation and harvesting. An understanding of this relationship and its interaction with insect management decisions will lead to the development of improved cotton production systems and better understanding insect/mite management.

POTENTIAL ECONOMIC VALUES OF DIFFERENT FRUITING SITES

Fruiting forms at different sites do not have the same potential economic value (Jenkins, 1990; Jenkins *et al.*, 1990a,b). The value of a given fruiting site is a function of its average weight (and quality) and the probability it will be harvested. Table 1 gives the dollars per acre value by fruiting site for solid planted cotton in Mississippi. In lower yielding areas of the Cotton Belt, plants may have fewer fruiting branches. Nevertheless, while specific estimates of dollars per acre value by fruiting site may vary by regions (and by varieties within region, and by years) the important trend in value remains unchanged.

There is much valuable information summarized in Table 1. On every fruiting branch, the first fruiting position produces two to ten times more money than the second position.

All first position bolls begin their life as square primordia or baby squares in the terminal (Jenkins, 1990). Every first position boll begins its life in the terminal. No other position fruit does that. Damage to the terminal will affect the first position bolls or the more valuable bolls. In the terminal there are square primordia for the next four nodes or fruiting branches (Jenkins, 1990). Terminal damage can show up as missing first position squares at the next four nodes. And, when observed, will be impossible to correct (Jenkins, 1990).

The best site, 11.1 (e.g. 11th node, 1st position) is approximately 16 times more valuable than site 20.1 (20th node, 1st position) and over 600 times more valuable than site 20.2. Therefore, in simple economic terms, based on the physiology of the plant, we should spend 16 times more money to protect fruiting site 11.1 than 20.1, etc.

Insecticide treatments provide protection for a period of time (The length of the protection period can be influenced by several factors). Sites 11.1 and 9.2 are the same age with a total value of $62.15. Sites 21.1 and 19.2 have a total value of $1.46. The rational grower will spend over 42 times more money to protect sites 11.1 and 9.2 than 21.1 and 19.2. The bottom or early sites are more valuable than the sites near the top of the plant.

Plant stress can cause shedding of fruiting forms and/or interfere with maturation of harvestable bolls fruit from fruiting sites. The major stresses (or causes of stress) are: water stress, nitrogen stress, carbohydrate stress (low solar radiation, etc.) and insect

Table 1. Dollars per acre value by fruiting sites for solid planted cotton in Mississippi[1,2]. (Source: Jenkins [1990].)

Position 3	Position 2	Position 1	Mainstem Node	Position 1	Position 2	Position 3
	$ 0.09	$ 0.91	21			
			20	$ 2.73	$ 0.07	
$0.01	$ 0.55	$ 5.86	19			
			18	$11.44	$ 1.02	$0.09
$0.13	$ 2.09	$17.22	17			
			16	$25.54	$ 4.31	$0.30
$0.62	$ 6.65	$35.28	15			
			14	$41.11	$ 8.11	$0.63
$1.26	$11.00	$42.65	13			
			12	$44.66	$11.47	$1.84
$3.09	$13.36	$44.98	11			
			10	$41.39	$16.22	$2.56
$2.87	$17.17	$38.15	9			
			8	$32.13	$14.98	$3.08
$1.65	$ 7.57	$21.12	7			
			6	$ 8.33	$ 2.99	$0.21
		$36.82	V[3]			

[1]Based on 60 cents price of lint.
[2]Mean values of 8 varieties and 2 years.
[3]Vegetative branch (V).

damage. When the majority of the important fruiting sites are squares, water, nitrogen and carbohydrate stresses are not usually present. Most of the important sites that are lost as squares especially in early season, are lost to insects.

EARLY MATURING/SHORT SEASON CROP

An early maturing crop (with acceptable yield) requires a short squaring period with little or no stress (fruit loss) during the effective squaring period or prior to first bloom. A 135-day crop (an important consideration in most of Coastal Texas, most of the Mid-South and most of the Southeast) is one that allows an early harvest and requires that all the fruit to be harvested develop from the squares from the first four (4) weeks of squaring. With modern varieties and technology this is not difficult if the plant is not stressed. The idea is to rush the plant or crop along to a natural carbohydrate cutout as soon as possible. The easiest and surest way to accomplish this is to set more fruit than the plant can support and allow the plant to decide which sites to abort. The plant will retain the oldest, largest, most valuable fruit and shed the youngest, smallest, least valuable fruit (Mauney and Stewart, 1986).

