MANAGING RESISTANCE - WHAT CAN WE DO NOW?

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Abstract

An insecticide resistance management plan for the mid-south states (Arkansas, Louisiana, Mississippi, Missouri, and Tennessee) has been developed for 1996. The plan is designed to help maintain full season control of all cotton insects on Bt and non-Bt cotton. Specific treatments are recommended during discrete intervals or phases. For non-Bt cotton, the plan recommends that bollworm/tobacco budworm populations be managed with foliar Bt products plus an ovicide between planting and July 1 (Phase I). After July 1 (Phase II), bollworm/tobacco budworm populations should be managed with pyrethroid tank mixtures. Tank mixture partners for pyrethroids are selected based upon the insect pest spectrum present at application. After August 15 or a pyrethroid control failure, organophosphate tank mixtures should be used for bollworm/tobacco budworm control. Management options for boll weevil, cotton aphid, and tarnished plant bug also are included. To forestall resistance development to Bt cotton, additional recommendations (beyond those of Monsanto Chemical Co.) are included. The plan recommends that no more than 200 acres of contiguous Bt cotton be planted without separation by refugia.

Introduction

Management of cotton insect pests with insecticides has become more difficult due to the development of insecticide resistance and lack of newly registered insecticides. Only one new class of insecticide, the chloronicotinyls, has been labeled for foliar use on cotton since 1978. The lack of new insecticides had led to extensive reliance on three major classes of insecticides (carbamates, organophosphates and pyrethroids). Consequently, several cotton insect pests have developed resistance to these insecticides, including the tobacco budworm, tarnished plant bug, cotton aphid, and beet armyworm.

In response to tobacco budworm populations developing resistance to pyrethroids in 1986, a resistance management plan was implemented. This plan was designed to delay the total loss of pyrethroid insecticides as an effective tobacco budworm control tool until new insect control technologies become available. In the interim, however, tobacco budworm populations have developed resistance to several organophosphate and carbamate insecticides.

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New tobacco budworm control technology will become available in 1996 with the introduction of cotton plants that produce the *Bacillis thuringiensis* endotoxin (Bt-cotton). New foliar insecticides for tobacco budworms and other cotton insects, however, may not become available before 1997. The availability of Bt-cotton will be limited in 1996 and the lack of new foliar insecticides will force most cotton producers to rely on carbamate, organophosphate and pyrethroid insecticides for cotton insect control.

Previous resistance management plans have focused primarily on tobacco budworm. However, tobacco budworm resistance management is complicated by broad-based resistance in other insect pests such as the cotton aphid and tarnished plant bug. Thus, the insect pest management strategy for 1996 must consider problems with these pests and be compatible with the introduction of Bt-cotton.

The 1996 resistance management program is designed to maintain full season control of all cotton insect pests without placing excessive reliance on a single class of insecticide. In the plan, specific treatments are recommended during discrete intervals or phases. Treatment recommendations should be based upon the pest spectrum present and the susceptibility of the crop during that phase. This will maximize the utility of each class of insecticide and help maintain season long insect pest control.

Insect pest management guidelines for Bt-cotton also are considered. Cotton producers will be required to follow tobacco budworm resistance management guidelines on Bt-cotton defined in an agreement with Monsanto Chemical Company. Insecticide resistance in other cotton pests warrants continued use of a foliar insecticide resistance management strategy on Bt-cotton.

Because cotton insect pest management is dynamic, these guidelines cannot address all situations. Therefore, these recommendations are not intended to limit the professional judgement of qualified individuals. Maximum benefit, however, from following a resistance management strategy can only be realized if all producers in a wide geographic area participate. Also, it is important to remember that selection of specific compounds should be based on consideration of all insect pests in the fields to be treated, stage of crop development, effect on non-target organisms, and risk of contributing to resistance problems in subsequent generations.

1996 Foliar Insecticide Recommendations

Managing for Earliness

Managing for early crop maturity is an important component of these guidelines. Early crop maturity decreases the period of crop susceptibility to yield loss by

insects, reduces insect control costs and lowers selection pressure for insect resistance development. Cotton producers should plant an early maturing cotton variety during a 30-day period between April 15 and May 15. In-furrow fungicides and insecticides are recommended to help avoid plant stand loss, promote seeding growth, manage early season insect pests and accelerate crop maturity. The goal is to obtain an optimal stand of healthy and actively growing cotton with timely planting.

Producers should avoid practices that delay crop maturity and increase the attractiveness of cotton to late-season insect pests. Excessive use of insecticides such as methyl parathion or chlorpyrifos during the early season has been documented to delay crop maturity and reduce yield. Post-emergence herbicides for over-the-top applications should be limited to those compounds that do not adversely affect plant growth. Avoid excessive rates and late-season foliar applications of nitrogen-containing fertilizers. Terminate irrigation as soon as possible to mature the crop but not adversely affect crop yield.

