Chapter 22

INSECT AND MITE PEST MANAGEMENT IN THE SOUTHWEST[1]

James F. Leser
Texas Agricultural Extension Service
Lubbock, Texas
and
Miles A. Karner
Cooperative Extension Service
Altus, Oklahoma
and
Charles R. Ward
Cooperative Extension Service
Albuquerque, New Mexico
and
J. K. Walker
Texas A&M University
College Station, Texas

INTRODUCTION

The Southwest region of New Mexico, Oklahoma and Texas is rich in entomological history. Contributing to the story have been the insects of cotton and man's efforts to manage them. It was at Brownsville, Texas where the boll weevil first entered the United States in 1892, forever changing the face of cotton production and shaping the development of insect management for years to come. Both Texas and Oklahoma have shared the weevil experience that has molded the development of their current management strategies. Lacking infestations of weevils, New Mexico's management approaches are more similar to the Texas High Plains area, another area where the boll weevil has failed to gain a foothold. The successful development of cotton insect management systems in all three states was dependent upon the unique ecological conditions found in these regions of limited rainfall. In this chapter we will examine the historical progression of insect and mite control recommendations and management guide changes, and the factors responsible for these changes.

[1]USDA's Crop Reporting Service, the United States cotton industry and other groups generally include New Mexico in the West region along with Arizona and California. Because of similarities in insect and mite problems and management practices to those in Texas, the authors of this chapter chose to include New Mexico in the Southwest region along with Texas and Oklahoma.

TEXAS RECOMMENDATIONS

The 1920s were a time of optimism for Texas cotton growers. Acreage had been increasing yearly, with about 18 million being grown in 1926. The chief cotton entomologist of the Bureau of Entomology of the United States Department of Agriculture (USDA), B. R. Coad, had only recently declared that the long awaited solution for the boll weevil, *Anthonomus grandis grandis* Boheman, problem, calcium arsenate, had passed all reviews and now was ready for farmer use (Little and Martin, 1942). This came as the best of news to Texas growers farming about 13 million infested acres. Moreover, airplane application of calcium arsenate, technology pioneered by Coad, seemed imminent. To expedite the development of calcium arsenate at the farmer level, special USDA agents were dispatched to key locations in all cotton growing districts, where they conducted on-farm demonstrations (Parencia, 1978).

On another front, the Texas Agricultural Experiment Station had been graced in 1927 with a special appropriation from the Texas Legislature, money that would hire seven entomologists to research cotton insects (Little, 1960). The Legislature had been moved to this action by the outcries of farmers from South Texas who were suddenly encountering the unanticipated damage from an insect that had long infested cotton but apparently had caused no damage. The insect was the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter). In 1933, following emergence of this new pest, a USDA laboratory at Port Lavaca, Texas was established for fleahopper investigations. In short order a remedy seemed at hand — sulphur dust and sulphur mixed with certain arsenicals (Parencia, 1978).

A third insect was discovered infesting limited cotton acreage in the far western area of Texas in 1918, the pink bollworm, *Pectinophora gossypiella* (Saunders). In 1936, the pest invaded the Lower Rio Grande Valley (LRGV), a cotton district of substantial acreage. Lacking an effective insecticide for the insect, USDA and later state experiment station scientists concentrated on developing cultural management tools that gave farmers the means to control the pink bollworm. But for the other pests, insecticides seemed the only answer.

Hence, insecticide research by the entomologists necessarily involved the boll weevil, the cotton fleahopper—and to an extent the bollworm, *Helicoverpa zea* (Boddie). Many small and large plot experiments were conducted in the 1930s in East, Central and South Texas. Apparently, the results of this experimentation overstated to farmers the value of sulphur and calcium arsenate. The positive benefits noted in controlled experiments were rarely as evident when the materials were applied by farmers. Sulphur, in reality, was a poor material for the fleahopper, and if calcium arsenate was a superb remedy for the weevil, its use was commonly followed by secondary insect outbreaks (Walker, 1984). The cost-benefit ratio, especially of calcium arsenate, was not a persuasion for wholesale farmer adoption. Though imperfect insecticides, the base of understanding derived from their testing cleared the way for the organic insecticides of post-World War II.

No matter that farmers never wholeheartedly accepted calcium arsenate or sulphur, the experiences involving them set the stage for the more effective insecticides that were to come. Current Texas cotton insect control philosophy often has evolved from the experiences with the far less effective insecticides of sixty years ago. For example, earliness in cotton production was emphasized as a goal when it was recognized that the cotton fleahopper was interfering with the process, and the mediocre results of sulphur applications certainly intensified the focus. With calcium arsenate applications for the boll weevil, there appeared the problem of secondary insects: cotton aphid, *Aphis gossypii* Glover, and to some extent, the tobacco budworm, *Heliothis virescens* (Fabricius), and the bollworm. Calcium arsenate often created more problems than it solved. When the modern and effective insecticides became available in the late 40s, mixtures were commonly recommended to specifically answer the anticipated secondary pest problems.

The outlook and agenda of cotton entomologists of the 1930s were influenced by the stark realities of their situation. If they knew that the boll weevil could be managed by prompt and early stalk destruction in the fall, they also recognized that such a practice was beyond their means. Hand harvesting, lack of harvest-aid chemicals, a protracted harvest period, and stalk destruction severely limited by the available equipment, was the dominating reality. Entomologists being utilitarians, could conclude only that, in a practical sense, boll weevil control really meant controlling summer generation weevils with a series of insecticide treatments during the blooming period. They saw this as the logical course. The prevailing management today, by contrast, is to avoid multiple applications during the blooming period, if at all possible. Today, earliness is the heart of insect management in Texas, and we understand how to secure it with effective insecticides.

Sulphur and calcium arsenate, admittedly inferior products, may well have been effective if the materials had been applied properly and in a timely manner. We can never answer that, but because of the limitations of the Texas Agricultural Extension Service (TAEX) education program in cotton entomology at that time, many growers might not have been properly informed. There was only a single extension entomologist from 1920-1938, and this person, R.R. Reppert, had educational responsibilities in all areas of entomology including: crops, household and livestock.

According to J. C. Gaines, one of the seven entomologists of 1927 and later Head of the Department of Entomology at Texas A&M University (Personal communication), the research entomologists of the 1930s were often called upon for extension activities because of the limited extension capability. Adding a second extension entomologist in 1939 improved the lines of communication and increased extension's capabilities. The new extension entomologist, Cameron Siddall, worked closely with J. C. Gaines, and conducted extension demonstrations on calcium arsenate throughout Central Texas. Gaines saw an improvement in grower understanding after Siddall's arrival. In contrast to only two extension entomologists in the late 1930s, there are over forty extension entomologists in Texas today.

The idea of a statewide extension guide to aid growers in cotton insect control originated with Cameron Siddall. The first such guide was published in 1942 (Siddall and

Gaines, 1942). A single guide served all the different cotton regions of Texas. USDA entomologist K. P. Ewing, of the 1939 created cotton insect laboratory at Waco, also helped draft the 1942 guide. Interrupted by World War II, the development and publication of an annual state guide did not resume until 1947. It has continued each year since.

The remainder of this section is an examination of the changes and evolution of the Texas cotton insect management strategy and extension guide as chronicled through the guides since first published in 1942.

PRODUCTION AREAS IN TEXAS

There are several production regions of Texas that differ significantly in growing season, rainfall, temperature and pest problems. Because of these dramatic differences, a single guide of recommendations for the entire state is no longer published. Instead, specific guides are developed for each of the regions. An understanding of the geography and climate that shapes regional pest problems is necessary to follow the development of Texas' insect and mite management recommendations as presented in the guides. Texas is a large state with several cotton production regions that have evolved over time. Rainfall ranges from near 50 inches per year in extreme East Texas to about 10 inches in western El Paso. The boll weevil, a much more serious pest in high rainfall areas, encouraged the planting of considerable acreage in the lower rainfall areas to the west. These were the very areas that provided the environmental resistance that farmers were looking for to manage the boll weevil, i.e., shorter growing season, lower fertility (and hence more rapid maturing cotton), harsher winters, and less overwintering habitat for the boll weevil. Most Texas cotton production now is located in areas receiving 35 inches or less rainfall per year. Roughly 90 percent of Texas cotton acreage is planted to short-season stripper cottons.

The major cotton production areas of Texas today are the: (a) Lower Rio Grande Valley (LRGV), (b) Gulf Coast, (c) Winter Garden area near Uvalde, (d) Blacklands Prairie area, (e) Central River Bottoms, (f) the Rolling Plains, (g) the High Plains, and (h) Far West Texas. The Lower Rio Grande Valley encompasses 300,000 acres utilizing a medium season system without relying on rapid-maturing varieties. Fifty percent is irrigated. The Gulf Coast is characterized by moderate temperatures, fertile soils, and an annual rainfall ranging from 26 to 56 inches. Cotton is planted on 266,550 acres of cropland from immediately east of Houston to Kingsville. Most of the cotton production is dryland, but only 20 percent is stripper harvested. The Winter Garden area consists of 40,000 mostly irrigated acres of high input production, including Pima cotton. At various times, the Lower Rio Grande Valley, Gulf Coast, and Winter Garden areas were combined into a single management region referred to as South Texas. The Central River Bottom area, mainly the Brazos Valley, is a very fertile production area of 50,000 acres utilizing management practices that were employed in the era of season-long insecticide programs. It is the one place that has not embraced the shorter-season production concept. The Blacklands Prairie area from Dallas to Austin has shrunk from five million acres of cotton during the 1920s to about 200,000 acres of mostly dryland stripper-harvested cotton. The River Bottom and Blacklands Prairie areas often were referred to collectively as Central Texas. The Rolling Plains consists of 1,000,000 acres of predominantly dryland stripper-harvested cotton. The High Plains area encompasses about 3,000,000 acres of short-season stripper cotton. Less than 50 percent is irrigated. The Far West Texas area is a desert area with isolated pockets of production totaling 400,000 acres. The High Plains, Rolling Plains, and Far West Texas areas make up what is known as the West Texas region.

INSECT AND MITE PROBLEMS IN TEXAS

Major insect pest problems in the state are the boll weevil, bollworm, tobacco budworm, cotton fleahopper, early-season thrips, and recently the cotton aphid. Sporadic pests include: spider mites, plant bugs, pink bollworms, stink bugs, cutworms, grasshoppers, leafworms and the silverleaf whitefly, *Bemesia argentifolii* (Bellows and Perring). The importance of pests varies geographically. The boll weevil is important to all areas except the High Plains and most of Far West Texas. The cotton fleahopper can be important in all state areas and its management can have a profound effect on the development of later pest problems. Plant bugs, in association with fleahoppers, can be a serious Blacklands problem. Thrips are primarily a problem in the Blacklands and High Plains areas. Bollworms are a major concern for most of the state while the tobacco budworm, a pest that has developed resistance to several insecticides, tends to plague the more southern and eastern production areas. The cotton aphid only recently has been elevated to major pest status, primarily in the western part of the state.

Boll Weevil — Successful management of the boll weevil has been of paramount consideration in developing workable management systems for Texas cotton insects and mites. From the earliest days of weevil infestations until the present, insecticides have been an integral part of that management. Calcium arsenate dust was the first effective weevil insecticide, but its benefits were never fully realized in the state because of various shortcomings. Cotton aphids, and at times bollworms, would appear in calcium arsenate treated fields; and there were no adequate insecticides for controlling these pests. Nevertheless, researchers often showed that the use of calcium arsenate in experimental plots made money—cotton yields were increased. Entomologists developed economic thresholds for the material in the 1930s. The economic threshold used for the boll weevil in the early 1940s for calcium arsenate applications was set low, insuring that most acreage met the criteria to dust from early to late season (Table 1). However, by 1947, Texas entomologists were recognizing the value of insecticides applied to presquaring cotton for controlling overwintered weevils. This permitted an early crop set and avoided the need to make late season applications to protect late fruit. Late-season weevil applications destroyed beneficial insects, leading to bollworm outbreaks (TAEX 1947). Nevertheless, entomologists of those times believed that in the long-season production areas such as the irrigated Lower Rio Grande Valley, multiple late-season treatments were a reasonable course.

Table 1. Evolution of key boll weevil control recommendations in Texas.[1]

Year	Region	Recommendation
1942	State	Overwintered weevil control. At 1/3rd grown squares, ET[2]=10 percent punctured squares. Late season[3] control, ET=15 percent punctured squares. Calcium arsenate dust.
1948	State	Overwintered weevil control. Presquare applications where history dictates. Late season control, ET=10-25 percent punctured squares.
1949	State	Late season control, ET=25-35 percent punctured squares. Organochlorines.
1957	State	Recommended organophosphates for organochlorine resistant weevils.
	LRGV[4]	Late season control, ET=15-25 percent punctured squares.
1964	West Texas	Overwintered weevils. Where weevils found. Late season, ET=15-25 percent punctured squares.
1979	State	Overwintered weevils. ET=1 weevil found or field history. Two automatic sprays 3-5 days apart.
	West Texas	Late season, ET=30 percent punctured squares.
1982	Corpus Christi	Overwintered weevils, Trap Index.
1988	West Texas	Overwintered weevils, Trap Index. Field ET=5 weevils per 100 row feet.

[1]Recommendations from published extension guides.
[2]ET=economic threshold.
[3]Late season=boll period.
[4]Lower Rio Grande Valley.

The weevil-infested acreage of Texas needed a product other than calcium arsenate for these scheduled application programs. This need was met shortly after World War II with the appearance of several new insecticides of different chemistry. First mentioned in the Texas guide in 1947, the gamma isomer of benzene hexachlorine (BHC) met part of this need but caused bollworm problems. DDT dust, an ineffective chemical for the boll weevil but effective for bollworms, was added to BHC in one of the first dust mixtures designed to avoid these bollworm flareups. Toxaphene dust, another new insecticide, also provided good weevil and bollworm control and fair aphid suppression. Later, toxaphene sprays were found not to be as effective as the dust formulations, and DDT was added to increase weevil and worm control.

The addition of the organochlorine insecticides in 1947 provided Texas farmers a cheap and effective means for controlling the boll weevil and secondary pests. First used as dusts, the organochlorines were later applied in spray formulations. Dusts had far more application limitations than sprays and could only be applied at daybreak or at dusk when the air was calm. Automatic application programs were adopted and promoted by banks and chemical companies (Walker, 1984). Increased nitrogen use and the acceptance of prolonged fruiting varieties followed. Without the threat of the weevil, cotton farmers "pulled out all stops" and yields increased dramatically.

