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AN ANALYSIS OF THE ECONOMIC IMPACTS OF INSECTICIDE USE IN ARIZONA COTTON

by

John Joseph Haydu

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL ECONOMICS

In Partial Fulfillment of the Requirements
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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

Figure Page

ABSTRACT

This study measures economic impacts to representative large and small farms in Pinal County, Arizona, of a tax or standard that restricts per-acre insecticide use in cotton production. In contrast to previous studies, a variable damage function is incorporated into a dynamic economic model that more closely approximates actual insect-crop dynamics. An analysis is conducted comparing a constant damage function with the newly developed variable damage function. Comparisons of farm profits, optimal insecticide applications and optimal levels of insecticide use are made considering two controls, a tax, and a standard.

Results show that, although the total restriction of insecticide is equal for both control actions, the standard incurs an efficiency cost from its implementation. A tax has no efficiency cost, yet significantly affects per-acre profits for the two farms. Policy makers are presented with a choice between an inefficient standard, which will negligibly affect long-run farm survival, or the efficient tax, which, in addition to reducing insecticide levels, generates a tax revenue for society. However, the effect of the tax on farm profits is enough to cause concern for the long-term survival of many farms.

An analysis of constant versus variable damage functions shows significant differences in farm profits and optimal application rates. Results suggest that farm producers may be overapplying insecticide treatments throughout the cotton growing season.

CHAPTER 1

INTRODUCTION

In recent years there has been an increasing concern for potential human and environmental damages caused by pesticide use in crop production. Restrictions of some pesticides used for crop and livestock production have occurred, and future restraints are probable. Such restrictions, however, are not without costs. Pesticides are a major input to modern agriculture. Limits to agricultural use of these chemicals will have numerous environmental as well as economic repercussions.

One major repercussion of restricting pesticide use is the potential effects on crop producers. This study hypothesizes that legislated restrictions on pesticides used in crop production will alter the economic efficiency of cropland farmers and change the distribution of net benefits of the pesticides. The level of such impacts will depend on the control strategy used to regulate pesticide use.

To analyze these potential effects, a representative farm firm model is specified for a particular area in Arizona. This mathematical model is formulated to depict the production activities of two farm sizes. To simplify the analysis, a particular insecticide, methl-parathion, is utilized in the model (as opposed to utilizing a class of pesticides, e.g., fungicides, herbicides, rodenticides, etc.). This model is then used to derive profits as a function of insecticide use for each farm size. In turn, the distribution and efficience effects of alternative insecticide control actions are examined and contrasted between farm firms. The results and implications of the alternative controls are then analyzed.

Need for the Study

Use of insecticides for crop protection has become an important aid to the American farmer. Farmers' use of insecticides has helped reduce the risk of crop losses and aided in improving the quality and quantity of farm products. Total U.S. consumption of insecticides actually decreased 5 percent between the periods 1971-1976. The decline was primarily due to the U.S. Environmental Protection Agency (EPA) restriction of DDT and a 50 percent reduction in the use of aldrin; aldrin and DDT accounted for 35 percent of all insecticide used by farmers in 1971. In 1976, 162 million pounds of insecticide were applied to 75 million acres of major crops, and of these, cotton accounted for half of total use (U.S. Department of Agriculture [USDA], 1978). Unlike the nationwide trend, Arizona's use of insecticides increased 33 percent between the period 1973-1977 to a 1977 total of 9.4 million pounds (University of Arizona Council of Environmental Studies, 1978). Increased use is largely explained by heavy infestations of the pink bollworm and tobacco budworm in Arizona cotton, the state's number one economic field crop.

The tobacco budworm infested Arizona cotton in 1972. The toxaphene, methyl-parathion mixture initially used for control became less effective as resistant strains of tobacco budworm emerged. Today, the budworm continues to be an insect pest of importance to cotton producers. With increased insect resistance to toxaphene and the advent of EPA restrictions, toxaphene is being replaced by synthetic pyrethroids as a major input to cotton production. However, these chemicals will likely increase insect control costs in cotton production.

Information is needed that will show the impacts governmental restrictions on insecticides will have on the economic viability of cotton. Particularly, this information should reflect the efficiency and distributive impact particular chemical restrictions have on farms of various sizes. This is a major aim of this research.

With the ever-increasing social concerns for environmental and other external effects of insecticide, it is conceivable that public decision makers may underestimate the cost effects of such regulations to the farmer. Yet, if the farmer's economic viability is substantially reduced by controls, the long-run economic productivity of society as a whole will be affected. Insecticide restrictions could utlimately lead to a decrease in supply and an increase in food prices. Thus, improved information concerning the benefits and costs of insecticide control will benefit both farm producers and society as a whole by providing an effective evaluation of the trade offs between the risks of insecticide pollution and the benefits of increased crop production. A social balance between the two can then be sought.

Characteristics of the Area

Pinal County is the location of the hypothesized farms analyzed in this study. It has an area of 5,400 square miles and is located between Tucson and Phoenix in south-central Arizona. It has a population of nearly 70,000 people and possesses approximately 376 irrigated farms comprising 227,000 acres, or one-fifth of the irrigated cropland in

Arizona (U.S. Bureau of the Census, 1977). The climate is hot and dry necessitating year-round irrigation for cropping. The crops generally grown are cotton, wheat, safflower, barley, grain sorghum, alfalfa, and some vegetables. Nearly 60 percent of cropped acres consist of cotton (Arizona Crop and Livestock Reporting Service, 1979)

The soils, generally favorable for the field crops previously mentioned, consist of deep, moderately fine to moderately course, reddish soils, with the greatest acreage possessing low slopes (0-3 percent), (U.S. Soil Conservation Service, 1971).

Water for irrigation in Pinal County consists of both surface and ground water. The surface water is obtained from the San Carlos Project, which initiated distribution in 1928. The project is designed to provide irrigation water for 50,000 acres of Indian land and 50,000 acres of non-Indian lands in the Coolidge, Florence, Eloy, and Casa Grande areas. However, over the years it has provided an average of 90,000 acre-feet of water per year, despite its 1.3 million acre-feet capacity. In very recent years, due to heavy rains and snow, the reservoir is nearly full with just over 1 million acre-feet of water. Some farmers, especially in the Casa Grande area, will increase irrigated acreage as a result of this above-average supply (U.S. Soil Conservation Service, 1977).

Ground water developed for Pinal County began in the 1930s. Ground levels have fallen continuously since pumping began, resulting in pump lifts ranging from around 200 feet to more than 800 feet around the Eloy area. Without additional water supply, many of the area farmers are looking at an uncertain future.

Thesis Objectives and Organization

The primary objective of this research was to provide an analysis of the economic efficiency and distribution effects of alternative insecticide control strategies on two representative farm sizes in Pinal County, Arizona.

A significant constraint to developing an economic model that represents farm production activities is the relationship between the environmental eco-system and final crop production and sales. Such a model requires incorporating a biological model that links crop yield to insect-population dynamics. To date, such research has assumed constant damage per insect over the growing season (Talpaz and Borosh, 1974). Crop growth patterns and insect population dynamics are not accurately represented by such methods. To improve the realism of insect control analysis, this study estimates damage throughout the growing season for cotton. This modification enables a more accurate depiction of the insect, crop, and insecticide relationship and, therefore, provides a needed improvement to previously used models.

The economic model developed by Talpaz and Borosh (1974) provides the base for this research. A single-crop, single-insect framework is utilized. A key point of the research is to incorporate a time-dependent damage function into the model, thereby more closely approximating actual insect-crop dynamics. An additional part of this thesis was to obtain insecticide cost information. Many large farm firms of Arizona obtain volume discounts on the purchases of insecticides, thus realizing significant cost savings over small farm firms. This data provides a basis for the differentiation of insecticide by farm size.