With timely planting and proper insect pest management, most of the harvestable bolls will be set on the plant by early August. Under these conditions, the cotton crop will be mature enough to avoid severe damage by the August generation of tobacco budworm. Early crop maturity also will reduce the probability of economic losses from fall armyworm, beet armyworm, loopers, bandedwinged whitefly and western flower thrips.

Phase I (Pre-Bloom: Planting to Late June/Early July)

Phase I corresponds to that time between planting and first bloom. The first generation of tobacco budworm in cotton generally occurs during this time. Phase I recommendations for insect control on Bt and Non-Bt cotton are similar.

The primary objective in Phase I is to preserve the efficacy of the pyrethroids and the organophosphates, Curacron 8E and Bolstar 6E. Preserving the efficacy of these products is the most important component of the resistance management plan. Use of these products in June will render them ineffective in July against populations of tobacco budworms, tarnished plant bugs, and cotton aphids. Resistance monitoring clearly shows that resistance levels increase sharply each season after use of these products is initiated.

Economic infestations of early season insect pests should be controlled to mature the crop in 120-140 days (planting to defoliation). Treatment thresholds should be flexible to account for fruit retention, yield potential, cost of insecticide treatments, complexes of insect pests, the price of cotton, etc. Insecticides should not be applied for control of any insect pests unless scouting suggests economic thresholds have been exceeded. Producers should strive for 75 to 80% first position fruit retention.

Properly timed pinhead square treatments are recommended to control overwintering boll weevils. Insecticides should be selected based upon activity on boll weevils, other pests present and beneficial insects. Organophosphates used for boll weevil control are generally more disruptive, thus more likely to result in increased bollworm/tobacco budworm problems, than are carbamates and chlorinated hydrocarbons. Furthermore, organophosphate use will select for resistance in tarnished plant bug and cotton aphid populations.

Tarnished plant bugs should be treated only when population levels exceed the treatment threshold. Pyrethroid use during Phase I will select tarnished plant bug populations for resistance. Early-season use of pyrethroids also increases the likelihood of flaring populations of cotton aphids and spider mites. Use of the organophosphates Bolstar or Curacron for tarnished plant bug control should be avoided during Phase I, because use of these compounds could select for resistance.

Cotton aphid populations should be managed initially using at-planting insecticides to suppress populations. Foliar insecticides should be selected based on previous insecticide use patterns and activity on non-target organisms. Control failures are more likely to occur if the class of insecticide has been previously used on that field.

Population densities of tobacco budworms during June are relatively low on much of the mid-south cotton acreage. Cotton is less susceptible to yield loss by bollworm/tobacco budworm during Phase I than during Phase II, so higher populations can be tolerated without sustaining economic damage. Additionally, beneficial insects are typically most abundant in cotton at this time and can contribute to bollworm/budworm control. Most populations can be effectively managed with *Bacillis thuringiensis* (Bt) products + ovicides without causing other cotton insect pest problems. Larvin 3.2F at larvicidal rates is recommended in situations where high densities of bollworm/tobacco budworms are present, or on tobacco budworm refugia for Bt-cotton. Foliar Bt products should not be used on cotton designated as tobacco budworm refugia for Bt-cotton.

Insecticide applications during Phase I may induce an economic infestation of tobacco budworm by destroying beneficial insect populations. Selection of specific compounds should be based on consideration of all insect pests in the field to be treated, activity on beneficial insects and risks of contributing to control failures in subsequent generations (Table 1). Selection of materials during Phase I is particularly critical because effects on all pests can multiply through the remainder of the season.

The use of prophylactic or scheduled treatments of any insecticide is highly discouraged. Use of scheduled treatments for any insect increases the cost of insect pest control, may flare secondary insects and undermines the

value of an agricultural consultant. Most cotton producing regions have highly trained agricultural consultants whose expertise should be used to scout and treat insect pest populations only when necessary.

Phase II (Early Bloom to Boll Maturation; Early July to end of season)

Non-Bt Cotton

Phase II includes the blooming and boll development period during which the second and subsequent field generations of tobacco budworm occur. Fields should be checked at least twice weekly. If pyrethroids have not been used during Phase I, resistance in tarnished plant bug, boll weevil, cotton aphid, and tobacco budworm populations should be low at the initiation of Phase II. Pyrethroids should be the initial insecticide of choice and should provide cost-effective control of a broad spectrum of pests including boll weevil, tarnished plant bug, cotton aphid, tobacco budworm, and bollworm. Other insecticides should be added in a tank mixture to improve control. Selection of the appropriate tank mixture should be based on the insect pest complex in the field.