While farmers enthusiastically followed the scheduled programs, extension was advocating a more conservative insecticide use approach with an elevated economic threshold of 25-35 percent punctured squares for late-season weevil control (TAEX, 1949). State entomologists were also recommending the use of early uniform planting dates followed by timely stalk destruction and general field cleanup to reduce the potential overwintering weevil population. These were old practices, but advances in mechanical harvesters and stalk cutters were making these practices a reality in the 1950s.

Boll weevil resistance to the organochlorines was first reported in 1956 in Robertson County and soon was detected in the remaining infested areas. Disaster was averted in 1957 by recommending the use of low but effective rates of the organophosphate insecticides, first mentioned in the 1951 guide (TAEX, 1957a, 1957b). DDT was routinely added because organophosphates, applied at weevil rates, did not adequately control bollworm/tobacco budworm. When both the bollworm and tobacco budworm exhibited resistance to the organochlorines (DDT in most instances), organophosphate rates were sharply increased and application intervals were reduced. Even these adjustments did not bring the level of organophosphate insecticide control up to that provided by DDT in its first year of use. Control programs were increasing in complexity while becoming more expensive. With cheap control no longer a reality, automatic scheduled spray programs ceased to be attractive. Farmers became more willing to follow the advice presented in extension guides advocating cultural control coupled with an early season spray program.

The value of adding either methyl parathion or azinphosmethyl (Guthion®) to defoliant applications was not overlooked as an effective means of reducing potential overwintered weevil numbers. This 1966 Guide recommendation provided yet another management tool that minimized the necessity of disruptive in-season applications (TAEX, 1966a, 1966b, 1966c).

The boll weevil expanded its range in East Texas to include the Rolling Plains, with spotty infestations detected as early as 1920. Overwintering weevils did not reach alarming numbers until the early 1960s (Walker, 1984). Harsh winters, limited hardwood leaf litter (important for successful weevil overwintering), and hot, dry summers had severely limited weevil survival. But the pest apparently adapted to these environmental constraints. The boll weevil invaded the eastern edge of the High Plains in 1963 as the culmination of its westward expansion across the Rolling Plains. Growers reacted strongly, initiating in 1964 a large scale diapause control program which stretched north to south along the Caprock Escarpment separating the High Plains from the Rolling Plains (Moritz, 1979; Rummel *et al.*, 1975). The technology used was developed by J. R. Brazzel in 1961. It was extraordinarily successful and has continued to keep the High Plains production area weevil-free for the last 27 years. In this approach to weevil management, adult weevils are killed with insecticides before they can move to leaf litter and successfully overwinter. Smaller diapause control programs have been successful to varying degrees in other West Texas areas.

The latest additions to weevil management have addressed the early part of the production season. The value of delaying planting until after mid-May and then planting uniformly across a community was recognized as a means of maximizing suicidal emergence of overwintered weevils in the Rolling Plains (Rummel, 1965). This practice has been aggressively promoted and widely adopted as a voluntary control method since 1980 in the Rolling Plains area (Slosser, 1978; Masud *et al.*, 1985).

The 1979 recommendation for overwintered weevil applications was augmented for the first time since 1947 with the addition that "when one or more weevils are found, apply an insecticide". Only field history had been considered before (TAEX, 1979a,b,c,d). This permitted a slightly more conservative insecticide use approach for many areas where the vagaries of winter weather often had made field history an unreliable basis for prediction.

Studies first conducted between 1977 and 1979 established a positive relationship between the number of overwintered weevils caught in pheromone traps and the percent oviposition-damaged squares during the early one-third grown square period (Rummel *et al.*, 1980). This led to the development of the more accurate Trap Index method for determining the need for overwintered boll weevil control in the Rolling Plains area. Four to five traps are placed along field margins near weevil overwintering habitat or near areas of the field with a history of early infestations. The Trap Index guidelines suggest that if more than four weevils are found per trap during the week that first squares appear, treatment is probably justified (Leser *et al.*, 1988). If one or fewer weevils are caught per trap during this key week, treatment is not required. When trap catches average more than one but less than five weevils during the pinhead-sized square week, field inspection is necessary to make a management decision. A field monitoring-based economic threshold of five weevils per 100 row-feet examined, was developed by J. Slosser, Texas Agricultural Experiment Station Entomologist at Vernon, and added to the extension service's overwintered boll weevil management guidelines in 1988.

A different Trap Index was developed for the Corpus Christi area (Benedict *et al.*, 1985) and incorporated into the management guidelines for that area in 1982 (Parker and Benedict, 1982). This index was based on the cumulative average weevil numbers caught during the six week period prior to the appearance of one third grown squares. Treatment is justified using this method when weevil numbers average more than 2.4 per week. When weevil numbers average less than one per trap per week, treatment is not needed. An insecticide application is warranted only when field scouting confirms the presence of weevils or damage when weevil numbers average 1 to 2.4 per trap-week. The pheromone trap index has presented a much more efficient and reliable method of assessing the need for overwintered weevil control for the Corpus Christi and Rolling Plains areas of Texas.

When tobacco budworms became resistant to organophosphates in the late 1960s, entomologists again were reminded that insecticides might not be the long term solution to most insect pest problems. Bollworms were increasingly a problem, probably the result of weevil insecticide applications that destroyed the beneficial insects, which otherwise controlled the early flurries of bollworms (Walker, 1984). The registration of pyrethroid insecticides in 1979 returned highly effective control for bollworms and tobacco budworms but did little to provide the cure-all insecticide everyone desired. In the mid 1980s, pyrethroid resistance in tobacco budworms began to appear, again making insect management a tenuous affair. While pyrethroids were proven to be as effective as organophosphates for weevil control when used on a 3- to 5-day schedule, their use for this pest is impractical due to cost and is discouraged to prevent the unnecessary risk of increasing resistance levels in the tobacco budworm and bollworm.

It was not until the insect management potential of the new rapid-maturing varieties was elucidated that the short-season cotton production system for weevil management began to flourish. These varieties shortened the vulnerability period, providing a means of escaping high late season weevil and worm infestations. Reference to this important management component did not appear in any of the Texas guides until 1979 when short-season varieties and their production was compared to the long-season production system in the Lower Rio Grande Valley guide (TAEX, 1979d). By the early 1980s, short-season cottons had all but replaced the slower fruiting Lankart types in the Rolling Plains.

Prompt stalk destruction following harvest, long regarded as a boll weevil management tactic, did not receive concerted farmer compliance. There were no laws that required this farmer activity for weevil management. But there were laws in place for stalk destruction for the management of the pink bollworm. Since 1947, the Lower Rio Grande Valley had relied on these pink bollworm regulations to assist in managing weevils. While the value of these practices is well documented, compliance often was not adequate to obtain the desired results with weevils. The absence of damaging pink bollworm infestations for many years had made it impossible to enforce these regulations. In 1986, new mandatory plow-down, stalk destruction and planting dates were legislated for weevil management. Compliance is enforced by the Texas Department of Agriculture. These regulations presently affect pest management zones established in South Texas (includes Lower Rio Grande Valley and Gulf Coast, but excludes the Winter Garden Area near Uvalde) and part of Far West Texas.

Current management practices to exploit the weaknesses of the boll weevil are: (a) utilizing planting dates suitable for the region and more rapid fruiting varieties that shorten the vulnerability period; (b) crop residue destruction to deny food, oviposition sites, and habitat for overwintering weevils; (c) the addition of insecticides to defoliants prior to harvest to eliminate as many weevils remaining in the field as possible; (d) use of diapause control programs where appropriate; and (e) early season applications at the time of first appearance of pinhead-sized squares for control of overwintered weevils. These combined practices often eliminate or reduce the need for mid- to late-season insecticide applications for weevils and preserves beneficial insects that are needed to defend against later bollworm and tobacco budworm problems.

Cotton Fleahopper — In 1947, DDT as a mixture with sulphur quickly began to replace sulphur dust alone for controlling cotton fleahopper. It was soon recognized that the addition of DDT could release secondary pests or bollworms. Also important was proper timing, as early season DDT applications were far less disruptive. By 1947, the 1942 economic threshold, (15-25 percent infested terminals), had been elevated to 25 percent (Siddall and Gaines, 1942; TAEX, 1947). But as the years passed, different thresholds would be used (Table 2). For example, in 1949, area-wide preventative programs for overwintered weevils and cotton fleahoppers tended to replace the threshold concept (TAEX, 1949). These programs were to be completed early in the season, well before blooming.

Applications made after blooms appeared were treated with much reservation in 1949 because of the threat of bollworm problems that could follow cotton fleahopper control applications. The economic threshold was raised for this period to 25-35 percent infested terminals. Entomologists vacillated considerably on establishing thresholds as they tried to avoid early bollworm problems, yet prevent unnecessary losses to cotton fleahoppers. After all, early fruit set was the cornerstone of the emerging short-season production system.

There were, as well, geographical differences in approaches to cotton fleahopper management. Initially the Lower Rio Grande Valley (TAEX, 1952a) and then the Blacklands (TAEX, 1959b) set thresholds lower than the rest of the state. West Texas soon followed in 1961 (TAEX, 1961c). The Blacklands fleahopper problem is exacerbated by the multitude of alternate hosts, from which adult fleahoppers often move to cotton as the first tiny squares are forming in the plant terminals. Significant delays in earliness can follow as a result of square loss from cotton fleahoppers. Hence, a lower threshold was needed to avoid these losses which seemed to be excessive for cotton grown on Blackland soils. Applied at the sixth to eighth node stage, insecticide applications are made no later than 10 days before first blooms appear. The Lower Rio Grande Valley refrained from the use of insecticides for overwintered weevil control between 1968 and 1976, a practice viewed as ineffective there, but did advocate fleahopper treatments more aggressively than some other areas of the state. Applications were to cease at least 10 days before bloom to allow beneficial insects to build up prior to the bollworm season (TAEX, 1976a).

Cotton fleahopper control in Central and South Texas is practiced to shorten the production season and avoid late season weevil, bollworm and tobacco budworm problems. The High Plains area has a weather-induced short growing season. Hence, farmers here can ill afford to lose their early crop to fleahoppers. A low threshold of 15 to 35 percent infested terminals was used until 1976 (TAEX, 1976b).

The increasing difficulty of controlling organophosphate resistant tobacco budworms and less than adequate management of bollworms encouraged state entomologists to retreat from the more liberal insecticide-use fleahopper control guidelines of

Table 2. Evolution of key cotton fleahopper control recommendations in Texas.[1]

Year	Region	Recommendation
1942	State	ET[2]=15-25 percent infested terminals.
		Sulphur dust.
1947	State	ET=25 percent infested terminals.
		Organochlorines.
1949	State	2-3 weekly applications early in area-wide program.
		Late season[3]
		ET=25-35 percent infested terminals.
1953	LRGV[4]	ET=10-15 percent infested terminals.
1959	Blacklands	ET=25 percent infested terminals.
		Carbamates and organophosphates.
1961	West Texas	ET=15-25 percent infested terminals.
1962	LRGV	ET=15-35 percent infested terminals.
1970	West Texas	ET=25-35 percent infested terminals.
1971	River Bottoms	ET=35-50 percent infested terminals.
1974	Gulf Coast	ET=25-50 percent infested terminals
	River Bottoms	
	Blacklands	ET=15-25 percent infested terminals.
1975	Blacklands	ET=25-50 percent infested terminals.
1977	Blacklands	ET=15-25 percent infested terminals.
	LRGV	ET=25-50 percent infested terminals and 15-25 percent square damage.
1978	West Texas	ET=25-35 infested terminals and 15-25 percent damaged squares.
1979	Gulf Coast	ET=15-35 percent infested terminals.
	River Bottoms	
1987	Gulf Coast	ET=15-25 percent infested terminals.
	LRGV	
	River Bottoms	
	Blacklands	ET=10-15 percent infested terminals.

[1]Recommendations from published Extension guides.
[2]ET=economic threshold.
[3]Late season=boll period.
[4]Lower Rio Grande Valley

the 1960s and elevate the economic threshold to 25 to 50 percent infested terminals in 1971 (TAEX, 1971a, 1971b, 1971c). However, the Blacklands could not afford to follow these conservative guidelines and has maintained a lower threshold of 15 to 25 percent during most of this period (TAEX, 1974a). The return of adequate bollworm and budworm control in 1979 with the introduction of the pyrethroids, eventually encouraged extension entomologists to lower thresholds to 10 to 15 percent for the

Blacklands (Robinson and Stewart, 1987), and 15 to 25 percent for the remainder of Texas, except West Texas, where a more conservative approach had evolved.

Cotton produced in the weather-shortened growing season of the High Plains is particularly vulnerable to early fruit losses. But severe infestations of cotton fleahoppers are uncommon because of the scarcity of alternate spring hosts (Leser, 1986b). Fleahopper numbers are often low when cotton begins to square, requiring one or more generations to reach potentially damaging levels. This typically does not occur until after cotton has the fruit it can mature. This is particularly true of the dryland acreage. Treatment levels are higher, set at 25 to 30 fleahoppers per 100 plant terminals since 1970 (TAEX, 1970). Even these levels of fleahoppers sometimes fail to cause noticeable losses, especially as the bloom period approaches. Square damage exceeding 15 to 25 percent was added to the cotton fleahopper number economic threshold in 1978 to address this problem (TAEX, 1978d).

The attainment of an early-season prebloom management system of both fleahoppers and boll weevils before bollworms appeared has been crucial to the management of bollworms and other late season pests. In spite of 63 years of often intense research efforts since the Texas Legislature appropriated funds to address the cotton fleahopper problem, management is still a controversial subject. Perhaps a greater knowledge of the cotton plant and its response to the insect will eventually bring understanding.

Though there are risks in triggering secondary attacks of bollworms and tobacco budworms with insecticide treatments for cotton fleahoppers, entomologists generally agree that the risk of losing earliness due to cotton fleahoppers is the transcending consideration. Earliness reduces much of the threat from these pests as well as from the boll weevil, even if insecticides are used to secure this earliness.