A development of the economic theory of insect control is presented in Chapter 2. Contrasted are the theoretical economic efficiency and distribution effects of insecticide regulation (tax vs. standard) on two farm sizes are contrasted.

Chapter 3 discusses the physiologies of the cotton plant and the tobacco budworm and the relationship between them. This provides the basis for development of the biological model used in this thesis.

A complete presentation of the economic model is developed in Chapter 4. Discussed are basic assumptions of the model, insect population dynamics, the kill efficiency function, the variable damage function, the profit function, and the solution method.

Chapter 5 provides the empirical results of this study, comparing the standard vs. a tax and the effects constant and variable damage have on farm profits, optimal insecticide application rates, and levels of insecticide use.

A summary of the empirical results, model limitations, and distributional considerations are in Chapter 6.

Finally, Chapter 7 presents the conclusions of the thesis and recommendations for additional research.

CHAPTER 2

ECONOMICS OF INSECT CONTROL

Frequent and growing instances of agricultural use of insecticides result in external costs to society. Man in a desire for higher profits and increased food supply has sought means of reducing the short-run risk of crop losses without considering the long-run effects of these decisions. This philosophy may be seen as a concerted effort of "man against nature" or, perhaps, "man controlling nature," and in the short-run there are positive results to such effort. In the last three decades, many new methods of agricultural production have developed within the United States. The contribution of these innovations are extremely impressive if production augmentation is the evaluation criterion. But these efforts have not been without their costs. In the quest for independence from nature, farmers and society have become manacled to yield increasing technologies. With increasing use of limited energy and environmental resources, flexibility in social and technological change is constrained. Dependence on man-made innovations has increased at an alarming rate, and with the use of these innovations much of the modern world is beginning to witness the emergence of longer run consequences. Insecticide effects are just one such consequence, but an important one. Examples of external effects from insecticides are the polluting of streams and ground waters, human health hazards due to ingestion of contaminated fruits, vegetables, and cereals, and the poisoning of wildlife from treated crops or forest lands.

Baumol and Oates (1975) described such effects as externalities. An externality occurs when an individual's utility is altered by another's action (whether a person, corporation, a government), without concern for the effect this action has on the individual's welfare. Frequently individuals affected by external effects do not receive compensation equal to their loss in utility or welfare.

An emerging realization by federal, state, and local governments as to the present and potential hazards of insecticide use has precipitated the initiation of legislative control of many agricultural chemicals. Chemicals that can be shown to be hazardous to the environment or the public welfare are subject to a rigid review by the U.S. Environmental Protection Agency [EPA] (Appendix A for RPAR procedure). Chemicals that violate the specific standards set by the EPA may be restricted in use or banned completely. Additional attention should be drawn to the effects these restrictions or bans have on crop producers.

Analysis of Insecticide Restrictions to Crop Producers, by Farm Size

This research attempted to evaluate the efficiency and distributional consequences of insecticide control actions on farm producers. These effects are examined for two farm sizes, assuming that some economies of size exist in the use of insecticides via volume discounts. Thus, the distributive effects analyzed are those resulting from variations in farm size in Arizona, a state where individual farms tend to be increasing in acreage.

Farm Size Characteristics

Over the past 25 years the pattern for the firm or industry in the U.S. economy has been one of selective elimination. The criterion for this elimination is efficiency. The firm or industry that maximizes the net benefits of producing given output is considered efficient. Technological innovations have greatly contributed to production methods specialized enough to reduce unit costs while simultaneously increasing the quantity of an output. Today, with the cost of inputs continually rising, marginal or less efficient firms tend to be forced from the industry. The general trend in agriculture is toward fewer but larger farms. Farm firms in Arizona follow this pattern. Table 1 shows a large decline in the number of Arizona farms while total acres have declined minimally. Such a pattern suggests acreage increases on a per farm basis.

Table 1. Number of Harvested and Irrigated Acres for Arizona, 1974, 1964, and 1954

	1974	1964	1954	Percent change in acres Number of farms, 1954-74
Harvested				
Acres	1,505,072	1,589,630	1,614,859	-7%
Number	3,533	4,191	6,209	-43%
Irrigated				
Acres	1,153,478	1,125,350	1,177,407	insignificant
Number	3,828	4,697	6,809	-44%

Source: U.S. Bureau of the Census, 1977, Vol. 13, Part 3, p, iv-67.

Stults (1968) stratified farms by size for Pinal County as shown in Table 2. Since farms have been getting fewer and larger, Stults's farm-size estimates are no longer valid. They provide a general description of farm firm stratification that is sufficient for purposes of this study.

Table 2. Amended Stratification of Farm Size, Pinal County, Arizona

Size Group	Number of Farms	Range of Cropped Acres	Average Cropped Acres
Farm Size 1	103	0	106
Farm Size 2	107	221-520	341
Farm Size 3	111	521-950	675
Farm Size 4	79	961 and above	1,705

Source: Stults (1968).

This study focused on the economic effects to farms due to insecticide regulations. The model was restricted to a single product, cotton, and a single input, insecticide. Profits and marginal profits are estimated as a function of insecticide application levels. The theoretical development in the remainder of this chapter compares the differences in per acre profits and insecticide levels for large and small farms due to two insecticide control strategies.

Theoretical Foundation: Development of the Marginal Profit Function

The economic analysis of two farm sizes rests on the assumption of perfect competition. Perfect competition is characterized by conditions that specify that each farm firm is a price taker, the product is homogeneous, each farm possesses perfect knowledge (information), and there is free entry and exit of farm firms (mobility of resources). In addition, each firm seeks to maximize profits subject to its resource constraints.

This theoretical analysis assumed two farm sizes, small (Type 1) and large (Type 2). Each farm is restricted to using a single input in the production of a single output, or specifically, the dependent variable is cotton and the independent variable is the level of insecticide use. All other inputs are assumed fixed for the purpose of this study. Per acre output of cotton is assumed equal for both farms, which implies that any economies of size between farms is restricted to insecticide quantities in the form of volume discounts, which chemical companies may give to the larger farms.

The profit-maximizing level of insecticide to apply per acre for each farm will differ with the price of the insecticide. For each farm it occurs in the second stage of production, when the positive distance between total revenue (TR) minus total cost (TC) is a maximum (Figure 1). On a marginal basis, profit-maximizing levels of insecticide occur when the marginal value product (MVP_y) is exactly equal to the price of the input (P_x). Mathematically, profits for the small farm (Type 1) are