Physiologically, the plant is designed to handle water, nitrogen and carbohydrate (physiological) stress with minimal damage or delay. At each fruiting site, there is a "valve" (called the abscission "valve" or abscission zone) at the base of the peduncle stem that supports the fruit. With physiological stress, the plant simply closes this "valve" on enough fruiting sites to reduce the stress. Physiologically, this process is part of the genetics of the plant. When the "valve" is shut, nutrients stop flowing to the fruit, and in a few days the fruit aborts (falls off) leaving a well healed scar. With insect damaged fruit, nutrient transfer will continue for several days after damage occurs—a complete waste. And, insects do not always feed on the youngest, smallest, and least valuable fruit. As a matter of fact, during the first few weeks of fruiting (pre-bloom), most of the squares are associated with important sites that are most likely to be harvested. Clearly, from an economic and plant physiology standpoint, the dominant insect management strategy is to assist the plant to retain as much of the early fruit (squares) as possible. Cotton grows in a regular, systematic, and predictable manner thereby enhancing ease of management.

There is another advantage from managing or providing for a high percentage of fruit setting during the first few weeks of fruiting. However, it is difficult to quantify in terms of monetary value or economics. Depending on weather conditions and other factors, many varieties of cotton will get into a "vegetative mode" if fruit are not set on the early sites. In such cases, the grower tends to lose control over management of the cotton plant itself (with respect to vegetative growth and fruit development).

HARVESTING CONSIDERATIONS

Harvesting of cotton is time consuming (Cooke *et al.*, 1991). The failure to harvest a significant portion of a crop can lead to immediate economic disaster in terms of the farm firm's ability to survive. Failure to harvest in a timely fashion or producing the crop in such a manner that maturity is delayed also can create a disaster (Jones *et al.*, 1979; McClendon *et al.*, 1981; Parvin, 1990a,b). Recent improvements in cotton varieties and production practices have greatly increased the potential for earlier maturing cotton with increased yield and returns. Consequently, the timing of the cotton harvest can have a substantial impact upon economic returns—for a given potential yield, timely harvesting, as it affects the producer's ability to initiate and complete harvest at an earlier date, generally will result in a higher yield being realized (Parvin, 1990e).

On the average, mechanical cotton pickers (two-row) in the central area of the Delta region of Mississippi are used to harvest 302 acres with a 50 percent (151 acres) second pick (Parvin and Cooke, 1990). The performance rates (fraction of an hour required to harvest one acre) are: 0.53 hour for first pick and 0.39 hour for second picking. First pick time requirements are 302 acres at 0.53 hours per acre or a total of 160.06 hours for 302 acres. Second pick time requirements are 151 acres at 0.39 hours per acre or a total of 58.89 hours. Therefore, harvest (first and second picks) requires a total of 218.95 hours to complete.

The amount of work that can be accomplished (hours worked per week) is a function of "days fit" (days suitable for harvest) and the number of hours that can be worked per day (Table 2). The number of acres harvested per week is a function of hours worked per week and the performance rate. The pounds of lint that can be harvested per week are related to acres harvested, agronomic yield, and the rate at which yield deteriorates over time (Parvin, 1990d).

Conceptually, in the Mid-South, harvest can be completed in 22 ten-hour days (based on a 2-row picker being able to harvest [1st and 2nd picking] 302 acres in 22 hours). However, due to weather conditions, on the average, first pick requires 29 days and second pick requires an additional 20 days. Or, simply stated, in many years harvest will require more than seven weeks. How a cotton grower views the risks associated with harvest season weather conditions as a function of harvest initiation date affects his decisions on planting dates and on insect control, especially during early season. Delayed maturity lengthens the harvest in terms of calendar days by more than the delay in harvest initiation date.

It is important to note that, in regions of the Cotton Belt with uniformly favorable harvest weather (as may exist in parts of the extreme western portion of the Cotton Belt), the relationship between harvest efficiency, the plant's ability to compensate, and the implications for insect control are much different. Therefore, the appropriate treatment threshold for a given insect pest will vary by regions of the Cotton Belt, due primarily to differences in the severity of weather during the harvest season.

Realized yield is often referred to as commercial, farm or producer yield. The term "economic yield" is also appropriate. These terms embody the concept of harvesting over a lengthy period of time. Research terms like maximum yield, potential yield, agronomic yield and experimental yield embody the concept of rapid sampling, usually less than one day. Extrapolation of experimental yields to farm yields should be done with extreme care. The maturity/harvesting relationship is critical and must be considered carefully in the design, conduct and interpretation of cotton research.