Bollworm and Tobacco Budworm — Prior to the arrival of the boll weevil in 1892, only sporadic damage was described from insects. Cotton leafworms, *Alabama argillacea* (Hübner), aphids, and bollworms occasionally caused damage but most farmers ignored these infrequent problems. With a concerted insecticidal effort to control the boll weevil, bollworm problems appeared with greater frequency. This proved true with calcium arsenate and later with the organic insecticides. Bollworm problems could develop suddenly, producing a tremendous amount of damage. Bolls were vulnerable to damage for a much longer period than from the boll weevil.

Texas' first extension guide recommended calcium arsenate dust for bollworm control. The product was to be applied every five days until eggs and larvae were no longer found in the field (Table 3). These treatments were triggered by the economic threshold of 35 to 40 eggs or small worms found per 100 terminals (Siddall and Gaines, 1942). Calcium arsenate was only marginally effective, primarily on small larvae. This almost preventative-like approach all but insured that considerable acreage was targeted for treatment, even though knowledgeable entomologists were well aware that many times bollworm/tobacco budworm infestations caused little damage because of the great amount of biological control of eggs and small larvae that we now know occurs in untreated cotton (Walker *et al.*, 1978). Fortunately, it seems that many cotton growers ignored the calcium arsenate recommendation, and the use of the material was restricted to areas that often experienced bollworm outbreaks, such as the Brazos River Valley (Personal communication, J. C. Gaines, former entomologist and department head, Entomology Department, Texas A&M University, College Station, TX).

By 1947, a DDT recommendation had been added to the guide. DDT was very effective for bollworms when applied against small larvae (TAEX, 1947). Not effective against boll weevils, DDT was added to those organochlorines that were effective for weevil control. It was recognized that these mixtures, applied on a multiple application schedule, eliminated the beneficial insects that might suppress egg and larval populations from bollworm moths moving from maturing corn to cotton. Hence, DDT was added as a bollworm preventative to each weevil insecticide application. In 1948 the economic threshold was changed to 4 to 5 small worms per 100 terminals inspected (TAEX, 1948). This threshold provided little improvement over that of 1942 but remained in place until 1972 with only minor revisions. The recommendation was expanded in 1949 with the addition of eggs to the worm number threshold (TAEX, 1949), perhaps to emphasize that without the threat of further infestation pressure, there was no need to spray these lower worm infestations. Five-percent square damage was added to the worm threshold in 1956 (TAEX, 1956a).

Organophosphates were added to the guides for aphid, cotton leafworm, and spider mite control by 1953 (TAEX, 1953a, 1953b), but were not routinely added to the organochlorine mixture for boll weevil control until boll weevil resistance appeared in 1956. By the early 1960s, bollworms were no longer readily controlled by organochlorines, and a five-day schedule was recommended to maintain control (TAEX, 1961a,b,c). The 1963 guides first mentioned organochlorine resistant tobacco budworms and provided separate comments for tobacco budworms and bollworms (TAEX, 1963a,b,c). In 1967, higher rates of the more expensive organophosphates were recommended (TAEX, 1967a,b,c). These compounds provided only short residual activity against small larvae and were much harsher on beneficial insects than the lower rates used for weevil control. Application intervals were often reduced. Suddenly the bollworm and tobacco budworm had become more important than the boll weevil as pests of Texas cotton. As the organophosphates were increasingly used, resistance in the tobacco budworm began to appear (Adkisson, 1965; Adkisson and Nemec, 1967).

The resistance of the tobacco budworm to all known insecticides in the late 1960s and the concern that pesticides were contributing to the deterioration of the environment caused governmental agencies to assess the wisdom of relying solely on insecticides for control of cotton pests. In 1972, pilot stage integrated pest management (IPM) programs were established in the Lower Rio Grande Valley, Blacklands, Winter Garden, and Far West Texas areas (Frisbie and McWhorter, 1986). These programs provided the opportunity to test IPM practices and educational methods over a wide variety of agricultural systems. Starting with cotton entomology, IPM programs have evolved into multidisciplinary educational efforts to assist and train producers to properly manage all facets of production for cotton and several other crops.

Table 3. Evolution of bollworm and tobacco budworm management recommendations in Texas.[1]

Year	Region	Recommendation
1942	State	ET[2]=35-40 eggs per 100 terminals or small worms found. Calcium arsenate dust every 5 days until eggs and worms gone.
1947	State	Organochlorines added.
1949	State	ET=4-5 small worms per 100 terminals.
1952	LRGV[3]	ET=4-5 small worms + eggs per 100 terminals or 5-7 percent top square damage.
1953	State	Organophosphates added.
1956	State	Added 5 percent damaged fruit to ET.
1969	State	(A) Terminal ET=4-5 small worms + eggs or 5 percent square damage per 100 samples. (B) Whole plant ET=1,5 larvae per 10 row feet.
1972	State	(A) Prior to first insecticide application 1. Prebloom—15-25 percent square damage. 2. After bloom—5-8 percent square damage. (B) After insecticide application. 1. Eggs and 4-5 small worms per 100 terminals and 5 percent damage. 2. 2 larvae per 10 row feet.
1979	State	Added microbial insecticides.
1980	State	Added synthetic pyrethroids.
1980	West Texas	(A) Preblooming ET=15-25 percent square damage. (B) After bloom. 1. ET=8-10 percent square damage and less than 20 percent predator infested terminals. 2. ET=4 worms/10 row feet.
1981	West Texas	(B) After bloom 1. Random whole plant method ET=5,000 small worms/acre and less than two predators per worm.
1987	LRGV[3]	(B) After insecticide: 6 to 10 young worms/100 terminals and five percent squares and small bolls damaged.
1989	West Texas	Cluster scouting method substituted for single random whole plant inspection.

[1]Recommendations from published Extension guides.
[2]ET=economic threshold.
[3]Lower Rio Grande Valley

An extension IPM professional (Extension Agent-Entomologist) with at least a bachelor's degree (preferably a master's degree), is headquartered locally to provide leadership for introducing the IPM concept to producers. The Texas Pest Management Association was established in 1977 as a statewide, producer-operated, non-profit organization dedicated to encouraging the implementation of pest management practices, coordinating statewide pest management activities, providing a mechanism for producer-operated scouting services, and to serving as a liaison between various state and federal agencies. Program acreage has expanded to include 2.3 million crop acres in 22 program areas across Texas.

While field scouting and the use of economic thresholds are the highly visible components common to all programs, they are by no means the only tactics utilized to insure the appropriate use of insecticides. The Texas short-season cotton production system is central to the success of IPM programs. The elements of this system include: (a) selection for rapid fruiting and early maturing varieties; (b) planting dates, (c) nitrogen and irrigation water management; (d) host plant resistance for disease control; (e) crop rotation for nematode control; (f) conservation of beneficial arthropods, (g) use of pheromone trapping and predictive computer models such as MOTHZV; (h) weed management; (i) vegetative growth management with mepiquat chloride (PIX®); (j) use of harvest-aid chemicals for early crop termination; and, (k) stalk destruction and crop residue elimination (Frisbie *et al.*, 1989).

Educational methods used include either intensive individual field scouting or community survey programs where appropriate, use of print and electronic media and weekly newsletters to provide insect situation reports and management advice, turn-row meetings to train producers in proper field scouting techniques, demonstrations to evaluate and facilitate adoption of new IPM technology, and economic evaluation of the IPM program. Texas programs have been very successful and have fostered the rapid development of the private consulting industry. Improved crop management promoted by IPM programs has contributed to the successful management of bollworm/tobacco budworm and other cotton pests over the last 18 years.

The first real improvement in the bollworm/tobacco budworm economic threshold appeared in 1969 when the "row-foot" monitoring method was added as an alternative to the existing threshold choices (TAEX, 1969a,b,c). Whole plant inspections of five 10-foot row sections in each field was advocated. Treatment was recommended when counts averaged 1.5 larvae per 10 row-feet. This averaged about 2,000 larvae per acre and was similar to the 4-5 larvae per 100 terminal method in estimating economic thresholds at 2,000 to 2,500 larvae per acre. This threshold was increased to two larvae per 10 row-feet or about 2,500 worms per acre in 1971 (TAEX, 1971a,b,c).

The lack of an adequate insecticide to address the resistant tobacco budworm problem, the need for multiple applications of short residual organophosphates to combat the bollworm, and the devastation of beneficial insect populations by insecticides finally led to the first major breakthrough in bollworm/tobacco budworm management since 1949. The 1972 guides recognized for the first time that there was a difference between fields that had been treated with an insecticide and those that had not (TAEX, 1972a,b,c). Two sets of economic thresholds that drew on this distinction were offered to cotton farmers. The 1972 guides further recognized that early, preblooming worm damage could be compensated for and set a higher threshold of 15 to 25 percent square damage as the spray trigger. For blooming cotton, the threshold was lowered to 5-8 percent square damage. This was increased to 8-10 percent in 1974 (TAEX, 1974a,b,c,d). Once insecticides had been used and beneficial insects were no longer available to regulate bollworms and tobacco budworms, the older thresholds were followed. Above all, the extension service cautioned farmers to try to avoid treating bollworms until after blooms appeared. This provided at least a ten-day window from the last early-season application to the first needed bollworm spray, hopefully sufficient time for beneficial insect numbers to recover.

Methyl parathion plus toxaphene became the most widely used spray mixture for bollworms and budworms. This lasted until the pyrethroids were first widely used in 1979. It was recognized that under heavy infestations and high resistance, there was no chemical cure for the tobacco budworm problem. Abstinence, or at least restraint, appeared the best course. And for much of Texas cotton, perhaps 95 percent, this view was appropriate. In spite of the problems with the then current arsenal of chemicals, there were no easy-to-use alternatives when damaging infestations appeared. As early as 1964, state guides had added statements that the release of *Trichogramma* or lady beetles had not proven to be an effective control method (TAEX, 1964a,b,c). This advice remains in the guides today.

The MOTHZV computer model developed by Hartstack *et al.* (1976) has been used in Texas for the last fifteen years to predict the occurrence of bollworm and tobacco budworm eggs and larvae. MOTHZV is a heat-unit based model which utilizes pheromone trap catches to provide an area or county-wide prediction. This information is utilized by extension entomologists to alert growers and consultants as to the need to intensify field scouting. The timing of crop irrigations in relation to predicted peak oviposition by bollworm/tobacco budworm moths is a crop management practice that has been recommended to growers for twelve years. (TAEX, 1979a). Termination of crop irrigation at least ten days prior to a MOTHZV predicted peak egg-lay is recommended to reduce plant attractiveness to bollworm/tobacco budworm and to provide less favorable field humidity conditions for survival of eggs and newly hatched larvae.

TEXCIM50 is the current version of a decision-aid computer model developed to provide pest management decisions based on the predicted cumulative economic losses from cotton fleahoppers, boll weevils, and bollworm/tobacco budworm (Hartstack and Sterling, 1989). Simulations for bollworm/tobacco budworm can be initiated using pheromone trap catches and MOTHZV or field counts of eggs and larvae. The estimated costs of pest damage can be used to evaluate the economic benefits of natural and insecticidal control. While TEXCIM50 claims to be user-friendly, it has not gained wide acceptance in the agricultural community. The time required to collect and enter the necessary data on an individual field basis discourages most crop managers from using the model. Perhaps the main benefit of TEXCIM50 is as a research tool. Through the development, validation and implementation of this type of model, areas of weakness in our knowledge base can become evident.

The microbial insecticides provided some promise of control without the destruction of beneficial insects. Entomologists discussed the use of *Bacillus thuringiensis* (Bt) and the commercial formulation of a nuclear polyhedrosis virus, Elcar®, in newsletters by 1978, recommending them officially the next year in the state guides (TAEX, 1979a,b,c,d). Microbials were most effective against low to moderate worm numbers and when moderate to high numbers of beneficial insects were found. Results were inconsistent, with some good successes, but many resounding failures. These products were recommended before adequately researched for appropriate use patterns. Farmers, consultants and state entomologists alike, reluctant to disturb the delicate balance that existed in a cotton field, often used microbials in place of the harsher organophosphates. After all, once organophosphates were used and beneficial insects were eliminated, bollworm management meant multiple sprays for the rest of the season. Little did they realize, as we shall discuss later, that field scouting coupled with realistic economic thresholds could preclude this outcome.

Microbials were widely and indiscriminately used. As a result of the attendant frequent failures, most crop managers became reluctant to use these specialized materials. This was unfortunate since they do indeed have a place in the management of bollworm/tobacco budworm. By 1982, research was demonstrating that the biological materials should be recommended only before blooms are present, recognizing the coverage problem with larger plants as well as the nature of bollworms to remain sequestered inside large cotton bolls. (Allen and Norman, 1982; Fuchs *et al.*, 1982; Parker and Benedict, 1982; Turney *et al.*, 1982). Microbials can be effective at an infestation level of up to 15 larvae per 100 terminals. A specific microbial section was added to the 1983 guides (Allen and Norman, 1983; Buxkemper *et al.*, 1983; Cole, 1983; Neeb *et al.*, 1983). Basically, it recommended the use of microbials in prebloom cotton for infestations of 6,000-10,000 small larvae per acre if beneficial insect numbers were high. Once pyrethroids were registered, microbial insecticide use plummeted to the extremely low levels that exist today.

The addition of the ovicide chlordimeform (Galecron®, Fundal®) to the guides in 1974 provided yet another approach to combating organophosphate resistant bollworm/tobacco budworm (TAEX, 1974a,b,c,d). Texas did not recommend the use of ovicides alone. Methomyl (Lannate®, Nudrin®) and thiodicarb (Larvin®) were later added as contact ovicides with the same use restrictions. Chlordimeform was voluntarily removed from the market in 1977 but returned in 1980, and lasted until 1989, when it was withdrawn permanently from the cotton market. In later years, chlordimeform was also recognized as a synergist for pyrethroids when these were used against pyrethroid resistant tobacco budworms. Many Blacklands producers have been using ovicides since 1987 to forestall the need to use pyrethroids and minimize the risk of enhancing resistance and losing control completely (Personal communication , Allen Knutson, Texas Agricultural Extension Service, Dallas). Not based on research, this approach may have resulted in many unnecessary applications.