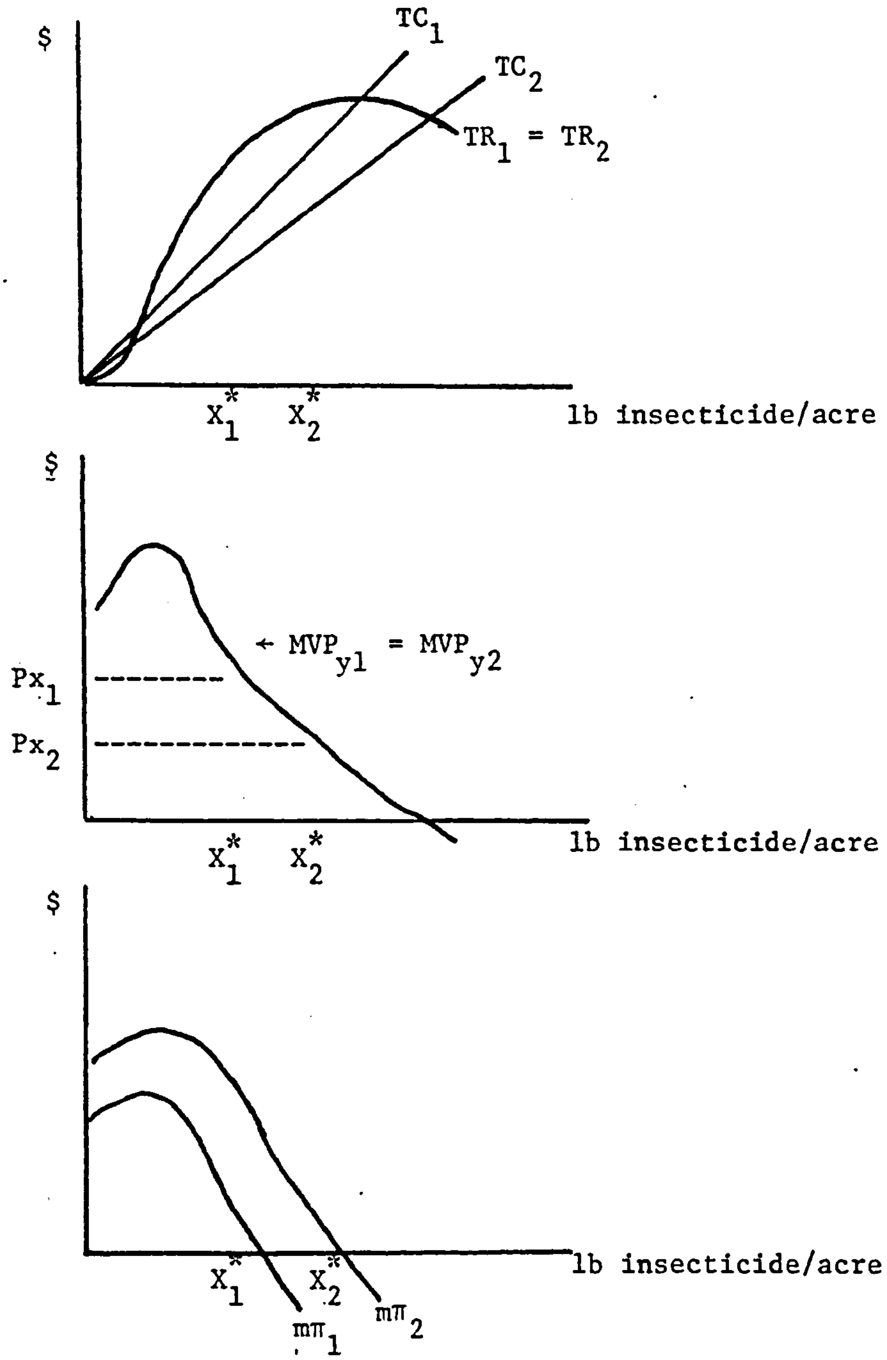

Figure 1. Derivative of marginal profit curves for a small ($m\pi_1$) and large ($m\pi_2$) farm

$$\pi_1(X_1) = P_y \cdot Y(x_1) - P_{x_1} \cdot x_1 - FC \quad (1)$$

and profits for the large farm (Type 2) are

$$\pi_2(X_2) = P_y \cdot Y(x_2) - P_{x_2} \cdot x_2 - FC \quad (2)$$

where:

π_1 = profit for Type 1 farm

π_2 = profit for Type 2 farm

Y = units of cotton, pound

P_y = price per unit of cotton

X_1 = units of insecticide used on Type 1 farm

X_2 = units of insecticide used on Type 2 farm

P_{x_1} = price of insecticide for Type 1 farm

P_{x_2} = price of insecticide for Type 2 farm

FC = fixed costs

$P_{x_1} > P_{x_2}$

Therefore, the profit-maximizing rule for Type 1 is

$$\frac{\partial \pi}{\partial x_1} = P_y \cdot \frac{\partial y(x_1)}{\partial x_1} - P_{x_1} = 0 \quad (3)$$

and for Type 2 is

$$\frac{\partial \pi}{\partial x_2} = P_y \cdot \frac{\partial y(x_2)}{\partial x_2} - P_{x_2} = 0 \quad (4)$$

Total revenue is represented by $P_y \cdot Y$, which is the same for each type farm; therefore, $TR_1 = TR_2$. Total cost is $P_{x_1} \cdot x_1$ for Type 1 and $P_{x_2} \cdot x_2$ for Type 2, where $TC_1 > TC_2$. Both total revenue and total cost curves are shown on the top portion of Figure 1.

Figure 1 depicts the optimal levels of insecticide use, which are x_1^* for Type 1 and x_2^* for Type 2. At any point along the MVP curve, marginal profits ($m\pi$) are derived by subtracting the MVP_y curve from the marginal cost (price) of the input insecticide (P_x). As noted earlier and shown on Figure 1, total cost for Type 1 is greater than total cost for Type 2. This is because the unit cost of insecticide is a function of the quantity of insecticide purchased and thus increases as the farm size becomes significantly large. Many chemical companies apparently initiate volume discounts for insecticide if cotton acreage on a farm exceeds approximately 1,000 acres. Average price discounts on insecticide range from 5 to 8 percent. Application or set-up costs are generally a fixed rate; although, discounts for large farms are not uncommon. These discounts are often around 5 percent.

Effect of Regulatory Actions

Two insecticide regulatory control actions on the quantity insecticide are considered in this study, a tax and a standard. Both generally imply a predetermined target of insecticide use, selected by a regulatory commission like the EPA. The objective of each action is to restrict total insecticide use to an "acceptable" level. However, the method by which this objective is met varies in each case.

Efficiency Considerations

A tax on the insecticide possesses the attribute of efficiency. A tax is efficient because it equates the marginal cost of abatement across firms. The firm that can abate in the least expensive way will abate the most. In addition, the tax has the characteristic of flexibility and provides continuous incentive to adopt new pollution abatement technology. A tax level is initiated after an acceptable target of restriction has been selected. Because a tax is equimarginal, smaller, less efficient farms may be hurt more by a tax method.

A standard implies a selected target that meets the criterion of a policy board as to its potential for reducing emission levels. A strength of imposing a standard is its relatively low cost of implementation, but it is criticized for significant weaknesses. The standard itself is arbitrary. Emission levels are difficult to measure and verify. The fact that one standard applies to all polluting firms suggests inefficiency. Marginal-cost of abatement will vary among farms. As stated earlier, for efficiency to be satisfied, the abatement must be equated across farms. Finally, the standard provides no incentive for polluters to reduce emissions beyond the selected level.