Bollworm/tobacco budworm treatments should be applied against eggs and one- to two-day-old larvae. Eggs and small larvae of resistant tobacco budworm populations can still be effectively controlled with labeled rates if insecticide treatments are accurately timed and properly applied. Agricultural consultants and producers should use all available information including results of adult vial tests indicating resistance levels, pheromone trap captures and moth flushing counts indicating species composition (bollworm vs tobacco budworm) to make informed decisions about specific insecticide treatments. Pyrethroid combinations (at median rates) should be used for bollworm and tobacco budworm control. Table 2 lists recommended tank mixture partners for pyrethroid insecticides. Pyrethroid insecticides should never be used alone for tobacco budworm control.

At least two treatments on intervals of four to five days are generally required to provide effective control of even low to moderate tobacco budworm populations. Closer intervals (three to four days) may be required to manage heavy populations of tobacco budworms. Recommended application methods are necessary to ensure satisfactory insecticide performance.

Organophosphate tank mixtures should be used after August 15 or if pyrethroid tank mixtures fail to control tobacco budworms because of resistance (recommended tank mixture partners are listed in Table 3). Multiple applications, at median rates, on a four-to five-day interval are more effective than a single application at the highest labelled rates. Avoid using pyrethroids against tobacco budworm after August 15. Damaging populations of armyworms or loopers should be managed with Larvin 3.2F or other effective treatments.

After "cutout," an early maturing cotton crop is not very attractive to late-season insect pests. Economic thresholds can be adjusted to higher levels in late August than those used during the critical fruiting period. Insecticide applications can often be terminated by mid to late August. Monitor crop maturity and do not apply insecticides after most of the crop is resistant to insect damage because the unnecessary late-season use of insecticides is rarely cost effective and further selects for insecticide resistance.

Diapause applications of insecticides for boll weevil management are recommended to delay the development of economic infestations the following year. Timely stalk destruction and/or tillage will reduce overwintering survival of bollworm, tobacco budworm and boll weevil.

Bt-Cotton

Insect populations on Bt-cotton should be controlled with the most cost-effective insecticides. Pyrethroid insecticides can be used after August 15 for insect pest control. Foliar Bt products should not be applied to cotton designated as bollworm/tobacco budworm refugia for Bt-cotton.

When Unsatisfactory Control with Foliar Insecticide Occurs

Because of high levels of insecticide resistance, available chemistries may not provide control of high populations of tobacco budworm, cotton aphid or tarnished plant bugs when they occur over a prolonged period. It is not realistic to expect 100% control of any insect pest with any insecticide treatments. Attempts to manage insect pests at near-zero damage levels in cotton fields are not cost effective and result in early field control failures. Despite the insecticide selection strategy used, some cotton producers are likely to experience unsatisfactory control of resistant insect pests during the season. Do not expect satisfactory control of tobacco budworm larvae (>five days old) after control failures, regardless of the insecticide treatment used. Sometimes, infestation levels remain high after treatment, but little or no crop damage occurs. Infestations of 2500-5000 bollworm or tobacco budworm larvae per acre can be tolerated without a significant yield loss.

Do not panic when it appears control with insecticides is unsatisfactory. Do not automatically assume that the presence of insect pests after an insecticide application is the result of an insecticide failure. All control problems are not related to insecticide resistance, and several factors should be considered in response to these problems. Treatment decisions should consider a variety of factors that influence insecticide efficacy and damage potential; species composition, population density, population age structure, application timing, insecticide dosage, application methods, application carriers, treatment evaluation timing, need for multiple applications, environmental conditions and insecticide resistance levels.

Under continuous insect pressure, multiple insecticide applications are required to reduce crop damage. Frequent applications of recommended economical treatments are often more effective than longer intervals with expensive mixtures at higher rates. Do not use excessive rates of one or more insecticides in these mixtures because, in most situations, control will not improve above the recommended rate ranges. (See appropriate state recommendations for insecticide use rates.) If a field failure is thought to be caused by insecticide resistance, do not reapply the same insecticide at any rate. Alternate to another class of insecticides or use mixtures of insecticides from different classes.

When experiencing high populations of tobacco budworms, the goal of a control program should be to manage the population, not eliminate it. Multiple applications (on four-day intervals) of an insecticide combination will usually keep tobacco budworm larvae feeding in the top of the plant away from the bolls.