Under the emergency use provisions of Section 18 of FIFRA in 1977 and 1978, and with conditional registration in 1979, pyrethroid use reintroduced a level of bollworm and budworm control not seen since the early days of DDT use. Much more expensive, these products had long residual activity and were effective against even larger larvae. These characteristics made them widely accepted by state entomologists and farmers. A period of relative impunity from bollworm/tobacco budworm problems lasted until tobacco budworm resistance resurfaced in 1986. By 1987, the cotton guides were addressing resistance management (Fuchs *et al.*, 1987; Cartwright and Norman, 1987; Robinson and Stewart, 1987). Resistance monitoring using traps and the vial bioassay technique was initiated, and special resistance management guidelines were published. Essentially, pyrethroid use is discouraged early in the season and against pests other than bollworm/tobacco budworm or the pink bollworm. Pyrethroid applications are advocated only during the July generation of bollworms and budworms. Carbamates, organophosphates, and microbials are recommended at other times. This meant that pyrethroids were not to be used prior to first bloom and not late in the season. The short-season cotton production system developed for boll weevil management is a very effective adjunct to this insecticidal approach. The resistance management program appears to be working thus far in preserving the effectiveness of the pyrethroids.

West Texas recommendations began to diverge from other areas of the state by 1979. Extension entomologists observed that economic thresholds defined from Brazos River Valley small plot work dealt with mainly chronic, relatively low level, multi-generation bollworm problems. This was the situation that the 1949 economic threshold of 2,500 larvae per acre clearly addressed. But West Texas infestations generally occurred later in the boll maturation period. These were acute infestations of shorter duration. The 1979 West Texas guide increased the state recommendation from two to four per 10 row-feet, the number of larvae necessary to initiate a treatment (TAEX, 1979a). This represented about 5,000 larvae per acre. The five-point field scouting method of 1942 was replaced with four quadrants per 100 acres with 25 squares or terminals examined in each quadrant.

Recognizing the role of biological regulation of eggs and small larvae, entomologists integrated predator numbers more fully into the economic threshold during the boll period in the 1981 and 1982 guides (Leser *et al.*, 1981; Fuchs *et al.*, 1982). This eliminated the distinction of pre- and post- insecticide treated fields, which remains in other area guides today. West Texas guides advise producers that control measures may not be needed or that a microbial insecticide may be a more appropriate control measure when two or more key predators are found for each small larva or egg. These key predators include several species of spiders, the big-eyed bugs (*Geocoris* spp.), the damsel bugs (*Nabis* spp.), assassin bugs (*Zelus* and *Sinea* spp.), minute pirate bugs (*Orius* spp.), lady beetles (*Hippodamia* spp.), and green lacewings (*Chrysoperla* spp.)

The development of annual, widespread bollworm problems in the High Plains area, starting in the 1970s, provided further impetus for area entomologists to refine existing economic thresholds. The weakness of the row-foot method and square-damage techniques was apparent to several West Texas extension entomologists. The row-foot method was too time consuming and did not appear to permit adequate, representative sampling of the whole field. The square- monitoring technique did not satisfactorily define the larval infestation, often underestimating its magnitude. Consequently, the row-foot scouting method for the boll period was augmented in 1981 with the random whole-plant method where individual dominant plants were inspected across the field; a minimum of ten plants were checked per quadrant (Leser *et al.*, 1981). The use of dominant plants permitted reasonable decisions with less sampling. The economic threshold was set at 5,000 small larvae per acre. This system has worked for several years on the High Plains and detects the frequent infestations that occur below the plant terminal. Numbers are expressed on a per acre basis rather than as percent infested plants. This compensates for probable errors resulting from plant densities varying between fields.

The terminal checking method was added in 1983 mainly for the Rolling Plains area where terminal infestations are more the rule than the exception (Neeb *et al.*, 1983). A cluster method replaced the single dominant plant method in 1989. This sampling technique was developed from the research of Walters *et al.* (1990) where probabilities for accuracy for a given economic threshold also are presented. Sample units consist of 3-5 clusters of consecutive plants at each field check point. Five such clusters are checked per field quadrant. The economic threshold has remained the same although experienced crop advisors often elevate it to 8,000-10,000 per acre with no indication of a problem. The key is the recognition that considerable numbers of bollworms can be tolerated without undue damage if the infestation is of short duration. Chronic infestations are another matter and are not altogether adequately addressed by the current set of economic thresholds.

Bollworm/tobacco budworm management in Texas succeeded in isolating worm problems from the issues of early season fleahopper and boll weevil control and their consequences. Early season applications for overwintered boll weevils and fleahoppers are terminated with sufficient time to allow beneficial insects to repopulate before the bollworm and tobacco budworm egg flurries begin. More conservative economic thresholds and reliable scouting techniques have reduced the use of insecticides while still preserving yield. Where the tobacco budworm is a mid-season problem, the pyrethroid resistance management program is followed by the majority of crop managers. The short-season cotton production system that has evolved for weevil management in Texas provides the rest of the tools necessary to manage bollworm/tobacco budworm successfully.

Thrips — The status of thrips as a pest has vacillated from time to time, as much a product of changing management philosophies as to actual damage potential. Several species of thrips have been involved including tobacco thrips, *Frankliniella fusca* (Hinds); flower thrips, *Frankliniella tritici* (Fitch); and western flower thrips, *Frankliniella occidentalis* (Pergande). Recently the western flower thrips has been the more serious and extensive species. Control of thrips is first mentioned in the 1952 Lower Rio Grande Valley guide where preventative sprays were recommended when leaf silvering appeared (TAEX, 1952a). This corresponded with the prevailing philosophy of preventative control for early season pests in general. In 1956, the state guide added phorate (Thimet®) seed treatments to the list of foliar insecticide treatments for early season infestations of thrips, leafminers, aphids, and spider mites (TAEX, 1956a). At the same time, Lower Rio Grande Valley entomologists took a more conservative insecticide use approach to early season insect control and removed all preventative treatment recommendations from their guide (TAEX, 1956b). This corresponded with concerns for controlling organochlorine resistant boll weevils and with a general consensus that early season treatments usually created more problems than they solved.

By 1961, thrips control was suggested based on the mere presence of thrips at plant emergence in Texas areas other than the Lower Rio Grande Valley (TAEX, 1961a). Disulfoton (Disyston®) granules were added as an in-furrow application at planting with the realization that cool, wet weather could cause stand reductions. Even multiple early season sprays were often observed to retard plant growth and squaring, a poor tradeoff for insect control. Phorate (Thimet®) was added by the Texas Agricultural Extension Service (1963a) as an in-furrow granular application recommendation for thrips control.

A reaffirmation of preventative treatments was observed in 1964, even in South Texas. At-planting insecticides were listed in the table of insecticide recommendations for the first time and the very effective foliar organophosphate insecticide dicrotophos (Bidrin®) joined the ranks of control tools (TAEX, 1964a,b,c). The economic threshold had changed little during the 20-year period since 1952. Thrips infested fields were treated either based on damage, presence of thrips, or both criteria. West Texas guides made a major change by removing all at-planting insecticides, preferring to rely on actual observed need rather than field history of problems (TAEX, 1971a). This change took place just before aldicarb (Temik®) was registered for use on cotton, the first truly effective at-planting systemic insecticide offered to farmers. Even the Central Texas guide stated a preference for treatments based on need over preventative at-planting applications (TAEX, 1971b).

The river bottom area of Central Texas was the only area still recommending at-planting insecticides for early season insect control in 1974, even though this advice had been removed from the insecticide table proper (TAEX, 1974a). Aldicarb was added with the warning that higher rates could cause bollworm problems. Clearly, the early research with aldicarb had shown the effectiveness of the material but at the same time noted the potential for increased bollworm problems. It was not recognized for another ten years that the higher rates initially tested were not needed to achieve thrips control, and that lower rates did not aggravate the bollworm situation. Accordingly, the 1977 South Texas guide removed discussion of systemic insecticides entirely (TAEX, 1977a). The underlying issue in all this, of course, was the persuasive argument of one of IPM's tenets, that insecticides should be applied only as needed, based on field scouting. Little did entomologists realize in those days that the onset of thrips damage can be so sudden in some areas that only preventative treatments could adequately address the problem.

Research was beginning to identify several areas of the state that did not benefit from thrips control (TAEX, 1978a,b,c). This included the Central Texas River Bottoms, Gulf Coast and Lower Rio Grande Valley. South Texas went so far as to eliminate thrips as a pest from the guide. During the period from 1979 to 1982, thrips were removed from the table of insecticide recommendations for the Central River Bottoms and Gulf Coast areas. Clearly the sentiment was against preventative treatments and early-season control of insects other than weevils and fleahoppers. After all, early-season thrips, leafminers, aphids and spider mites were viewed as minor pests—more an emotional problem than one with substance—with little research to show an economic advantage in their control.

West Texas entomologists generally concurred with the rest of the state but could not completely ignore the fact that High Plains farmers were addressing thrips as a serious problem, treating over 500,000 acres with aldicarb (Temik®) (Leser, 1986a). Research tests by 1976 had showed little yield response from thrips control. Thrips had been relegated to minor pest status with damage often exacerbated by weather problems common during the emergence period on the Texas High Plains. But the research findings of Rummel and Quisenberry (1979) showed the faults of earlier tests, which based treatment timing on damage and not on actual thrips numbers. Treatments delayed until damage appeared did not result in yield increases while those applied prophylactically, before damage was evident, were successful in providing respectable yield increases. Clearly, entomologists had been misled by earlier faulty research. Increasing concern for what was now obviously a more serious pest led extension entomologists to add the first thrips economic threshold to the West Texas guide, utilizing counts of 2-5 thrips per plant during poor growing conditions as an action level (Leser *et al.*, 1981).

Extensive thrips control testing was done between 1981 and 1986. Treatments tested included at-planting granular insecticides, seed treatments and foliar sprays based on damage, thrips numbers, or applied automatically (Leser, 1986a). These tests clearly demonstrated that preventative treatments were superior in providing yield increases, averaging 22 percent in irrigated production areas north of Lubbock. Other conclusions drawn from these tests were: (a) wheat acted as a reservoir for thrips that move to emerging cotton as wheat matures; (b) planting dates influenced the juxtaposition of thrips moving from wheat to cotton; (c) aldicarb (Temik®) was the best of the at-planting insecticides; (d) higher rates of aldicarb (Temik®) and lower rates of phorate (Thimet®) and disulfoton (Disyston®) could cause considerable phytotoxic problems including a reduction in early set squares; and (e) moisture limitations in much of the dryland acreage often eliminated earlier advantages gained from thrips control. One other conclusion drawn from these studies was that there could be no yield response from insecticide treatments without damaging thrips numbers. Many of the earlier thrips control tests lacked sufficient thrips numbers to cause yield reductions.

These findings led to the reintroduction of at-planting systemic insecticides into the West Texas guide in 1986 after a hiatus of 15 years (Leser *et al.*, 1986). The Blacklands guide had already added at-planting systemic insecticides back into the thrips control recommendations four years earlier (Turney *et al.*, 1982). By this time it was recognized that the Blacklands and High Plains areas were generally the only regions with damaging thrips problems. The large winter wheat acreage and coincidence of cotton emergence dates with wheat maturity is probably responsible. The Rolling Plains area has the wheat acreage but the use of a delayed planting date for weevil management places cotton emergence later than wheat maturity. Thrips simply are not a problem.

Pink Bollworm — While calcium arsenate and sulphur appeared to be the answer for most cotton pests, the lack of an effective insecticide encouraged USDA and state experiment station entomologists to develop a cultural control strategy for the pink bollworm. This pest had invaded the substantial acreage of the Lower Rio Grande Valley in 1936 after an initial sortie in the limited cotton acreage at El Paso in 1918. The second state cotton guide issued in 1947 reflected the cultural control research addressing the pink bollworm (TAEX, 1947). The state was divided into zones with planting dates and stalk destruction following harvest regulated by the county or the Commissioner of Agriculture. The adoption of the proposed post harvest cultural control practices was not possible until mechanical harvesters and stalk cutters were available, the same limitations facing entomologists waging a war against the boll weevil.

The 1950s saw severe outbreaks of pink bollworms up into Central Texas. Insecticidal control was first advocated in 1949 with the arrival of the effective organochlorines, DDT and BHC (TAEX, 1949). Much of the control was realized from the destruction of the adult stage. Generally, insecticidal control was not recommended unless winter carryover created a problem. Treatment of fields was advocated where rosetted blooms indicated a heavy infestation. Insecticides were to be applied on a weekly schedule until cotton bolls opened. The 1953 Lower Rio Grande Valley guide first mentioned an economic threshold, recommending control when there were 10 percent rosetted blooms or 200 larvae per acre prior to the boll setting period (TAEX, 1953a). Treatment was to be delayed until bolls were 20 days old if only five percent rosetted blooms or 100 to 200 larvae per acre were found. All other infestations were to be addressed when 10 to 15 percent of the bolls were infested.

The 1959 economic thresholds were modified only slightly by elevating the pre-boll economic threshold to 500 larvae per acre, based on the new sampling technique where rosetted blooms were counted in 1500 feet of row in each field checked (TAEX, 1959a). Harvest-aid chemicals were advocated to force open remaining bolls as an encouragement for early harvest and stalk destruction. By 1960, the economic threshold had evolved to 350 larvae per acre or 10 to 15 percent infestation once bolls were present (TAEX, 1960a). Worm count criteria were used for the period prior to the appearance of bolls. New insecticides augmented the organochlorines for pink bollworm control with the addition of azinphosmethyl (Guthion®) in 1956 and carbaryl (Sevin®) in 1959 (TAEX, 1956b, 1959a). Except for the addition of monocrotophos (Azodrin®) in 1975, no new insecticides were listed until the synthetic pyrethroids were added in 1983 (TAEX, 1975a,b; Neeb *et al.*, 1983).

The only area remaining with occasional problems with pink bollworms is Far

West Texas. The Lower Rio Grande Valley guide ceased to list the pink bollworm as a pest of cotton after 1976, following several years of only spotty problems (TAEX, 1976a). The pink bollworm is a late season pest in Far West Texas. The goal there is to produce an early crop and then terminate by mid-September. Generally, the first three weeks of the boll setting period are addressed with insecticides when 10 to 15 percent of the bolls are infested. Late infestations as high as 40 to 50 percent are not a problem in top bolls that will not mature. By 1983 the West Texas guide had added the lower economic threshold of 5 to 10 percent for Pima cotton, distinguishing it from the less susceptible upland cottons (Neeb *et al.*, 1983). Pheromone traps were also added as an early indicator of pink bollworm problems. Once moths are captured in traps, fields are to be inspected for rosetted blooms. Treatment is recommended when bolls are 15-20 days old, using the 1953 Lower Rio Grande Valley guide recommendation.