Figure 2 depicts the hypothetical marginal profit curves developed from equations (1) and (2) and presented in Figure 1. Marginal profits for each farm size are a function of insecticide use. Optimal levels of insecticide occur where the marginal profit functions intersect the horizontal axis, shown in Figure 2 as x_1^* for the smaller (Type 1) farm and x_2^* for the large (Type 2) farm. If use of insecticide were increased one unit beyond the optimum values for each farm size,

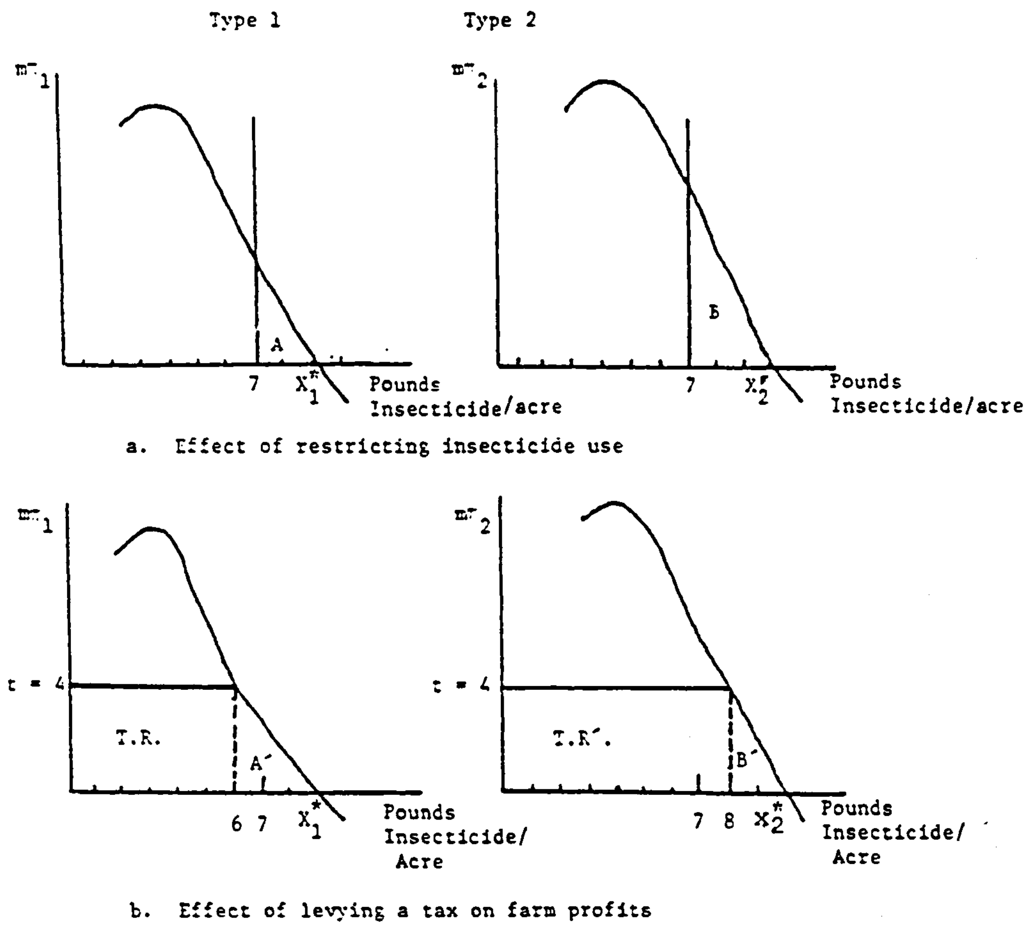

Figure 2. Comparison of effects of restricting insecticide use with levying a tax on farm profits

negative returns would result. These marginal profit curves are used to summarize the implications of imposing a standard or a tax on small and large farms.

Costs of Implementing a Standard and a Tax

A standard is set to restrict total per acre insecticide use. This restriction assumes that there is no substitutability among insecticides. In Figure 2, insecticide use is restricted to 7 pounds/acre for each farm, or a combined total of 14 pounds for the two farms. After implementing this standard at 7 lb/acre, Type 1 loses marginal profits equal to area A and Type 2 loses marginal profits equal to area B; and $A < B$. These areas represent the respective costs to each farm due to restricting per acre insecticide use. Finally, the total cost of implementing the standard is area A + area B.

Efficiency costs refer to the loss in revenue due directly to the implementation of a specific control action, other than the least cost way (a taxing strategy). Categorized are three costs associated with insecticide regulation. The first is the direct loss in profits to each farm size. The second is the cost of imposing the controls (implementation costs) while the third is the efficiency cost attributed to the specific insecticide regulation. A tax is the criterion for efficiency (maximizes net benefits) and therefore realizes a zero efficiency cost. With the exception of a tax, the efficiency costs for other control strategies are derived by subtracting the cost of levying a tax from the cost of imposing the alternatives regulatory action (standard). For a standard, the direct cost to the farm (loss in profits) and the implementation costs are equal (area A for Type 1 and area B for Type 2).

As previously mentioned, a standard restricts per/acre insecticide use, in this case, at 7 lb/acre, per farm, for a total of 14 lbs. for both farms. A tax also restricts per acre insecticide use; however, for purposes of analysis it helps to look at total restrictions in specific farm reductions (i.e., $x_1^* = 9$ lb, $x_2^* = 10$ lb), therefore $x_1^* + x_2^* = 19$ lbs. A standard and tax both restrict total use from 19 lb to 14 lb, however, the <u>distribution</u> of allowable insecticide for each farm differs under a tax while they are equal for a standard. With a tax (t) = $4, Type 1 loses area (TR + A′) in marginal profits while Type 2 loses area (TR′ + B′) in marginal profits. Areas (TR + A′) and (TR′ + B′) represent the respective costs to each farm due to the tax. The total implementation cost of implementing the tax is the sum of area A′ and B′, where A′ > B′.

Tax vs. Standard

In comparing the tax with a standard, three basic criteria are analyzed: (1) the direct cost to the farm, expressed as a loss in profits; (2) the specific cost of implementing the standard or the tax are compared; and (3) the level of allowable insecticide use under the specified control actions are compared. Theoretical results are shown in Table 3.

Referring to Table 3, loss in profits for each farm are larger under a tax than under a standard. That is, areas A and B are less than areas (TR + A′) and (TR′ + B′), respectively. However, the implementation costs follow a reverse pattern. Specifically, for Type 1, area A under a standard is less than area A under a tax; for Type 2,

Table 3. Effects of a Tax and a Standard, by Farm Size[a]

	Loss in Profits (area)	Implementation Cost	Allowable Insecticide (lb)	Unconstrained Insecticide Use
Standard				
Type 1	A (Fig. 2)	A	7	9
Type 2	B (Fig. 2)	B	7	10
Tax				
Type 1	TR + A´ (Fig. 3)	A´	6	9
Type 2	TR_1 + B´ (Fig. 3)	B´	8	10

a. Letters indicate areas depicted on Figure 2.

area B with a standard is greater than area B under a tax. In more general terms, a tax penalizes the small farm while the standard penalizes the large farm. As for allowable levels of insecticide, where as the standard restricts both equally, the tax allows the more efficient producer (Type 2) to use more insecticide (8 lb/acre) than the small farm (6 lb/acre). Finally, when comparing total costs of implementing the control actions, areas (A + B) under a standard are greater than areas (A´ + B´) under a tax, making the standard a less efficient method of control.

Distributive Considerations

Distributive considerations look at the long-run effects on farm firms of implementing respective control strategies. Essentially, such an analysis requires comparing the costs and benefits associated with the insecticide restrictions. Gains to society from regulations may or may not require large, long-term costs to the farm producers. Table 4 presents a summary of the costs to farms and gains to society due to a restriction of insecticide levels via a tax or a standard.

Table 4. Comparison of Costs to Farms and Gains to Society Due to a Standard and a Tax on Restricting per Acre Insecticide Use[a]

	Costs of Imposition		Insecticide Use	
	Standard	Tax	Standard	Tax
Type 1	A	A'	7	6
Type 2	B	B'	7	8
	$A + B$	$A' + B'$	14	14
Gain to Society in Tax Revenue	0	$-TR + TR'$	—	—
Total	$A + B$	$(A' + B')-(TR + TR')$	14	14
Efficiency Cost	$[A' + B' - TR - TR'] - [A + B]$	0		

a. Letters indicate areas depicted on Figure 2.