Table 2. Expected days suitable for harvest, hours per day suitable for harvest and acres harvested per week, Mississippi Delta. (Source: Bolton *et al.*, 1961; Cooke *et al.*, 1991; Parvin and Cooke, 1990.)

Dates	Days suitable for harvest	Hours/day suitable for harvest	Acres harvested per week First pick	Acres harvested per week Second pick
8/28-9/03	4.66	9.11	80	—
9/04-9/10	4.77	9.02	81	—
9/11-9/17	4.88	8.97	83	—
9/18-9/24	4.90	8.88	82	112
9/25-10/01	4.74	8.84	79	107
10/02-10/08	4.72	8.75	78	106
10/09-10/15	4.39	8.66	72	97
10/16-10/22	4.04	8.55	65	89
10/27-10/29	3.59	8.39	57	77
10/30-11/05	2.34	7.91	35	47
11/06-11/12	1.96	7.51	28	38
11/13-11/19	1.44	6.97	19	26
11/20-11/26	1.35	6.60	17	23
11/27-12/03	1.30	6.37	16	21

We have failed to understand the difference between taking yield estimates in small plots and harvesting commercial cotton and have missed the relationship between the timing of the initiation of harvest, length of harvest and realized yield as a percent of agronomic yield.

Even though the cotton plant, in terms of yield potential, may "compensate" for a loss of early fruiting forms by replacing them with a later fruiting form, the consequent delay in maturity would be expected to result in reduced economic returns (Parvin, 1990a,b). Earliness of maturity of cotton is affected by a complex set of factors that complicate both: (a) research design, conduct and interpretation of results; and (b) production management of commercial cotton. Such things as variety (genetics and physiology of the plant); soil type; drainage conditions; fertility practices; weed, insect and disease control practices; and irrigation practices can be managed to enhance earliness of maturity and economic returns. The magnitude of the expected increases in economic returns suggests careful consideration be given to "earliness" and to the lack of compensation in commercial cotton in the development of recommendations and the management of insects in much of the Cotton Belt.

Until recently, the consensus view in the public sector research/extension community was that early season insects in cotton delayed maturity but did not decrease yield.

For cotton grown in small research plots and harvested quickly, the view is true. For commercial cotton, this view is false, because of the difference between small plot experimental yield and producer yield.

Experimental trials using small plots where yields are obtained on a rather instantaneous basis can result in yield estimates in which the cotton appears to have compensated for the early season insect damage or delay in maturity. Such is not the case in commercial cotton due to the length of the harvest season as a function of maturity. Improvement in cotton maturity will increase harvesting efficiency, commercial yield and returns even though agronomic yield in unchanged.

CONSIDERATION OF FRUIT LOSS COMPENSATION

The ability of the cotton plant to compensate for early fruit loss is well known among growers and professional agriculturists. It is a major factor in approaches to insect control or management.

Figure 1 indicates that squaring begins about day 40 (approximately 30 days after emergence), increases to approximately day 75, levels off to day 95 and declines. Since 80 to 95 percent of the fruiting sites will shed their fruit as squares or very small bolls (in the absence of insect damage), the compensation principle states that the early squares (days 40-70) are not important since they easily can be replaced by a small fraction of the large number of squares being formed after day 70 (during the heavy fruiting period, days 75-95). Because of this relationship, treatment thresholds for early season insects which damage squares (or other plant parts) have been kept artificially high, avoiding insecticide treatments and enabling beneficial insects to increase in early season so that they can aid in the control of bollworm/tobacco budworm in mid and late season.

The phenological events summarized in Figure 1 are relatively simple but have important implications for insect control. Much of the Cotton Belt is confronted with a 135-day effective growing season. For the Mid-South this translates to a planting day of May 1 and a harvest initiation date of about September 15. Consequently, the mature/open boll period can only extend from relative day 100 to day 135 (35 days). Therefore, all the harvestable bolls must occupy fruiting sites that were squares on days 40 to 70 (30 days). The difference in the 35-day open boll period versus the 30-day effective squaring period is partly due to lower temperature during late season.