Cotton Aphids — By the time of the drafting of the 1948 guide, research had established that the gamma isomer of BHC, one of the new organochlorines, would control cotton aphids (TAEX, 1948). The product was formulated as a dust and mixed with sulphur (for spider mite suppression) and DDT (for bollworm control). BHC also controlled boll weevils. This represented the first insecticide that could control aphids and be accepted by growers. Earlier, nicotine sulphate had been added to calcium arsenate for aphids, but this product was not widely accepted. Organophosphate insecticides were added in 1951 (TAEX, 1951). Initially, infestations were to be controlled when honeydew appeared (TAEX, 1949), but later, leaf curling was added as a damage symptom (TAEX, 1952a). By 1971, Texas guides were presenting a more restrained approach to insecticidal control of aphids, suggesting that beneficial insects generally hold aphid numbers below damaging levels (TAEX, 1971a,b,c). The 1979 West Texas guide went one step further, indicating that bollworm outbreaks were probable following insecticide applications targeting aphids (TAEX, 1979a). In truth, there were no data to support this statement, which had been added to further discourage what was perceived as unnecessary aphid control applications.

In 1979, after a four-year hiatus from the last severe outbreak (Rummel, 1975), a serious, widespread aphid problem occurred in West Texas. These late season infestations have been an annual problem ever since. Statements to the effect that sooty mold and incomplete fiber development from aphid infestations could reduce fiber quality were added to the guide (TAEX, 1979a). By 1983, early insecticide screening trials against late-season aphid infestations in West Texas dryland production acreage indicated yield reductions averaging 60 pounds of lint per acre would result from infestations above 50 aphids per leaf. At this time, very effective low rates of the insecticides dicrotophos (Bidrin®), disulfoton (Disyston®), and dimethoate (Cygon®) were available for aphid control (Neeb *et al.*, 1983).

Field monitoring currently consists of estimating the number of aphids per leaf by examining randomly selected mainstem leaves equally divided between the upper, middle and lower parts of the plant. Once aphid numbers reach 25 per leaf, infestations usually increase rapidly to damaging levels (Leser, 1989). This management approach is not presently recognized officially in Texas guides. By 1986 it was clear that aphids were a major yield detractor in dryland cotton fields to the south of Lubbock. Since 1979 between 500,000 to 850,000 acres have been treated annually either as applications solely for aphids or as combinations with bollworm treatments. Control problems were experienced in 1988 and 1989, when infestations appeared in June prior to squaring, two months earlier than usual. The 1990 season brought unofficial recommendations to increase insecticide rates to address a more insecticide-tolerant aphid.

Silverleaf Whitefly — This insect was recorded from cotton in the Lower Rio Grande Valley as early as 1946 (Russel, 1975), however, the first severe infestations in cotton were reported in 1990. Norman *et al.*, 1992 estimated the total impact of this pest on the overall cotton economy in the Lower Rio Grande Valley for 1991 was in excess of $73 million.

Silverleaf whitefly attacks many vegetables and fruits such as cabbage, cucumbers, cantaloupes, and watermelons; thus in subtropical areas, such as the Lower Rio Grande Valley, it is able to maintain populations through fall, winter, and spring to infest cotton through the spring and summer. This lack of a substantial host free period plus poorly timed and limited control measures have contributed to the tremendous outbreaks in the Lower Rio Grande Valley (Riley and Wolfenbarger, 1993). Other production areas (Far West, Gulf Coast, and Winter Garden) have experienced sporadic infestations, but damage to cotton has not reduced yields (Personal communication, John Norman, Texas A&M Extension Service, Weslaco).

Recommendations for management of this apparently well established pest in the Lower Rio Grande Valley involve integrating several control tactics with primary emphasis on temporal and spatial separation of host crops. Specifically, Norman *et al.*, 1993 suggest: (a) plant cotton early to avoid high infestation in the summer; (b) use resistant, tolerant, or non-preferred cotton varieties; (c) destroy old crop residues that harbor whitefly infestations; (d) avoid planting next to other crops infested with the pest; (e) delay planting fall vegetables until migrating whitefly populations diminish; (f) adopt application technology that improves coverage to the leaf underside; (g) incorporate one to two percent oil or soap mixtures in high volume spray treatments; (h) use insecticides selectively to preserve beneficial insects; (i) alternate insecticide chemistries to delay/avoid development of resistance; and (j) consult extension service for effectiveness of insecticides and other treatments.

Other Insect and Mite Pests — There are other pests of cotton that occasionally have created problems for Texas cotton farmers. They have been listed at various times in the cotton guides. These include cotton leafworm, *Alabama argillacea* (Hübner); brown cotton leafworm, *Acontia dacia* Druce; plant bugs; spider mites; armyworms; cabbage looper, *Trichoplusia ni* (Hübner); the soybean looper, *Pseudoplusia includens* (Walker); several species of grasshoppers; cutworms; wireworms; garden webworm, *Achyra rantalis* (Guenée); whiteflies; cotton square borer, *Strymon melinus* Hübner; false chinch bug, *Nysius raphanus* Howard; and others too restricted geographically and of limited duration to really matter.

Cotton leafworms were an old but serious pest of cotton prior to the use of calcium arsenate dust. Leafworms have received only limited attention in the development of state guides since 1942. Except for those rare years when leafworms have moved across Texas, causing extensive defoliation as far as the southern High Plains, leafworms have been relatively minor pests. Insecticides have dealt handily with predominantly late season, spotty leafworm infestations.

Plant bugs have been a continual problem mainly for Blacklands cotton production, although occasional serious infestations have developed in the South Texas area as well. The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the eastern species attacking cotton in the Blacklands and South Texas. The western lygus bug, *Lygus hesperus* Knight, is the western species. *Lygus* can be particularly damaging because, unlike the fleahopper, even larger squares, blooms, and small bolls are vulnerable to attack. The 1947 guide recommended toxaphene and sulphur for their control (TAEX, 1947). By 1959, organophosphate insecticides were beginning to be listed as effective *Lygus* control materials (TAEX, 1959a,b).

Economic thresholds for plant bugs have evolved since first introduced in the Lower Rio Grande Valley guide in 1952 (TAEX, 1952a). The economic threshold of 10-12 bugs per 100 squares that year lasted until replaced by the 1954 threshold of 8-10 per 100 sweeps (TAEX, 1954a,b). This threshold persisted until 1971 when an early bloom economic threshold of 10 bugs per 50 sweeps and a late season threshold of 20-30 bugs per 50 sweeps were added (TAEX, 1971a,b,c). Nymphs are counted as two bugs. These guidelines promoted a much more conservative insecticide use approach than the earlier treatment recommendations. Today the Blacklands area has a combination economic threshold for both fleahoppers and *Lygus*. A considerable arsenal of organophosphate and carbamate insecticides have been added since 1959 (Cole, 1988; Leser *et al.*, 1988; Norman, 1988).

Spider mite problems have invariably been regarded as the consequence of insecticide applications targeting other pests. The mite problem persists today where multiple applications of most synthetic pyrethroids can induce the development of later season spider mite problems. Two species are generally recognized, the carmine spider mite, *Tetranychus cinnabarinus* (Boisduval), and the twospotted spider mite, *Tetranychus urticae* Koch. The red spider mite, first identified as the desert spider mite, *Tetranychus desertorum* Banks, was the earliest recorded problem mite in Texas. This may have been a mis-identification since the desert spider mite and the currently recognized two species of mites can have red coloration and are not easily distinguished from each other. Regardless of species involved, these earlier mite problems were avoided by adding sulphur dust to calcium arsenate applications (TAEX, 1947). Aramite®, parathion, methyl parathion, malathion, and Systox® were soon added (TAEX, 1951; 1952a,b,a,b). Twospotted spider mites were addressed for the first time in the 1954 state guide (TAEX, 1954b).

Prior to 1966, the only changes in mite control recommendations were the addition and deletion of particular miticides. The 1966 guide covering the Blacklands and Central River Bottom areas mentioned resistance problems for the first time (TAEX, 1966a). By 1968, monocrotophos (Azodrin®) had been added to address control problems (TAEX, 1968). In 1979, state guides recognized that hot, dry, dusty conditions or elimination of beneficial insects with insecticides often led to mite problems (TAEX, 1979a,b,c). In general, no economic thresholds have been developed for these pests, and with the loss of monocrotophos (Azodrin®) in 1989, only bifenthrin (Capture®) and avermectin (Zephyr®) are available for effective, but very expensive mite control.

Armyworms, consisting of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith); yellowstriped armyworm, *Spodoptera ornithogalli* (Guenée); and beet armyworm, *Spodoptera exigua* (Hübner), have long been recognized as mainly foliage feeders. As such, state entomologists chose to ignore most infestations. Until an economic threshold of 10 to 20 percent infested plants was added to the West Texas guide (TAEX, 1971a), beet armyworms had been treated like any other armyworm *i.e.*, treat on an as needed basis. But this was dropped the next year, 1972. Following widespread, devastating beet armyworm problems in West Texas in 1980, it was recognized that this pest could feed on terminals, squares, blooms and bolls (Leser, 1986b). This resulted in the only significant management change for armyworms to date. Taking into account the relatively unimportant and high degree of leaf feeding by beet armyworms, West Texas entomologists set the armyworm economic threshold at 20,000 larvae per acre, four times higher than the bollworm economic threshold (Leser *et al.*, 1981). This was amended in 1984 to require at least 10 percent of the plants checked to be infested to avoid sampling problems resulting from the very clumped distribution of armyworms (Boring *et al.*, 1984). The addition of thiodicarb (Larvin®) in 1987 provided an effective material for armyworm control (Fuchs *et al.*, 1987).

Formerly, sudden appearance of some unexpected pest during one year precipitated a quick response at the fall guide revision conference with the listing of this new pest in the following year's management guide. These new pest listings rarely were accompanied with meaningful management advice, and control suggestions were often predicated on excessive damage. Usually ephemeral (short term), these pests often failed to appear in subsequent years. Recent years have seen a more prudent approach to the appearance of new pests. Rarely are these new, occasional pests listed in guides without sufficient data to support appropriate management recommendations.

OKLAHOMA RECOMMENDATIONS

HISTORICAL BACKGROUND

Cotton production has been a major cash crop in Oklahoma since the state's conception as Indian and Oklahoma territories. Maximum planted acreage within the state reached 5.4 million acres in 1925. However, by the end of the next decade, cotton acreage had dwindled to 1.9 million acres, which was largely due to drought (i.e., 1930, 1934, 1935 and 1936) and the inability of the producers to control cotton pests, primarily the boll weevil. Cotton acreage continued to decline during the next 40 years, bottoming out in 1983 with only 320,000 planted acres. Since the PIK (Payment In Kind program) year of 1983, planted acres have ranged between 350,000 and 420,000 acres annually with production concentrated in the southwest quarter of the state (Anonymous, 1982).

Prior to the arrival of the boll weevil in 1905, the bollworm was the dominant but sporadic pest. Heavy infestations of bollworms with concurrent significant yield losses were reported from Texas, Oklahoma, and the Indian Territory from 1903 to 1906 (Bishopp and Jones, 1907). In 1905 the Oklahoma Territorial Legislature attempted to prevent establishment of the boll weevil north of the Red River by imposing a quarantine that prohibited the importation of cotton seed, seed hulls, and sacks from neighboring states. These efforts failed, however, for in the summer of 1905, boll weevils appeared in fields along the railroad tracks near Caddo, in Byran county (southeastern Oklahoma). By 1915, the weevil had covered the entire state (Sanborne *et al.*, 1935). For the most part, damaging infestations of boll weevils remained in the eastern two-thirds of the state until the late 1950s.

The shift in cotton acreage from Eastern Oklahoma to the southwest quarter of the state was due, in part, to the farmer's attempts to escape the ravages of the boll weevil as well as to the economic advantage cotton enjoyed over alternative crops. Semi-arid conditions and lower winter temperatures enhanced boll weevil mortality and reduced the overall loss annually inflicted by weevils compared to losses in the higher rainfall areas of eastern Oklahoma.

The Oklahoma cotton industry lost over 438 million dollars in the 16-year period between 1916 and 1932. Most of this could be attributed to the boll weevil (Sanborne *et al.*, 1935). Without the efforts of the Oklahoma Cooperative Extensive Service in the introduction of cultural practices and the demonstration of the usefulness of calcium arsenate, the losses could have been much greater. Still, the lack of personnel, travel limitations, and poor communications hindered the adoption of these practices. There was only one extension entomologist for the entire state during this period (1917-1961) and this person, Charles Stiles, had responsibilities in all areas of entomology.

An increased incidence of cotton aphid and bollworm outbreaks was observed when arsenical dusts were used during the early attempts at controlling the boll weevil. Sulphur and nicotine dust were added to arsenical dusts in an effort to reduce these secondary pests. While the success of these early insecticide applications was limited, producers saw the merit of controlling cotton pests, and broadened the use, and perhaps areawide abuse, of insecticides as more efficacious products became available after World War II.

The Cooperative Extension Service was a separate entity of the university (Oklahoma State University) until 1964 when all state extension specialists were realigned and placed within the appropriate departments. This administrative action improved the interface between research and extension, allowing more collaboration to solve the problems facing the cotton producer in Oklahoma. In 1969, the state finally answered the cries for help from the cotton industry and hired the first area extension entomologist, Eldon Cleveland, at Cordell in southwestern Oklahoma.

INSECT AND MITE PROBLEMS IN OKLAHOMA

Major pest problems in the state are the boll weevil, bollworm/tobacco budworm and cotton fleahopper. Sporadic pests include thrips, cotton aphids, armyworms, spider mites, grasshoppers and loopers. Most years, the boll weevil is restricted to the southern tier counties (Harmon, Jackson, Tillman, Greer and Kiowa) because of climatic constraints. The bollworm infests the entire state, but annually causes the most damage in irrigated cotton concentrated in Jackson, Harmon and Tillman counties. The cotton fleahopper infests the entire cotton acreage and causes the greatest damage in late-planted cotton.