Bollworm/Tobacco Budworm Resistance Management on Bt-Cotton

Resistance management is extremely important on Bt-cotton to delay bollworm/tobacco budworm resistance development. The probability that at least one of these insect pests will develop resistance to Bt-cotton is extremely high because of the high toxicity to these pests and continuous exposure of bollworm/tobacco budworm populations to the toxin. Therefore, it is extremely important that everyone involved with Bt-cotton support resistance management to preserve the effective life of Bt-cotton.

Cotton producers agree to practice bollworm/tobacco budworm resistance management for Bt-cotton when the licensing agreement is signed with Monsanto Chemical Company. This contract is the minimum resistance management that the producer must follow. Because this technology is important to future profitability of cotton production, further resistance management techniques are recommended to delay bollworm/tobacco budworm resistance to Bt-cotton.

Monsanto's bollworm/tobacco budworm resistance management plan for Bt-cotton is based upon the theory that very few bollworm/tobacco budworms will survive in Bt-cotton fields and that susceptible bollworm/tobacco budworms will immigrate into Bt fields. Their resistance management strategy requires that a producer choose from among the following options to provide a refugia. For every 100 acres of Bt-cotton the producer must:

A. Plant 25 acres of cotton without the Bollgard gene that can be treated with insecticides (other than foliar Bt products) that control bollworms and tobacco budworms.

B. Plant 4 acres of cotton without the Bollgard gene that cannot be treated with insecticides that control bollworms and tobacco budworms.

It is very important that the refugia be planted next to Bt-cotton to ensure immigration of susceptible individuals into Bt-cotton fields. Also, it is recommended that Bt-cotton be planted in blocks not greater than 200 acres in size. Fields greater than 200 acres should be separated by refugia areas.

Bt-cotton will only provide satisfactory control of bollworms/tobacco budworms. Therefore, producers should follow appropriate guidelines for managing other pests. Recommendations for foliar insecticide use on Bt-transgenic and non-Bt transgenic varieties are the same, except after August 15 when pyrethroid insecticides can be used for insect control. In addition, foliar Bt products should not be applied to tobacco budworm refugia for Bt transgenic cotton.

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Table 1. Recommended insecticides for early season insect pest control.

Insecticide	Thrips	Aphid	Weevil	TPB	Benef.[1]
Bidrin 8L	X	X	X	X	100
Dimethoate 4E	X			X	80-90
Endosulfan		X			50-60
Guthion 2L			X		100
Metasystox-R 2E		X			100
M. Parathion 4E			X		100
Monitor 4E	X	X		X	100
Orthene 90S	X			X	80
Penncap M 2F			X		100
Provado 1.6F		X			?[2]
Vydate 3.77 CLV			X	X	70-80

X, recommended by mid-south states for control of insects listed (Consult appropriate state recommendations for additional recommended products).
[1] relative percent elimination of beneficial insects. Percent elimination will vary according to species of beneficial insect.
[2] insufficient data available to determine effect on beneficial insects.

Table 2. Tank mixture partners for pyrethroids during Phase II[1]

Insecticide	BW	TBW	FAW	BAW	Loop	TPB
Bolstar 6E	X	X				X[2]
Curacron 8E	X	X				X[2]
Lannate 1.8E	X	X	X[2]			
Larvin 3.2F	X	X	X[2]	X[2]	X[2]	
Orthene 90S	X	X				X
Ovasyn 1.5E	X	X				
Condor[3]		X			X[2]	
Design[3]		X			X[2]	
Dipel ES[3]		X			X[2]	
Javelin[3]		X			X[2]	
MVP[3]		X			X[2]	

X, indicates that these compounds will provide some control, beyond that of the pyrethroid alone, for those pests indicated.

[1] BW=Bollworm; TBW=tobacco budworm; FAW=fall armyworm; BAW = beet armyworm; Loop=cabbage and soybean looper; TPB=tarnished plant bug.

[2] At indicated rates, these compounds will provide suppression of low populations of these insects.

[3] These compounds should not be used on non-transgenic varieties designated as tobacco budworm refugia.

Table 3. Recommended tank mixture partners for Bolstar, Curacron or Orthene during Phase II[1].

Insecticide	BW	TBW	Ovici	FAW	BAW	Loop
Larvin	X	X	X	X	X	X
Lannate[2]	X	X	X			
Ovasyn	X	X	X			

X, indicates that these compounds will provide some control beyond that of the organophosphate alone, for those pests indicated.

[1]Insectici=insecticide; BW=bollworm; TBW=tobacco budworm; Ovici = ovicide; FAW=fall armyworm; BAW=beet armyworm; Loop=cabbage and soybean looper.

[2] Under certain environmental conditions, combinations of Curacron and Lannate may defoliated cotton.