If stresses remove enough squares from the fruiting sites that developed during the first 30 days of fruiting (days 40 through 70) so that the resulting green bolls do not induce a natural carbohydrate cutout early enough to end the open boll period by day 135, then the season is extended. Extension of the season dictates that the effective squaring period must be extended. If 20 additional days of squaring is required (days 70 through 90), then the open boll period is extended to days 135 though 160 (25 days). In simplest terms, this means that the bolls that were opened during days 100 through 135 are subjected to an additional 25 days of exposure to the environment and can suffer deterioration in weight and quality.

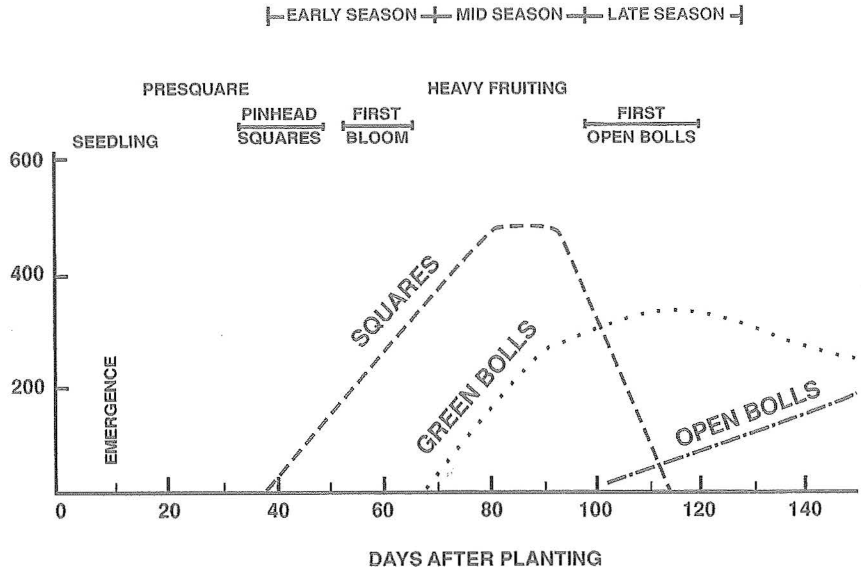

Figure 1. Seasonal development of cotton.

It is important to note that regions with a longer growing season and uniformly favorable harvest weather can extend the season and allow the plant to compensate for the early damage. However, the longer season may require the application of additional inputs such as: herbicides, insecticides, irrigation water, fertilizer, etc. And, if compensation must be attempted in regions with deteriorating harvest weather, per acre harvesting costs will also increase.

Delayed maturity will extend the growing season and delay the initiation of harvest. Additionally, because of the relationship between days suitable for harvest and the passage of time during the harvest season, the harvest season will be lengthened in terms of calendar days. Consequently, harvesting efficiency will be reduced and harvesting costs will be increased. And, because of additional exposure of some of the open bolls to deteriorating environmental conditions, commercial yield and quality will be lowered, resulting reduced returns.

It is not a question of insects causing direct yield losses; rather, it is insect damage resulting in the same or equivalent yield just a little later, i.e., a delay in maturity with full yield compensation. The delay in the initiation of harvest simply means that commercial or realized yield as a percent of agronomic or produced yield is reduced (Parvin, 1990b).

The process is best explained by looking again at our most important research data—yield. Even though we tend to use all yield terms as synonyms, and even though we have considerable research data indicating full compensation to early (and mid-season) damage, we now are beginning to understand that commercial cotton (in most of the United States Cotton Belt) cannot fully compensate because of the length of the harvest season and our deteriorating weather as the season progresses. Or conversely, our research data indicates full compensation because we took our yield estimates quickly and full compensation is not possible in commercial cotton because of the lengthy harvest season, harvest season weather, and harvesting cost. Yield compensation requires additional time. Time in and of itself has economic value. Compensation at the expense of time carries a cost.

EXAMPLE

The cost of delayed maturity and/or the value or earliness will differ by regions of the United States Cotton Belt. Because of the declining gradient in "Days fit" and "Hours/day" (columns 2 & 3 of Table 2), the cost of delay will be larger in absolute terms than the value of earliness.

Table 3 provides an estimate of the value of 14-day earliness (advancement in maturity) at Stoneville, Mississippi and at Moree, New South Wales (Australia).

Clearly, two weeks of earliness is desirable at Stoneville and at Moree but for very different reasons. For example, the increase in yield and quality amounts to 51 percent of the total value at Stoneville but only 14 percent at Moree. This is due to differences in the severity of harvest weather at the two locations. Other differences shown in Table 3 are a function of harvesting equipment cost, interest rate and soils.