Boll Weevil — Successful management of the boll weevil is the key to developing a workable management system for Oklahoma cotton insect and mite pests. Cultural practices have been emphasized for weevil management since approximately 75 percent of the total state cotton acreage is produced under dryland conditions in a semi-arid climate. With a relatively low yield potential, farmers of this dryland cotton area can not afford a large insecticide input. Adoption of cultural practices developed in the 1930s continues to be stressed. Throughout the 1950s, extension personnel recommended early uniform planting dates followed by timely stalk destruction after harvest.

Current management practices exploit the weakness of the boll weevil. Much of the changes in strategies to reduce or delay boll weevil infestations have been the result of agronomic advancements made over the last 20 years. Probably the two advances making the most impact have been the introduction of high-yielding, fast-maturing varieties and the use of harvest aids (desiccants, defoliants and plant growth regulators). These practices have shortened the length of time the crop requires protection from damaging insects and reduced the chance of accelerating resistance to insecticides. Harvest aid chemicals also reduce oviposition sites as well as the food supply that emerging weevils need to accumulate sufficient fat reserves to overwinter successfully.

Due to the uncertainties of weather and a limited growing season, the delayed, uniform planting date has never been widely accepted as an alternative to insecticidal control for overwintered weevils in early squaring cotton. Diapause boll weevil control applications of insecticides applied with a harvest-aid chemical have likewise met with only limited acceptance. The reasons for their limited success include: (a) lack of widespread organized support such as that associated with the West Texas Diapause Control Program, (b) limited use of harvest-aid chemicals especially in low input dryland cotton, and (c) the high mortality of boll weevils during years with harsh winters.

Besides in-season insecticidal control of boll weevils, the application of an insecticide for overwintered weevil control prior to bloom, and timely, post harvest stalk destruction are the most widely used practices within the state. Boll weevil pheromone traps are used for surveillance and to help determine weevil emergence and proper application timing to prevent weevil establishment in early-planted fields.

Prior to the introduction of organochlorine and organophosphate insecticides, the weevil economic threshold was set low, insuring that most of the infested fields that were treated received scheduled applications throughout the season (Table 4). As more effective tools in the form of organochlorine insecticides became available after World War II, Oklahoma producers fully employed the full-season spray programs that were being endorsed and promoted by chemical companies. During this period of cheap chemical control, cultural practices for insect control were deemphasized in favor of production practices emphasizing long season varieties and increased fertility to promote high yields. The extension service advocated a more conservative insecticide use approach by increasing the economic threshold in 1950 to treat either when one or more weevils were found per 100 feet of row or when 25 percent of the squares were infested. By the mid 1960s, insecticide resistance was causing problems in controlling both bollworms and boll weevils. The economic threshold was modified to 15-25 percent infested squares, where it remains today. The resistance problem reemphasized the importance of pinhead square insecticide applications for overwintered boll weevils in the traditional weevil infested areas.

Bollworm and Tobacco Budworm — The bollworm continues as a sporadic pest of dryland cotton. However its status has changed over the years as production practices emphasizing high yields were adopted for irrigated cotton. Prior to 1950, there was no exact economic threshold on which to base spray or dusting decisions. All recommendations dealt with control intervals, recognizing that most larval infestations would be controlled with insecticide applications for weevils. Determination of larval density was not regarded as important or necessary.

The first economic threshold of 4-5 bollworms per 100 terminals appeared in the 1950 state insecticide recommendations (Table 4). By 1955, the threshold had been expanded to include the presence of eggs and 5 small larvae. Perhaps the addition of eggs to the economic threshold was an attempt to recognize the cyclic nature of the bollworm and to emphasize that without additional oviposition, light larval infestations need not be treated. Detection of bollworms is the key to the success or failure of the economic threshold concept. To help alleviate the difficulty associated with scouting and detection of small larvae, the economic threshold was modified in 1960 to include infested squares.

Spray interval recommendations over the years have changed from a 3-5 day interval to as needed. The reason for this change was the arrival of the synthetic pyrethroids in the late 1970s, at a time when the other insecticides had lost much of their former activity due to bollworm/tobacco budworm resistance. Standard insecticides or mixtures relied upon during the mid 1970s were 2-1 toxaphene + methyl parathion. EPN was occasionally added to the formulation for bollworms and azinphosmethyl (Guthion®) for boll weevils. A formulation containing ethyl-methyl parathion (6-3) was also used by many producers. Reducing the spray interval and increasing the dosage rate did not give satisfactory bollworm control once resistance became widely established (Personal communication, Jerry Young and Richard Price, Oklahoma State

Table 4. Evolution of key cotton insect control recommendations in Oklahoma[1].

Year	Recommendation
	Boll weevil
1935	In-season weevil control. Late season control[2]= 10 percent punctured squares. Calcium arsenate dust.
1950	Overwintered weevil control. At 1/3rd grown squares, ET[3]=1 or more weevils found per 100 feet of row. Late season control, ET=25 percent punctured squares. Organochlorines.
1965	In-season control, ET=15 to 25 percent punctured squares.
	Bollworm
1950	ET=4 to 5 worms per 100 terminals.
1955	ET=5 worms + eggs per 100 terminals.
1960	ET=5 small worms and eggs per 100 terminals or 10 percent infested squares in July or 5 percent infested squares in August.
1988	ET=10 small worms and eggs per 100 terminals for preblooming cotton and cotton after Sept. 10th.
	Cotton Fleahopper
1950	Preblooming cotton, ET=25 fleahoppers per 100 terminals.
1975	Preblooming cotton, ET=40 fleahoppers per 100 terminals.

[1]Recommendations from published Extension guides.
[2]Late season=boll period.
[3]ET=economic threshold.

University, Stillwater). Routine field scouting coupled with the improved control achieved with the pyrethroids has allowed insecticide applications to be applied only as needed.

The average insecticide application interval for control of bollworm/tobacco budworm in cotton enrolled in the Oklahoma Cotton Improvement Association scouting program has increased to 17 days in 1986 and 15 days in 1987 (Stoll, 1987). Overall, insecticide applications have been greatly diminished in Oklahoma in the last 15 years. Part of the success of widening the spray interval was due to the addition of the ovicide chlordimeform (Galecron®, Fundal®) to the state recommendations in 1974. Oklahoma did not recommend the use of ovicides alone. Methomyl (Lannate®, Nudrin®) and thiodicarb (Larvin®) were also added as contact ovicides with the same restriction. Chlordimeform was widely used during the period it was available to cotton producers—much of its usage was with the pyrethroids and other insecticides to control bollworm/tobacco budworm. In many situations, chlordimeform was applied with insecticide applications targeting secondary pests to reduce the chance of a bollworm outbreak. The widest use of *Bacillus thuringiensis* (Bt) has been in conjunction with chlordimeform for bollworm control in dryland cotton. Success of these tank mixtures is dependent upon proper timing of the application. The higher cost of the microbial tank mixtures has limited their use, since insecticides such as the pyrethroids could be applied for less money.

Resistance resurfaced across the Cotton Belt in 1986. Although no control difficulties have resulted in Oklahoma, resistance to the pyrethroids in Oklahoma was confirmed in 1987. A resistance management section was added to the extension guide in 1988, and resistance monitoring using the Texas A&M University vial technique was initiated (Plapp, 1988). Economic thresholds were modified by eliminating percentage square damage and focusing on detection of bollworm larvae. The threshold was increased to 10 small larvae and eggs present per 100 terminals for preblooming cotton and for cotton after September 10th in an effort to reduce the number of early and late pyrethroid applications. Use of alternative insecticides of different chemistries is encouraged during these periods with pyrethroid usage limited to July and August. This works well for Oklahoma because these months represent the two peak activity periods for the bollworm, a pest still easily controlled with pyrethroids.

A major constraint for relying on beneficial insects for the control of bollworm/tobacco budworm has been the lack of knowledge on the level of protection a certain density of predators would confer. Collops beetles and lady beetles are the two most common predators in Oklahoma cotton fields. According to Young and Wilson (1984), when densities reach or exceed 0.9 beetle predators per row foot, the field will be protected from bollworm damage.

Cotton Fleahopper — Research conducted by the Oklahoma Agricultural Research Station between 1936 to 1945 showed the cotton fleahopper seldom caused significant yield reductions that would justify control costs. Extension recommendations implied that control losses would result only in those areas of the state where heavy infestations of boll weevil and cotton fleahoppers were found together (Brett *et al.*, 1946). The controversy surrounding the cotton fleahopper and its potential to delay maturity continued, and in 1951, a fleahopper section was added to the cotton insect recommendations (Personal communication, 1988, Newt Flora, Cooperative Extension Service, Oklahoma State University, Stillwater).

Unlike the rest of the cotton producing states which over the past 15 years have emphasized the importance of early season insect control, Oklahoma recommendations have increased the economic threshold for cotton fleahoppers from 25 per 100 terminals in 1950, and subsequently to the current threshold of 40 per 100 terminals (Table 4). In many cases, control of marginal cotton fleahopper infestations had predisposed fields to later bollworm damage. Much of the square shed attributed to fleahoppers has been caused by environmental stress related to Oklahoma's climate (Molnar, 1975). Increasing the economic threshold for fleahoppers reduces insecticide use thereby conserving the beneficial insect population. This is an essential component of the Oklahoma cotton insect management approach.

Other Insect and Mite Pests — There are other pests of cotton that Oklahoma producers may occasionally have to address. These insects may cause annual, isolated damage or sporadic widespread damage. These other pests include thrips, spider mites, armyworms, grasshoppers and cotton aphids. They are listed in the state insecticide recommendations.

NEW MEXICO RECOMMENDATIONS

HISTORICAL BACKGROUND

Cotton was first planted in New Mexico in 1918 with harvested acres totaling 97,000 by 1927. This acreage was due largely to the Elephant Butte Irrigation project of 1919 located along the Rio Grande River between the cities of Truth or Consequences, New Mexico and El Paso, Texas (Hauter, 1928). The Rio Grande (Mesilla) Valley in south central New Mexico has continued to be one of the four major cotton producing areas of the state. The other areas include the Far West region in the southwest corner, the High Plains along the eastern border adjoining Texas, and the Pecos Valley immediately to the west of the High Plains.

Statewide, cotton emerged early as one of the major cash crops; however, the total number of acres planted to the crop is small compared to Texas and Oklahoma. A "see-saw" cotton production pattern has been the case with a state record of 315,000 acres in 1953 and a low of 58,100 acres harvested in 1983 (New Mexico Department of Agriculture, 1962, 1989). Intervening years saw acreage fluctuate between 200,000 and 70,000 acres. Government programs have been the primary factor influencing state cotton acreage. Bollworm/tobacco budworm control difficulties were encountered during the late 1960s and early 1970s. This further contributed to the acreage decline precipitated by government programs. The pink bollworm was also a major pest in the southern-most counties during this period. Cotton acreage has made a modest advance in the late 1980s in response to record yields and higher prices, reaching 85,200 harvested acres in 1989.

INSECT AND MITE PROBLEMS IN NEW MEXICO

Major pest problems in the state are very similar to Texas, except for the absence of the boll weevil. Important pests are the bollworm, pink bollworm, cotton fleahopper and other mirids (plant bugs), early season thrips, and, recently, the cotton aphid. Other sporadic pests include: spider mites, stinkbugs, beet armyworms, cutworms, grasshoppers and leafworms. The importance of pests varies geographically. The cotton fleahopper and other mirids can be important in all state production areas and their management can have a profound effect on the development of later pest problems. Thrips are primarily a problem in the High Plains, Pecos Valley, and Far West areas. Bollworms are a major concern for most of the state while the tobacco budworm, an insect with a propensity for resistance, is not important in any area. The cotton aphid has only recently been elevated to major pest status and then only in the eastern part of the state that adjoins the Texas High Plains.

Cotton Fleahopper and Other Mirids — The cotton fleahopper, whitemarked fleahopper, *Spanagonicus albofasciatus* (Reuter), and plant bugs [especially pale legume bug, *Lygus elisus* Van Duzee; western lygus bug, *Lygus desertinus* (Knight); and tarnished plant bug] can be both mid- and late-season pests throughout the state (Ward, 1985; Wilborn and Ellington, 1984), but tend to be of less importance in the Far West production area. The eastern part of the state is very similar to the Texas High Plains, with the cotton fleahopper the primary pest.

Long-time observers of the cotton pest problems in the Pecos Valley production area indicated that damage from these pests is frequently ignored or considered as a minor problem when in fact they cause general economic damage in 8-9 years out of ten (Personal communications, Bill Campbell, Ag Products, Inc., Artesia, New Mexico and Carl E. Barnes, New Mexico State University, Agricultural Science Center, Artesia). Early loss of fruit from these pests also probably encourages farmers to try to produce a late crop of bolls when they discover that their yield potential is below expectations in the latter part of the season. *Lygus* problems in late season are sporadic, occurring one out of every five years (Ward, 1985). They may be associated with alfalfa hay cutting, but this has not been documented for New Mexico. Entomologists differ greatly on the importance of mirids in the Rio Grande Valley and Far West areas. The whitemarked fleahopper is also present in these areas as well as in the Pecos Valley (Ward, 1985). This species is believed to be involved in early-season fruit losses.

As in Texas, sulphur dust in 1942 and then DDT and sulphur dust mixtures in 1947, were the early products of choice for controlling these pests. Eyer and Medler (1942a, 1942b) tested insecticidal dusts on plant bugs during this period. Prior to the first extension service guides, there is no record available on any economic threshold adjustments made during these years, when it was recognized that bollworm problems often followed fleahopper applications. Although the importance of sampling was recognized (Moore, 1950), the first published guide in 1951 (NM A&M, 1951) placed heavy emphasis on automatic dust and spray applications of the organochlorine insecticides DDT, toxaphene and gamma BHC, for both early and late season pests. To a large extent these treatments were recommended to be made on a five- to seven-day schedule for fleahoppers and *Lygus* spp., beginning at the four leaf stage or earlier if necessary (Table 5). As with earlier Texas recommendations, these early-season insects were to be controlled on a community or countywide basis. The larger the area treated, the greater the benefits accrued. The last application was to be made 30 days prior to the usual appearance of the bollworm thereby allowing beneficial insect numbers to rebound. In spite of the bollworm concern, late season plant bugs (Table 6) were to be controlled when the economic threshold of 8-10 insects captured per 100 sweeps was reached (NM A&M, 1951).