When implementing a standard, the cost of restricting insecticide use to 7 lb/acre for Type 1 and Type 2 farms are A and B, respectively (Table 4). Both costs are negative since each represent a loss in profits for each farm. By initiating a tax, insecticide use is restricted to 6 lb/acre for Type 1 and 8 lb/acre for Type 2, with respective implementation costs of A′ and B′. A third party affected by the insecticide restriction is society as a whole. Society "gains" by a reduction in the level of insecticide use. However, another potential gain exists. With a standard, level of insecticide use is restricted to 14 pounds for the two farms. Society realizes no monetary gain from the restrictions. A tax, however, in addition to restricting insecticide use to the 14 pounds of the standard, also provides additional revenue for society, which amounts to areas (TR + TR′) in Figure 2.

By referring again to Figure 2 it is apparent that areas A + B are less than areas (A′ + B′ - TR - TR′). Summing the two areas, therefore, provides a positive amount of dollars for society. In summary, both a standard and a tax reduce total insecticide use to the same level (14 lbs.). However, the tax has an additional "gain" in the form of a tax revenue. Direct effects of the standard and tax to the small and large farm is now considered.

Under a standard, Type 1 loses area A while Type 2 loses area B. A visual comparison of Figure 3 shows that B > A, implying, that, under a standard, the large farm is hurt more than the small farm. With a tax the reverse occurs, the large farm is allowed to use more insecticide. The Type 2 farm loses the tax area as well as total loss in profits which are (TR′ + B′). Type 1 also loses a large profit area (TR + A).

Although the tax is considered efficient (implementation cost with the standard is (A + B) which is greater than area (A′ + B′) for a tax), it actually hurts both farms more than the standard due to a much greater loss in profits (A < A′ + TR).

Policy makers are faced with the dilemma of using a standard and penalizing the efficient, large farm, or using a tax, which not only reduces levels of insecticide use but also provides tax revenues. However, the tax penalizes both farms (via large loss in profits) to a greater degree than the standard. Such substantial profit losses could have potential long run effects to farm firm survival. As for comparing potential effects between farm sizes, results would be dubious since total farm profits would have to be assumed for both size farms. However, this comparison is covered in Chapter 5 when farm profits are estimated for two representative farms.

CHAPTER 3

COTTON AND THE TOBACCO BUDWORM

The primary objective of this research is to measure the economic effects insecticide restriction will have on farm firms. Before this objective can be suitably accomplished an understanding of the components of crop production is essential. The entire foundation of a cotton farmer, and, therefore, the foundation of this study as well rests on the cotton plant and the elements of nature that obstruct the farmer's production methods. Aside from the cotton plant itself, insects are a key variable that the farmer must account for in the growing season. Specifically, it is the crop-insect population dynamics and control that are under consideration in this study. Recent concern has developed for farmers in Pinal County as the tobacco budworm grows in economic importance. Because of the budworm's economic significance and increasing resistance to control measures, the budworm has been selected as the pest for this study. The budworm, the cotton plant, and the relationship between them are closely examined. This section examines these relationships, relying heavily on reports from other researchers.

The Cotton Plant

Two cotton species are grown commercially in Arizona, the upland, short staple (*Gossypium hirsutum* L.) and American-Egyptian (Pima) long staple. They are grown in elevations ranging from below 200 feet to above 4,000 feet (University of Arizona Cooperative Extension Service and Agricultural Experiment Stations [UACES/AES], 1969). In Pinal County, the cotton growing season generally begins in early- to mid-April and lasts until late October. The five growth stages of the cotton plant are summarized in Table 5.

Table 5. Approximate Time Intervals for Growth Stages of Cotton

Stages of Growth	Time Required (Days)
Plainting to emergence	4 - 16
Emergence to first true leaf	6 - 10
Emergence to first square	35 - 47
Square to flower	21 - 30
Flower to open boll	40 - 80

Source: UACES/AES (1969).

From Seed to Emergence

Cotton seed is commonly planted as early as possible in the growing season to avoid the fall frost and to complete harvesting before heavy infestation of harmful insects can occur. Soil temperatures at seed depth should ideally have a mean of 65°F or above. Ideal temperatures enhance seedling emergency by decreasing chance of insect, fungal, and other damage to the seed and aid in obtaining a healthy stand of cotton. Proper seed depth is determined by moisture and soil texture.

Excessive soil moisture may retard root growth and initiate seedling diseases. High-saline soils may also adversely effect plant growth.

Stem and Leaf Development

The plant stem consists of a series of nodes and internodes (see definition of terms in Appendix B). The length and number of these nodes and internodes is determined by genetic and environmental factors such as soil moisture, nutrients, climate, insects, and diseases. Plant height determines the number and length of these nodes.

Shortly after plant emergence, a rounded leaf develops immediately above the cotyledon, called the "true leaf." True leaves are usually three to five-lobed, four or more inches wide, thin and with epidermal and glandular hairs (USACES/AES; 1969, p. 9). The leaf lobes of the long staple varieties are longer and narrower than of the short-staple variety.

Vegetative and Fruiting Branch Development

Vegetative and fruiting branches are the two main branch developments on the cotton plant. Vegetative branches grow fairly vertical and are generally located on the lower nodes of the main stem. As leaf and stem density increases, vegetative branches per plant tend to decrease. The vegetative branch will also frequently develop a fruiting branch.

Fruiting branch development is the same whether it is located on the main stem or on a vegetative branch. However, if located on the vegetative branch it occurs later in the growing season. As the cotton plant grows, the fruiting branches develop characteristically at alternating locations along the plant. Over a period of time, these reproductive branches produce squares, flowers, and, eventually, the cotton boll. For central Arizona cotton, flowering generally begins around June 15. As elevation decreases, the flowering period occurs earlier.

The Flower

There is a definite pattern for flower emergence. The flower develops from a square on the fruiting branch. After the first flower emerges, it takes about 3 days for another flower to open on the same relative position of the next higher node. Aproximately 6 days elapse for two successive flowers to appear on the same fruiting branch. Like node development, flower emergence is influenced by soil moisture, climate, length of growing season, insects, and diseases. Pollination occurs in morning hours with the opening of the flower. Flowers are generally self-pollinated by a transfer of pollen from the anther of the stamen to the stigma of the postil. Fertilization of the ovules normally occurs within 30 hours after pollination (for pictoral representations, refer to UACES/AES, 1969).

Seed and Boll Development

Once fertilized, boll development is rapid. Within 21 days the boll reaches full size. Complete maturation takes an additional 21-35 days. Boll opening occurs as the carpel walls begin to dry, exposing the lint within. There 4-5 locks of cotton per boll of short-staple cotton (upland) and 3 locks per boll of long-staple (Pima). Factors

A common occurrence of cotton is the shedding of bolls, flowers, or squares. If shedding becomes excessive, vegetative growth increases, causing delayed maturity of remaining bolls and difficulty in harvesting. The causes for shedding are usually a combination of environmental factors such as cold, excessive heat, insects and improper nutrient supply.

Cotton Yield: No Insect Infestation

Insect populations are an integral part of the environmental ecosystem of the cotton plant. Total elimination of insects would very probably cause damage to the cotton plant and is therefore seen as an unrealistic assumption. However, for an adequate evaluation of the economic implications of insecticide regulations, an insect-free cotton yield is required.