Table 3. Summary of the estimated value of 14 days of earliness for cotton at Stoneville, Mississippi vs. cotton at Moree, New South Wales, Australia. (Source: Parvin, 1990f; Parvin, 1991.)

	Value per acre	
	Stoneville	Moree
	$US	$US
Decrease in interest charge of production loan	2.86	8.04
Increase in interest earned on net margin	0.62	2.70
Decrease in picker fixed cost	9.04	23.53
Decrease in variable irrigation cost	9.00	10.12
Decrease in insect control cost	16.01	17.41
Improvement in soil compaction	40.00	60.00
Sum	77.53	121.80
Increase in yield	52.20	14.79
Increase in quality	23.88	4.52
Sum	76.08	19.31
Total	153.61	141.11

IMPLICATIONS

The current debate over alternative methods of insect control was never over late season insect pests but concerns the best method of controlling early season insect pests within a commercial cotton production system in selected portions of the Cotton Belt. Late season insect pests tend to have definite generations within the cotton growing season, and the consequences of their damage is relatively easy to understand, i.e., compensation is no longer an issue. Much good research has been conducted on late season insects and our treatment threshold levels for these pests ar probably about as they should be. But, when the economic threshold is uncertain or unknown or is impractical to measure, as appears to be the case with most early season insect pests (Harris, 1988), the grower may opt to use a preventive application during early season with the expectation that it will: (a) enhance maturity; (b) result in reduced late season insecticide applications; and (c) increase harvesting efficiency, realized yield and returns.

When the cotton plant is managed in concert with its genetic makeup, management strategy tends to be more successful. In parts of the Cotton Belt—with 130-140- days to make the crop, with deteriorating weather as the harvest season is extended, and with treatable levels of early season insect pests in most fields in most years—the preferred approach to cotton management (based primarily on harvest economics and plant physiology) currently includes as a subcomponent the preventive approach to insect management during early season and a shift to the corrective approach for mid and late season. Growers, in parts of the Cotton Belt where it can be successfully utilized, are opting for this approach.

Intuitively, all parties involved (growers, consultants, researchers, extension workers, industry representatives, etc.) would prefer a corrective or threshold approach for early, mid and late season. However, the authors of this chapter believe the final decision rests with the grower. A few researchers (Barker, 1982; Carter, 1990; Harris, 1988; Parvin, 1990; Parvin & Harris, 1986; Parvin & Miller, 1986; Mauney, 1988; Smith, 1990) are beginning to address this complex area.

Preventive techniques need not conflict with IPM. Used correctly they can improve the effectiveness of IPM. Preventive approaches to insect management should be employed if, and only if, they are clearly superior to corrective approaches. Many growers have demonstrated a preference for the short run benefit of the harvesting economics associated with early maturity and its interaction with early season insect control versus late season insect control. Researchers are moving in that direction. For example, the current Mid-South Resistance Management Plan (Phillips, 1990) recommends the preventive use of an in-furrow insecticide applied at planting. Early maturity is now the key component of the Mid-South Resistance Management Plan.

The authors of this chapter recommend the consideration of resistance management program of the type suggested by Leigh (1989) and Wilson (1989) for secondary pests. It is a futuristic idea whose time has come. It is time to begin to move away from farm-by-farm or field-by-field approaches to insect management. Because they impact only a portion of the population, they are doomed to be needed year after year and in time, will fail (Knipling, 1979). We must move toward sustainable techniques which will reduce the pesticide load in the environment over time and which may need to include preventive techniques to lower original or temporary pest populations to levels suitable for management with current or modified IPM. Preventive techniques will be less controversial or more acceptable in areawide pest management programs. We should always remember that today's approaches will be unacceptable tomorrow.

SUMMARY

The current debate is over the early season insect control sub-component of the overall cotton insect management system. There is no significant disagreement concerning the use of thresholds to treat mid to late season insect pests.

Early season treatment has generally been discouraged because of the insecticide resistance and secondary pest(s) problems encountered in the recent past when cotton insecticides were widely used in a scheduled program. Even though the cotton plant may "compensate" for a lost early crop by replacing it with a later crop in terms of yield potential, the consequent delay in maturity (loss of time) can: lengthen the harvest season; reduce harvesting efficiency; increase harvesting costs; and lower commercial yield, quality and returns. Economic considerations of the interactions between crop phenology and insect management are the key to understanding these complex phenomena.