The reference to an areawide early season program was removed in 1953. Other recommendations were left unchanged (Swoboda, 1953). John Durkin (1961) replaced the recommendation for automatic early-season sprays for fleahoppers in 1961 with the economic threshold of 6-8 fleahoppers or *Lygus* per 100 sweeps with a 15 to 16-inch diameter insect net. Coppock (1962) provided separate economic thresholds the next year for the fleahopper (15 to 20 per 100 sweeps) and for *Lygus* (6 to 8 per 100 sweeps). This change may have been a response to research conducted by Race (1960) on sampling techniques. These guides included mixtures of organophosphates and organochlorines as recommended treatments for plant bugs and most other insects.

The sampling variability encountered using the sweep net for monitoring fleahoppers was recognized in 1973 by changing the economic threshold to 15-20 fleahoppers per 100 plants, with sampling to include terminals and small squares (Durkin, 1973). No further changes in threshold were made until 1984 when an economic threshold of 15 to 20 percent infested plants was coupled with square-set falling below 75 percent (Bozeman, 1984). The last change was to suggest sampling terminals rather than whole plants, with the range of infested terminals increased to 15 to 25 percent (Ward, 1991a). This is the same fleahopper economic threshold used in West Texas. (Boring *et al.*, 1989a).

Until 1962, fleahoppers and *Lygus* were considered equal in damage potential during the early part of the season (Coppock, 1962; Swoboda, 1953). The late-season *Lygus* economic threshold was lowered in 1953 from 8-10 to 7-10 insects per 100 sweeps. Coppock (1962) also introduced the concept of doubling counts of nymphal *Lygus* in determining the economic threshold. In 1966, Durkin (1966a) added the cautionary note that insecticide treatments for mirids could result in bollworm problems. Durkin (1973) made another significant adjustment of the late-season economic threshold in 1973 by raising it to 25-30 *Lygus* per 100 sweeps, coupled with 20 percent large square and/or young boll injury. The latter criterion was removed in the 1980 guide (Durkin and Gholson, 1980). Ward (1982) also advised that during late season, an ovicide should be added to any insecticide application for *Lygus* if 10-15 bollworm eggs per 100 terminals were found.

Bozeman (1984) presented a single, season long economic threshold of 6-8 *Lygus* per 100 sweeps, counting nymphs as two, paired with a square set reduced below 75 percent. Combining mid- and late-season thresholds was an error, which was corrected in 1989, (not published until 1991) by adding a late-season recommendation (Ward, 1991a, 1991b). Sweep counts for both mid- and late-season are the same as those used in Texas (Boring *et al.*, 1989a). However, the mid-season economic threshold for whole-plant counts remains as an alternative. In both cases, nymphs are counted double and the thresholds must be exceeded on two consecutive sampling dates four to five days apart. Also, a weighted combined economic threshold is recommended if both fleahoppers and *Lygus* bugs are present in the same field.

Bollworms — Since the boll weevil has never appeared at economic levels, the major late-season pest in New Mexico has been the bollworm. Although the tobacco budworm was considered to be involved in the apparent resistance problems encountered in the late 1950s and early 1960s, few documented reports of infestations of this species can be found. The bollworm has been of major economic concern in the Pecos Valley in about one out of every three years since the 1950s with from 3 to 6 insecticide applications made during peak years (Ward, 1985).

Table 5. Evolution of key fleahopper control recommendations in New Mexico.[1]

Year	Recommendation
1951	2-3 weekly insecticide applications beginning at 4-leaf stage or earlier in area-wide program. Late season ET[2]=8-10 fleahoppers per 100 sweeps of a 16 inch net.
1953	Removed mention of area-wide programs.
1961	ET=6-8 per 100 sweeps; treat at 5- to 7-day intervals.
1962	ET=15-20 per 100 sweeps.
1973	ET=15-20 per 100 plants (terminals & small squares).
1978	ET=15-20 fleahoppers per 100 plants.
1984	ET=15-20 percent infested plants; and square set drops below 75 percent.
1991	ET=15-25 percent infested terminals and square set drops below 75 percent.

[1]Recommendations from published Extension guides.
[2]ET=economic threshold.

Table 6. Evolution of key *Lygus* control recommendations in New Mexico.[1]

Year	Timing	Recommendation
1951	Early-season	2 to 3 insecticide applications beginning at the 4-leaf stage or earlier if necessary.
	Late-season[2]	ET[3]=8-10 *Lygus* taken per 100 sweeps of a 16 inch net.
1953	Early-season	Same as 1951.
	Late-season	ET=7-10 *Lygus* taken per 100 sweeps of 15- or 16 inch net.
1961	Early-season	ET=6-8 *Lygus* per 100 sweeps, treat at 5-7 day intervals.
	Late-season	ET=7-10 *Lygus* per 100 sweeps, treatment at 5-7 day intervals.
1962	Mid-season	ET=6-8 *Lygus* per 100 sweeps, treat at 5-7 day interval. Count nymphs as two.
	Late-season	ET=7-10 *Lygus* per 100 sweeps, treat at 5-7 day interval.
1973	Mid-season	Same as 1962.
	Late-season	ET=25-30 *Lygus* (count nymphs as 2) per 100 sweeps and 20 percent of large squares and young bolls show injury.
1984	Mid-season	Same as 1962 but added square set reduced below 75 percent.
	Late-season	ET not given.
1991	Mid-season	ET=10 *Lygus* (count nymphs as 2) per 50 sweeps or 6-8 *Lygus* per 100 plants checked on 2 consecutive sampling dates 4-5 days apart; use combined weighted ET if fleahoppers are also present.
	Late-season	ET=20-30 *Lygus* per 50 sweeps if plants failed to set sufficient fruit the first 4-5 weeks.

[1]Recommendations from published extension guides.
[2]Late season=boll period.
[3]ET=economic threshold.

During the early 1940s, the economic threshold followed was probably similar to that used in Texas, with calcium arsenate dust recommended every five days until eggs and larvae were no longer found. The first published economic threshold included the presence of eggs as well as 4-5 small larvae per 100 terminals (Table 7). Durkin (1961) raised the threshold to six small larvae per 100 terminals and recommended treatment on a five to seven day schedule. The threshold was raised again in 1966 to 6 to 10 small larvae plus eggs per 100 plants, with a warning not to count eggs as worms unless beneficial insects had been eliminated by previous sprays (Durkin, 1966a).

Following the mid 1960s, a growing number of producers discontinued treatments for bollworms. This was primarily due to the large monetary outlay being made for insecticides that had generally become ineffective. Insecticide resistance was the major factor producing poor control results. Several of these "non-insecticide users" attempted to utilize releases of the minute egg parasite, *Trichogramma minutum* Riley, and the convergent lady beetle, *Hippodamia convergens* Guerin-Meneville (Durkin 1959). This practice has not been studied in detail locally, but historically has met with little success in other states at the release rates reportedly being used (Durkin, 1959; Later personal communication, J. J. Durkin, Cooperative Extension Service, New Mexico State University, Las Cruces).

These early attempts at biological control and the introduction of *Bacillus thuringiensis* (Bt) and a nuclear polyhedrosis virus for bollworm control, led Durkin (1978) to include a warning to evaluate these products no sooner than 5 to 7 days following application. The microbial insecticides are slower acting than the organophosphates and pyrethroids. Durkin and Gholson (1980) also included Bt and virus combinations with ovicides in the 1980 guide as recommended treatments when beneficial insects were plentiful. This also was the first year the pyrethroids were included in the guide. The exceptional results obtained with these materials in bollworm control demonstrations in the Pecos Valley led to increased acreage being treated for bollworm infestations (Ward, 1985).

Ovicides also were first included in guides in 1980 with an economic threshold of 10 to 15 bollworm eggs per 100 terminals (Durkin and Gholson, 1980). This egg control suggestion was continued in 1982 (Ward, 1982), but was omitted in the 1984 abbreviated guide (Bozeman, 1984). Ovicides are now recommended to be used only in conjunction with larvicides (Ward, 1991a, b). Combinations with microbial insecticides are encouraged in blooming cotton against worm numbers up to 10,000 per acre. After bolls appear, the economic threshold is lowered to 8,000 larvae per acre.

The 1991 to 1992 guide largely follows the 1989-1990 Texas guide which suggests using either (a) cluster scouting of five whole plants and an economic threshold of 5,000 or more small bollworms per acre and less than two predators per larva or (b) dominant terminal scouting with an economic threshold of at least 8 to 10 percent of the terminals infested with small larvae and less than 20 percent of the terminals having key predators (Boring *et al.*, 1989a). Resistance management is also discussed in this guide in an attempt to extend the useful life of the synthetic pyrethroids. The Texas guidelines were largely followed.

Table 7. Evolution of key bollworm and tobacco budworm control recommendations in New Mexico.[1]

Year	Recommendation
1951	ET[2]=when eggs are present and/or 4 to 5 small worms per 100 terminals are found.
1961	ET=6 small worms per 100 terminals, treat at five day intervals.
1966	ET=6 to 10 small worms + eggs per 100 plants; count eggs as worms only if "beneficials" have been eliminated.
1982	ET=same as 1966 except monitor egg lays to time control for small worms; warning to evaluate Bt on basis of damage first, 5 to 7 days posttreatment, then evaluate worm control; also use combinations of Bt and ovicides when "beneficials" are plentiful.
1991	1. Cluster scouting of five whole plants, a minimum of 12 clusters per field: ET=5,000 or more small worms/acre and less than two predators found per worm. 2. Dominant terminal scouting: ET=8 to 10 percent small worms; higher if 20% of the terminals have key predators. 3. Biological and ovicide suggestions reinstated.

[1]Recommendations from published extension guides.
[2]ET=economic threshold.

Pink Bollworm — Hoyt (1953) indicated that the first major outbreaks of the pink bollworm in this country were recorded in 1952 in 39 South Texas counties with losses estimated at $29 million. However, there are indications that pink bollworms were a problem in the New Mexico Rio Grande Valley as early as 1949 and 1950 (Thompson, 1951). The 1951 cotton insect control guide included recommendations for controlling the pink bollworm (Table 8). White (1953) and Spencer (1953) also stated that all cotton producing counties in New Mexico were included in the 1952 Pink Bollworm Federal Quarantine Regulations.

The 1953 guide indicated that "during the past harvest season, enough pink bollworms were found to cause everyone . . . to be concerned" (Swoboda, 1953). Stalk destruction and farm cleanup on a community-wide basis was urged. These suggested cultural practices followed recommendations similar to those discussed by Spencer (1953) at the 1952 Beltwide Cotton Production Conference, and were basically the same as those listed in the first cotton insect control guide of 1951.

Pink bollworm infestations increased to economic levels in the 1960s but declined through the 1970s primarily as a result of mandatory stalk destruction promulgated by Regulatory Order No. 2 (Amended) Plant Protection Act of 1968 (New Mexico Department of Agriculture, 1968), requiring stalk destruction in that year (Durkin, 1966b, 1967, 1968). Even in the 1960s, only about 10 percent of the fields were treated in the Pecos Valley for this pest (Ward, 1985). Isolated fields in Eddy and Dona Ana

Table 8. Evolution of key pink bollworm control recommendations in New Mexico.[1]

Year	Recommendation
1951	Cultural practices, especially uniform planting date and late season stalk destruction required on a community-wide basis; recommended organochlorines as cupplemental control.
1961	Treat at seven day intervals when infested blooms or bolls are found.
1968	Mandatory stalk destruction law passed; required destruction by January 15 in seven southern counties.
1973	Listed cultural practices and bloom and boll inspection methods; rosetted bloom ET[2]=35 per 1500 of row 5 to 15 days after bloom; boll ET=5 to 10 percent infested green bolls; treat at five day intervals until 70 percent of bolls are open.
1984	Rosetted bloom ET=same as 1973. Boll ET=same as 1973 except >40 to 50 percent infested bolls in late September and October.
1991	Upland cotton ET=10 to 15 percent infested bolls and Pima cotton ET=5 to 10 percent infested bolls the first 6 weeks of boll set; the late September and October ET=40 to 50 percent was retained. Terminate treatments in upland cotton when last bolls expected to be harvested are 30 days old; in Pima cotton, continue until 70 percent of the bolls are open. Continue to stress cultural control and use of rosetted blooms and pheromone trap catches as indicators to initiate boll surveys.

[1]Recommendations from published extension guides.
[2]ET=economic threshold.

Counties frequently had pink bollworm problems even in the 1970s and 1980s. This pest continues to be a major potential threat, because mid- to late-September infestations can easily be missed when scouting of the crop is prematurely ended.

Research conducted from 1957 to 1960 in New Mexico on the effects of insecticides on beneficial insects, and on sampling methods, began to influence the recommendations for cotton insect control (NM A&M, 1957, 1958, 1959; Race, 1960). Except for preventative treatments with systemic insecticides, calendar spray dates were giving way to scouting and economic thresholds. This trend was reflected in the establishment of an economic threshold for pink bollworm in the 1973 guide (Durkin, 1973). Both bloom and boll thresholds were given. These thresholds remained unchanged until 1984, when the boll economic threshold of 5-10 percent infested green bolls was increased to greater than 40-50 percent for late September and October (Bozeman, 1984).

This increased late-season threshold was a reflection of other changes taking place in New Mexico cotton production. One major change was the switch from the production of primarily extra long staple Pima cotton types to shorter stapled upland cotton, especially the Acala types. Like Oklahoma and Texas, the introduction of these high-yielding, fast-maturing varieties, coupled with the use of harvest-aids (desiccants, defoliants and plant growth regulators), greatly affected insect management strategies. The length of time the crop needed protection from insects was shortened. Harvest-aid chemicals reduced the food supply that pink bollworms required to build up overwintering infestations late in the season.

The recent increase in cotton acreage devoted to the longer-season Pima-type cottons, especially in the Rio Grande Valley and Far West production areas, is again increasing the potential of pink bollworm outbreaks in New Mexico. This has led some growers to initiate adult control in the fall, on the basis of pheromone trap catches. This practice is placing additional selection pressure on late-season bollworms and other pests and could hasten the development of resistance. Therefore, this practice is specifically discouraged in the 1991 to 1992 Guide (Ward, 1991a). The economic thresholds are the same as those recommended in the 1989-1990 Texas guide (Boring *et al.*, 1989a), providing separate recommendations for upland and Pima cotton (Table 8). The threshold for rosetted blooms was eliminated to encourage boll sampling early in the pink bollworm season. Rosetted bloom surveys and pheromone trap catches are recommended only as indicators for the need to initiate boll sampling.