Considerable research has been conducted showing that an insect-free environment is not necessary for maximum yield. Watson and Sconyers (1965) developed 6 insecticide timing schedules over a 3-year period. The range of applications varied from a full-season, automatic schedule requiring an average of 23.7 applications, averaging 9.7 applications, to a program initiated after a 25 percent boll infestation. A comparison of results showed no significant yield differences in the various programs.

Adkisson, Brazzel, and Gaines (1963) conducted a similar study that looked at the effects of various pink bollworm infestations on the quality and quantity of cotton. The results showed that unless infestation exceeded 22 percent of fruiting forms yield losses were negligible.

Because data are not currently available to accurately determine a insect-free yield and an insect-free crop is not needed to produce a maximum yield, a control vs. no-control (untreated check) experiment was used to estimate insect-free yields. The controlled plots used chemical means to decrease infestation to below 6 percent, allowing for maximum yield.

Tables 6 and 7 show differences in yield on treated and untreated checks. The tables represent two separate experiments, different locations and times. Tables 8 and 9 are results of these numbers, expressed as percent yield gains of each protection method over the untreated checks.

By taking the average percent increase for both experiments, yield changes of the control vs. no control show an increase of 26 percent in cotton yield.

Utilizing cotton yield data for Pinal County (Arizona Crop and Livestock Reporting Service, 1979), a "no damage" yield can be approximated by increasing the yields by 25 percent. The damage yield estimated for Pinal County represents a yield farmers would realize under optimal insect control measures. Furthermore, the yield may be used as a reference in calculating cotton fruiting forms per plant for developing cotton.

Cotton Plants and Fruiting Forms

To relate the number of damaged fruiting forms on a cotton plant to yield loss, a number of factors must be identified. Basically, this requires knowing how many fruiting forms develop on a single cotton plant over the growing season. In addition, a "typical" per acre number of plants is also required.

Table 6. Number of Spray Applications and Irrigations Required to Complete Growing-season Phase of Pink Bollworm Treatment and Yields Relative to Termination Pink Bollworm Level Interaction, Yuma, Arizona

Irrigation Cut-off Date	Number Spray Applications 0% Level	Number Spray Applications 15% Level	Number of Irrigations	Mean Plot Yields[a,b] Treatment 1	Mean Plot Yields[a,b] Treatment 3	Infestation Level Treatment 2[c]
1971						
July 15	12	6	5	13.8 a	17.6 ab	19.7 b
July 29	15	9	6	19.0 a	28.2 b	30.8 b
Aug. 16	18	12	7	13.0 a	28.0 b	30.6 b
Sept. 3	21	15	8	17.6 a	28.7 b	30.7 b
1972						
July 17	13	9	5	13.0 a	15.6 ab	17.0 b
Aug. 4	14	10	6	16.1 a	18.3 a	17.9 a
Aug. 23	17	13	7	16.6 a	18.8 a	19.8 a
Sept. 7	17	13	8	15.6 a	17.8 ab	21.2 b
1973						
July 10	11	7	4	20.8 a	23.3 a	28.6 b
July 31	12	8	5	24.5 a	32.1 b	35.0 b
Aug. 21	16	12	6	22.8 a	29.5 b	33.9 c
Sept. 12	17	13	7	27.7 a	34.1 b	38.0 c

Source: Watson et al. (1978)

a. Duncan's new multiple range test; yields on the same line followed by common letters are not significantly different at the 0.05 level.

b. Harvested plot yields were converted to a standardized plot size of 0.0008 hectare.

c. Treatment 1 represents untreated check, treatment 2 represents control initiated at first boll formation, and treatment 3 represents control initiated at 15% boll infestation.

Table 7. Comparison of Cotton Yields Obtained from Three Insecticide-timing Schedules and an Untreated Check, Phoenix, Arizona, 1967

Treatment[b]	Yield (lb seed cotton/acre)[a]		
	First Harvest	Second Harvest	Third Harvest
Untreated check	833 a	143 a	976 a
Early-square protection	1,041 b	228 b	1,269 b
Early-boll protection	1,087 b	225 b	1,312 b
Late-boll protection	1,004 b	257 b	1,261 b

Source: Watson and Fullerton, 1969.

a. First harvest made November 9; second harvest made December 8.

b. For full description of treatments, see Watson and Fullerton (1969, Table 1).

c. Duncan's multiple range rest; yields having a common letter are not significantly different at the 5% level for the first harvest and at the 1% level for the second harvest and total yield.

Table 8. Percent Yield Gain over Untreated Check for Yuma, Arizona

Year	Control Initiated at 15% Boll Infestation	Control Initiated at First Boll Formation
1971	37%	42%
1972	13%	19%
1973	19%	28%

Table 9. Percent Yield Gain Over Untreated Check for Phoenix, Arizona

Protection Method	Yields (lb seed cotton/ acre)	Percent Yield Gains over Untreated Check
Early-square protection	1,269	23%
Early-boll protection	1,312	26%
Late-boll protection	1,261	23%

Planting procedures in Pinal County are typically narrow-row. A typical narrow-row field consists of 40-inch-wide rows, with 2 plants per foot, yielding approximately 26,000 plants an acre. The width of the row and the space between plants directly affect the development of fruiting forms. As plant density increases, fruit development decreases. Because yields per acre also depend on the number of plants per acre, an optimum is sought that can maximize yield subject to these opposing constraints. For Pinal County, narrow-row planting satisfies these conditions.

Fruiting form development varies by cotton variety. In Arizona, however, over 80 percent of cotton grown is of the upland species, specifically, varieties of Deltapine cotton. Under normal conditions, without insect pest damage, and using a narrow-row planting procedure, these varieties produce approximately 12.5 bolls per plant at maturity (Buxton, Patterson, and Briggs, 1979). However, a problem arises in trying to determine the average number of flowers and squares per plant. Because weather and other similar conditions directly affect fruit abscission, long-term observation has shown that, over a growing season, approximately a third of the developed squares will absciss by flower emergence. In addition, approximately a third of the flowers are expected to absciss by boll emergence (Briggs and Patterson, 1979), This implies that one cotton boll is equal to 1/0.44 of a square and 1/.67 of a flower. Assuming that these abscission rates adequately reflect fruit shedding for Arizona cotton, the emergence of 28.4 square per plant, which in turn develop into 18.6 flowers per plant is required to produce the 12.5 bolls per plant in the Buxton et al. (1979)

study. These numbers are only approximations of the number of cotton fruiting forms required in the production of final cotton production. So many variables affect the abscission of cotton fruit (wind, cold, heat, insects, disease, nutrient deficiencies, etc.) that changes will occur continually. Primarily because of these conditions, very few studies have been conducted on fruiting forms and abscission rates. However, a study was conducted by Briggs and Patterson (1979) which monitored square, flower, and boll development for Deltapine cotton varieties. Tables 10 and 11 present the fruiting forms over the development periods.

These data present information on numbers of fruiting forms per plant that can be compared to the Buxton et al (1979) study. The data also show a pattern of emergence for each fruiting form over time. Both of these points are significant contributions to the research because little documentation is available in these two areas, especially for Arizona studies. Graphical depiction of these data are presented in Figure 3.

Although square, flower, and boll development differs slightly from the data presented earlier in the Buxton et al. study (28.4 squares, 18.6 flowers, 12.5 bolls per plant), data are close enough to assure that the fruiting form data are a realistic approximation. As stated earlier, because of varying conditions affecting fruit development and abscission rates, only approximations are available. Data developed from the Buxton study on fruiting forms are therefore used in this study.

Using the Deltapine variety as representative of upland cotton, the development of individual cotton bolls must be related to final yield.