Thrips — The results of thrips control research conducted by Eyer and Medler (1941) and Faulkner (1950a,b) probably formed the basis for the early foliar automatic insecticide treatment recommendations for fleahoppers, *Lygus*, and thrips beginning at the "four-leaf stage or earlier if necessary" (NM A&M, 1951). Durkin (1961) continued this approach through 1961 by recommending three applications on a seven-day schedule, beginning at the two-leaf stage.

Research on systemic insecticides in New Mexico was initiated in 1958 (NM A&M, 1959) by J. G. Watts, R. C. Dobson, S. R. Race, and others. The 1961 and 1962 guides marked the introduction of preventative seed-furrow treatments with systemic insecticides for thrips, aphid and mite control (Durkin, 1961; Coppock, 1962). The 1961 treatments of granular disulfoton (Disyston®) and phorate (Thimet®) were "recommended for use on a trial basis . . . on seedling cotton." The 1962 Guide carried a full recommendation for these preventative treatments in areas where these insects appeared as perennial pests (Coppock, 1962). Foliar dust and spray treatments continued to be recommended on a scheduled basis.

New chemicals such as azinphosmethyl (Guthion®), carbaryl (Sevin®), carbophenothion (Trithion®), demeton (Systox®), malathion (Cythion®), dicofol (Kelthane®), and Aramite® had also appeared in the 1961 and 1962 guides. Several of these treatments were still being recommended in 1964 for thrips control using the earlier automatic guidelines or as an alternative, when damage first became apparent. Subsequent applications were recommended if thrips persisted (Durkin, 1964).

Recommendations for preventative thrips control persisted in guides until 1984 (Bozeman, 1984). At that time, the economic threshold proposed by Texas of 2-5 thrips per plant was adopted as a threshold for foliar sprays. Research conducted in Texas as well as in New Mexico (Ward, 1985) resulted in the deletion of damage as an economic threshold factor. With the elimination of damage as a treatment guideline, and because of the difficulty involved with scouting for this tiny pest, producers opted to treat much of the thrips-infested acreage with systemic insecticides as a seed or in-furrow treatment. Barnes estimated that as much as 40 to 50 percent of the state acreage has been involved, because of the prevalence of seedling damage in most years. (Personal communication, Carl E. Barnes, New Mexico State University, Agricultural Science Center, Artesia).

Other Insect Pests — One of the earliest references to insect problems in New Mexico was the grasshopper outbreaks in the late 1920s and mid 1930s (Quesenberry, 1936). Although cotton was not specifically mentioned, a total of 183,640 acres of cropland was reported to have been protected from grasshoppers in 1934, at the peak of the outbreak. Grasshopper management recommendations were added to the guide in 1961, and the application of baits containing aldrin or dieldrin were recommended for treating field margins to curtail migration into cotton fields. Spotty infestations of grasshoppers have required control five years out of the last twenty (Ward, 1985). Control efforts over most of the area have depended upon the Cooperative Control Program (state, federal, and private funds) in rangeland surrounding the cultivated valleys.

Other sporadic insect pests are: the seedcorn maggot, *Hylema platura* (Meigen); various species of wireworms and spider mites; darkling beetles; cutworms (especially the variegated cutworm, *Peridroma saucia* (Hübner); and armyworms (especially the yellowstriped armyworm, *Spodoptera ornithogalli* (Durkin and Gholson, 1980). Cotton aphids and beet armyworms have occurred as economic pests somewhat more frequently, the latter especially in late season. Aphids have been an economic problem in some fields in the Pecos Valley in two out of four years. Wireworms and darkling beetles tend to be a problem limited to cotton planted the first year following alfalfa or other high residue crops. Spider mites have been noted as early season pests in one out of four years. Late season problems with spider mites occur with similar frequency (Ward, 1985).

Cabbage loopers were a more consistent pest in the 1950s and 1960s with economic problems in one out of three years. High numbers of this pest were observed recently in only two of the last ten years (Ward, 1985). Treatments made for other pests have generally checked population increases of cabbage loopers. The cotton leafworm has not been a problem in the last decade, but two outbreaks were noted in the 1960s. Stink bug (various species) problems are generally associated with migrations from maturing small grains such as barley and oats (Ward, 1985).

Although a few boll weevils have been trapped in recent years in New Mexico on both the eastern and southern borders with Texas, a diapausing population has not become established. Therefore, the devastation experienced in Texas and Oklahoma in the early 1900s did not affect New Mexico's cotton producing areas. The effective diapause control program initiated in west Texas in 1964 is apparently largely responsible for keeping the boll weevil out of eastern New Mexico. The recent invasions of the boll weevil into the state however, has led to inclusion of the boll weevil as a pest in the proposed revision of the 1989 state guide but not published until the 1991 guide (Ward, 1991a, b). The recommended management strategies are the same as those for the Texas High Plains.

EXTENSION SERVICE GUIDES AND THE GUIDE REVISION PROCESS

TEXAS

Prior to 1949, the first extension service guides were developed informally by a handful of extension and research entomologists. In later years, the writing of the Texas guides became a pluralistic effort, involving a sizeable group of state and USDA cotton entomologists. Starting in 1949, an organized research review and guide revision conference was initiated where issues and proposed guide changes were discussed, debated and finally voted upon. The two-day, closed door affair was followed by a third day in which guide revisions were made public to invited representatives of the agricultural sector, chemical industry, and the press. Early guide revision relied heavily on testimony and opinion, often supported only by limited research. Strong personalities often prevailed over reason. As more entomologists swelled the ranks of the extension service and the experiment station, the process became more democratic. But sheer numbers sometimes have led to protracted discussions and limited progress.

Formal rules were established for the conference in 1982, requiring a minimum of two years of replicated, statistically analyzed, small plot tests for support of any guide change involving insecticides. For the first time, suitable data from other states' universities and USDA were accepted. Changes in sampling techniques, economic thresholds, and other management techniques require reproducible research results similar to those specified for insecticides. Only products and techniques suitable for Texas IPM programs are considered. Environmental issues are very important in molding the management advice in the extension guides.

Some of the guide changes, taken at face value, appear to be nothing more than format modifications. Much more was often involved. Often these arose out of heated philosophical battles over how to best encourage guide users into reading both cultural and chemical control recommendations. Guides were fold outs for many years; insecticide tables with economic thresholds and scouting methods were included with attendant small sections on cultural control. This format remained unchanged until a stapled 4X9 inch guide was introduced in 1980. Beginning in 1981, West Texas guides placed insecticide listings in tables under each pest narrative (Leser *et al.*, 1981). Guides expanded in the 1980s as more information was included on pest management, scouting techniques, pest descriptions and economic thresholds. Following a 1986 meeting in Dallas, the guides were published in a 8 1/2" X 11" format with insecticides listed in the back as a single table. Revision of area guides is now coordinated to prevent unnecessary differences from developing. Ultimately, publication costs won over the greater philosophical battles with a separate insecticide publication produced annually to supplement the biannual narrative guide (Boring *et al.*, 1989b; Norman, 1989b; Parker and Swart, 1989).

Differences in management philosophy and techniques have led to several area guides over the past four decades. The Lower Rio Grande Valley was the first to leave the state guide in 1951 and remained a separate guide until 1961, when it was combined with the Gulf Coast, resulting in the South Texas Guide (TAEX, 1961b). This guide lasted 13 years, until the Lower Rio Grande Valley once again became a separate guide, one of three that remain today. The Gulf Coast recombined with the traditional state guide. West Texas entomologists, recognizing the great differences that existed with East Texas, initiated a new guide in 1961 (TAEX, 1961c). The Rolling Plains area did not officially join this guide until 1966. The Blacklands area split from the state guide between 1974 and 1985. The decline in Blacklands cotton acreage and increasingly short publication resources prompted the absorption of this guide back into the state guide in 1986. The original state guide traditionally covered the Central River Bottom area, the Gulf Coast and the Central Blacklands area at various times. Presently there are three sets of recommendations: the Lower Rio Grande Valley, Central Texas and Gulf Coast, and the West Texas guide.

OKLAHOMA

Prior to the first Extension Agents' Handbook of Insect Control in 1958, information concerning insect pests, damage and control recommendations was disseminated to extension personnel, cotton producers and agribusiness through a weekly newsletter during the growing season. Control information presented in this newsletter was adopted by the Entomology Department and extension entomologists from information compiled annually by the Federal Cooperative Extension Service in Washington, D.C. Each state received copies of research and insecticide recommendations submitted by all cotton producing states in the United States. This procedure was followed during the 1950s (Personal communication, Newt Flora, Cooperative Extension Service, Oklahoma State University, Stillwater). A postcard survey was inserted weekly in the newsletter mailing. This weekly survey helped extension entomologists identify insect population trends and determine the type of information needed in upcoming newsletters.

The Extension Agents' Handbook is currently reviewed and revised annually. Information collected from insecticide screening trials and more basic studies conducted by research and extension personnel are reviewed and compared to similar work conducted in other parts of the Cotton Belt. Besides efficacy, environmental concerns are also discussed before a practice or pesticide is approved for the guide. A spin-off of the handbook was the publication of fact sheets that addressed specific topics. The first cotton fact sheet was printed in 1967.

State pesticide recommendations are more than a listing of the pests and products labeled for their control. The guide is a publication to assist cotton producers in making sound pest management decisions. The information provides a sound integrated approach firmly based on research trials from universities and USDA and adapted to Oklahoma's climate and production practices. Due to generally limited resources in Oklahoma, some of the research concerning economic thresholds and control measures were adapted from other states, especially Texas.

NEW MEXICO

The acknowledgement section of the 1951 cotton insect control guide indicated the contribution of the Texas A&M College, Agricultural Extension Service, and Experiment Station for information on which the circular was based (NM A&M, 1951). The author of the 1951 Guide, L.H. Moore (Personal communication, 1990, L. H. Moore, retired, Clemson, South Carolina), indicated that one of his associates in the experiment station, either E.J. "Pewee" O'Neal or earlier workers, may have had some "mimeographed" cotton insect control information, but it too would have been based on work from other states, especially Texas and Arizona. Watts (1980) also mentioned the use of mimeographed materials such as the College Courier (1912-1916), New Mexico Farm Courier (1916-1921), and the 400 Series (1945 to present) that included insect control suggestions for cotton and other crops. The Insect Letter (1970-1976) and Pesticide Chemical News (1970-1976) also included suggestions for cotton insect control and changes in pesticide registrations.

This dependence on Texas, Oklahoma and Arizona for research results has continued to a great extent to present times, but the written acknowledgment disappeared from the 1953 Guide (Swoboda, 1953) and has not been reinstated. With only one full-time extension entomologist and one research entomologist with part-time responsibilities for cotton during 1951 to 1980, efforts to cover all aspects of the pest problems in cotton have been limited. This situation has not improved in recent times. No formal guide revision procedure has been established such as followed in neighboring Texas.

The cotton guide has not been revised for several years. The 1991 revision is patterned after the 1989-1990 west Texas guide and 1990 insecticide supplement (Boring *et al.*, 1989a,b), and consists of two parts, with Guide 400 J-7A containing the narrative biology, economic thresholds, cultural, and biological control information and Guide 400 J-7B containing the chemical control suggestions (Ward, 1991a,b). This will allow the annual revision of the chemical control suggestions to match label and other use changes without necessitating the revision of the longer narrative portion which requires less frequent modifications. This allows more timely revisions in the future.

SUMMARY

Cotton insect and mite problems have varied in time in accordance with climatic conditions, geographical shifts in cotton acreage, advances in crop production practices and the availability of effective pest control technologies. The boll weevil initially shaped cotton pest management systems in both Texas and Oklahoma during the early cotton production years. While New Mexico lacked this menacing pest, the pink bollworm provided adequate incentive to follow a similar course of action adopted by its sister states to the east. All areas of the Southwest region have relied heavily on a shortened crop vulnerability period obtained from growing rapid-fruiting, fast-maturing varieties; and utilizing harvest-aid chemicals to terminate the crop so that timely harvest and stalk destruction can be implemented. These practices have been the cornerstones of a successful management system that continues to prosper into the 1990s. The result of this approach has been a greatly reduced reliance on insecticides and embracement of integrated pest management (IPM) programs and their concepts.

Recently the boll weevil and pink bollworm have relinquished the top pest ranking to the bollworm/tobacco budworm complex. This has been largely the result of the continuing insecticide resistance problem that almost counted the pyrethroids as a recent casualty. It is this threat of resistance and the unleashing of damaging late season bollworm/tobacco budworm problems that has encouraged the continued restraint in controlling early season plant bug infestations, as well as the occasional flurry of bollworm activity which sometimes occurs prior to bloom. Entomologists of the Southwest learned a long time ago to be cautious about destroying the natural enemies so important to managing these earliest bollworm cycles.

Early season thrips are the only pests remaining where preventative or automatic treatments still appear to fit best. Although Oklahoma does not perceive the thrips issue the same as its neighboring states, their lack of support for automatic treatments merely reflects the minor importance of this pest to their production area. Texas and New Mexico also recognize there are areas within their respective states where thrips are not the perennial damaging pest so often seen in the High Plains region.

The geographical diversity which exists among the three states in the Southwest is no greater than that found in Texas. This has lead to the development of regional management strategies and subsequent insect management guides. The guide revision process ranges from highly structured involving over twenty entomologists in Texas to the more informal process in New Mexico involving one or two entomologists often unable to maintain timely published recommendations. Both Oklahoma and New Mexico have relied heavily upon the research and control recommendations of Texas. Only recently has Texas begun to utilize information from other states. This cooperation has lead to a more efficient and timely guide revision process.

Entomologists of the Southwest region should never ignore the insect management lessons learned in the past. To embrace production systems that maximize yield without regard to pest consequences—or that promote excessive use of insecticides, fertilizer, and irrigation—will negate the management advantages provided by the environment, that is, the natural restraint on pest populations. These benefits can only be maximized through cultural and biological control practices. Sole reliance upon repeated insecticide applications will only bring ruin to a system that has persevered for many years and has been learned through pitched battles with the bollworm and boll weevil.

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