Table 10. Number of Flowers and Bolls per Plant as They Developed for the Period June 10-August 10, 1972. -- Figures represent an average five replications of narrow-row (40 inches) Deltapine cotton

Date	Deltapine Cotton Variety: Number of Flowers	Deltapine Cotton Variety: Number of New Open Bolls
June 10	1.3	1.0
17	7.7	5.9
24	12.9	10.3
30	11.8	7.8
July 8	15.6	5.7
15	11.1	3.2
22	8.9	1.9
29	6.1	2.8
Aug. 5	5.0	1.9
12	3.0	1.4
19	2	1.1

Source: Data from Briggs and Patterson (1979).

Table 11. Number of Squares per Plant as They Developed for the Period May 10-August 26, 1976. -- Figures represent an average of five replications of narrow-row (40 inches) Deltapine cotton

Date	Number of Squares	Month	Number of Squares
May 20	1.0	July 8	37.2
27	5.9	15	24.7
June 2	11.7	22	22.7
10	16.5	29	14.1
17	15.5	Aug. 5	9.0
24	34.2	12	4.5
30	37.2	19	5.7

Source: Data from Briggs and Patterson (1979).

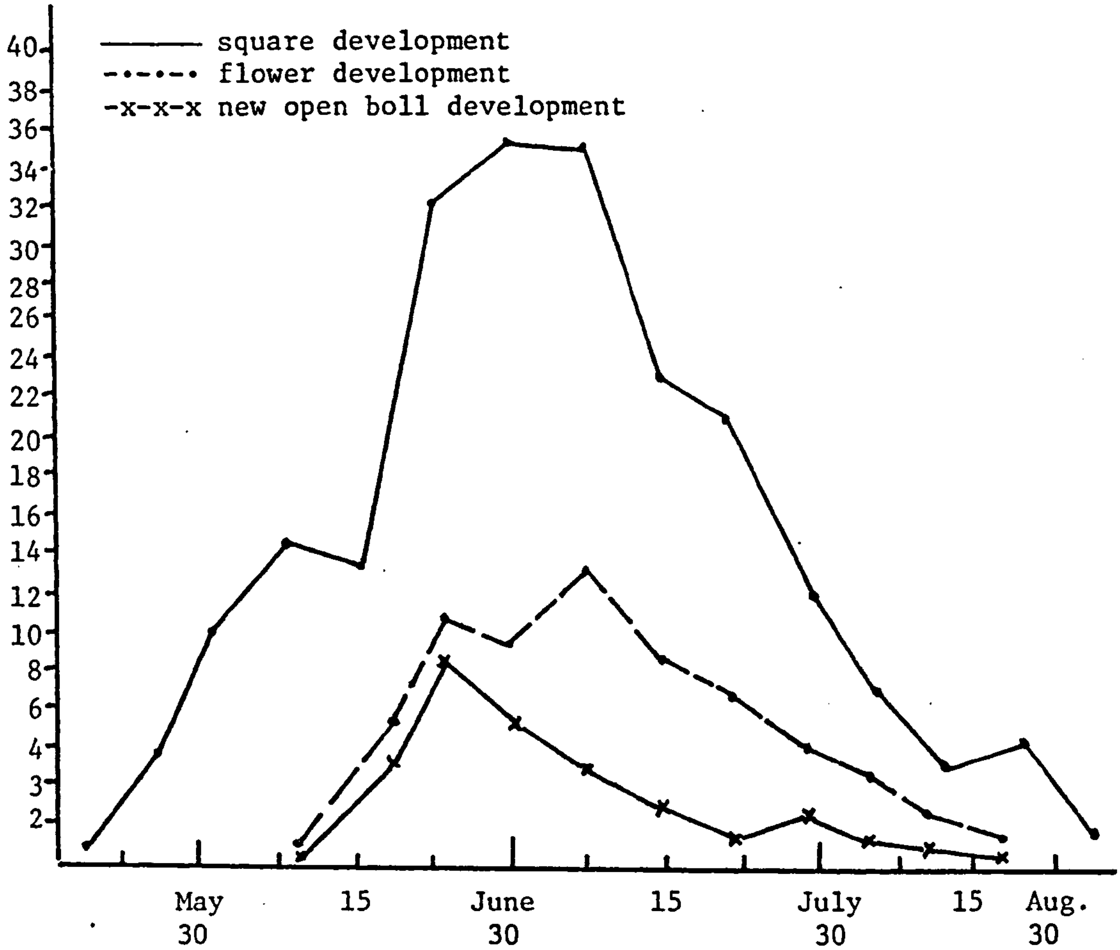

Figure 3. Pattern for Square, Flower, and New Open Boll Development of Cotton plant over growing season. -- Data points represent averages for five replications of Deltapine cotton variety. Data from Briggs and Patterson (1979).

The average boll of Deltapine 16 cotton weighs approximately 6.48 grams (USDA, 1975). Another way of stating the yield per boll is to recognize that each pound of cotton consists of approximately 70 cotton bolls. With 26,000 plants/acre at 12.5 bolls per plant, there are 325,000 bolls/acre, or 4,642 pounds of seed cotton per acre at harvest time. At 0.33 pounds of lint per pound of seed cotton, a "no damage" lint cotton yield of 1,532 pounds of lint cotton/acre results. The "no damage" yield value is assumed as a basis for the analysis of this study.

Patterns for fruit emergence as shown in Figure 3 represent individual fruit development over time. However, the basis of this data are controlled experiments and therefore, do not represent accurate fruit development patterns. Approximately two-thirds of total squares successfully develop into flowers, and two-thirds of these flowers successfully develop into bolls. However, a time lapse occurs between each stage of emergence. From peak square production to peak flower production a lapse of approximately 21 calendar days is normally expected. From peak flower production to peak boll production an additional average of 45 calendar days elapse. To more closely approximate fruit development over the growing season, these time lapses are accounted for. Figure 4 is the result of taking the Briggs and Patterson fruiting form data and staggering emergence periods as would likely occur in actual cotton growth conditions. Note should be made of the curve identified as "new open bolls." Harvest generally occurs when approximately 80 percent of total bolls are opened. This occurs on approximately the one-hundred and fortieth physiological day (for an understanding of physiological days, refer to the next section), or near the first of October. Harvest

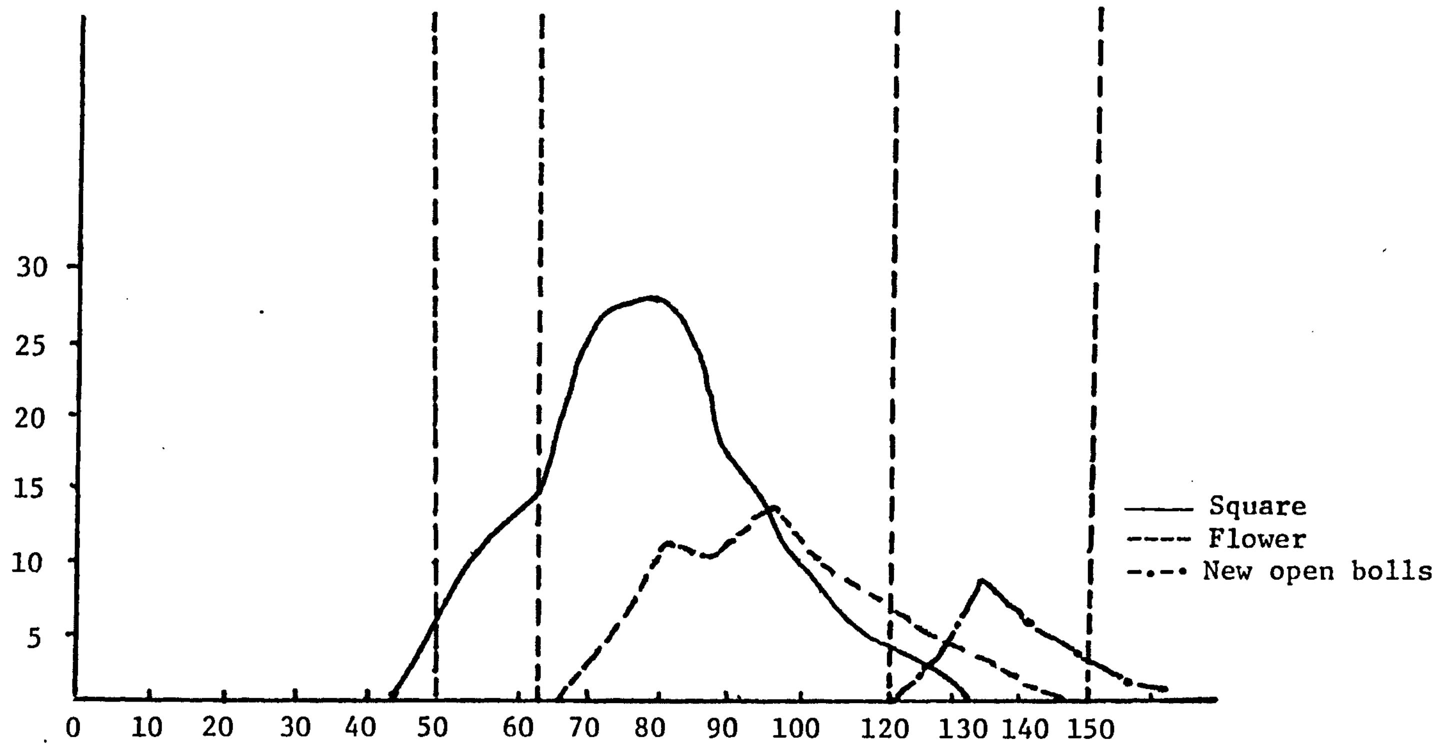

Figure 4. Fruiting form development of Deltapine cotton over growing season. -- Data from Briggs and Patterson (1979).

begins at this time in Arizona to avoid fall rains, which damage cotton lint and make harvest conditions difficult.

Finally, Figure 4, showing fruiting form patterns, provides a basis for computing potential damage in the use of proposed chemical treatments.

Physiological Days and Heat Units

The physiology of the cotton plant and the related insect pests are both directly affected by daily temperatures. A maximum and minimum temperature threshold exists for the insect as well as the cotton plant. If the temperature thresholds are exceeded in either extreme (above or below), developmental factors of the organism are disrupted. Exactly what this disruption consists of or its precise outcome are as yet undetermined (Huber, 1979). However, researchers know that growth and development factors are adversely affected, causing a retardation or, if variation is extreme enough, termination of life. Extreme tempera-
insect. Since the biology of the plant and insects are a function of
temperatures result in measureable reduction in plant damage by the insect. Since the biology of the plant and insects are a function of physiological days rather than calendar days, physiological days are a more precise measurement tool in assessing plant and insect development. For the above reasons physiological days are incorporated as the time measurement into an analysis of insect control used in this study.

Physiological days are made up of heat units. A physiological day may be shorter or longer than a calender day, the ultimate factors being the air temperatures and the upper and lower developmental thresholds of the insect in question. A heat unit is generally calculated by taking the average daily temperature and subtracting it from the upper threshold (Lucas, 1979). By subtracting the lower developmental threshold from this average, the number of heat units are determined. Assuming a mean temperature of 75°F for a particular day and a threshold of 55°F, then a total of 20 heat units are accumulated for that day. Each insect type has a "heat unit requirement" for development, whether a pupa in the soil or a larva on the plant. Table 12 shows this heat unit requirement for the tobacco budworm, as developed by Tollefson (1979).

Table 12. Heat Unit Requirements for Larval, Prepupal, and Pupal Development of the Tobacco Budworm in Cotton

	Heat Units Required[a]		
Treatment	On Plant[b]	In Soil[c]	Combined
Early	477 (265)	319 (177)	796 (442)
Mid	412 (229)	305 (169)	717 (398)
Late insecticide	400 (222)	304 (169)	704 (390)
Late - no insecticide	436 (242)	305 (169)	741 (410)

Source: Tollefson (1979).

a. Calculated from heat unit program developed by Huber (1979).

b. Based on air temperatures taken within cotton canopy; larval threshold--75°F high, 53°F low.

c. Based on soil temperatures taken within cotton canopy at a depth of 2 inches; pupal thresholds--75°F high, 54°F low.

The discrepancy between air temperature and the temperature within the cotton canopy, the developmental area of the tobacco budworm, must be accounted for in calculating heat units. In his experiments with the tobacco budworm, Tollefson recorded air temperature within the cotton canopy from June 15 to September 3 by placing a hygrothermograph between two rows of cotton plants.

For this study, physiological day units were determined throughout the growing season, a longer period than that recorded by Tollefson. Since no hygrothermograph measurements are readily available, air temperatures at Phoenix's Sky Harbor airport were used to approximate air temperatures. However, these air temperatures exceeded those within the cotton canopy (National Oceanic and Atmospheric Administration, 1978). The period June 1 through September 15 has air temperatures that exceeded the upper developmental threshold and are therefore adjusted to represent temperatures within the cotton plant. By dividing Tollefson's Mesa Farm temperatures (Mesa and Phoenix air temperatures are nearly identical) within the canopy by the Sky Harbor air temperatures an "adjustment coefficient" was derived. Multiplying daily Sky Harbor air temperatures by the particular monthly coefficient adjusts temperatures to represent the temperature within the cotton canopy. Mean monthly temperatures (based on 3-hour interval recordings) along with adjustment coefficients are presented in Table 13. A summary of calculations with the canopy temperatures are presented in Table 14. These canopy temperatures are used directly for computation of physiological days and are presented graphically in Figure 5.

Table 13. Calculated Mean Monthly Temperatures for Mesa Farm's Cotton Canopy at 3-hour Intervals, 1978

Month	Hour	Air Temperature[a]	Coefficient	Canopy Temperature[b]
June	02	84.7°F	.98	83°F
	05	77.6	.98	76
	08	86.7	.98	85
	11	99.0	.98	97
	14	105.1	.98	103
	17	106.6	.98	104.5
	20	99.0	.98	97
	23	90.8	.98	89
July	02	95.6	.91	87
	05	92.3	.91	84
	08	97.8	.91	89
	11	106.6	.91	97
	14	114.0	.91	104.5
	17	116.5	.91	106
	20	111.0	.91	101
	23	101.1	.91	92
August	02	89.5	.95	85
	05	85.3	.95	81
	08	88.4	.95	84
	11	99.5	.95	94.5
	14	107.3	.95	102
	17	108.4	.95	103
	20	101.1	.95	96
	23	92.6	.95	88
September	02	80.2	.985	79
	05	76.7	.985	75.5
	08	80.2	.985	79
	11	90.4	.985	89
	14	96.0	.985	94.5
	17	97.5	.985	96
	20	89.3	.985	88
	23	84.3	.985	83

a. Duncan's new multiple range test; yields on the same line followed by common letters are not significantly different at the 0.05 level.

b. Harvested plot yields were converted to a standardized plot size of 0.0008 hectare.

c. Treatment 1 represents untreated check, treatment 2 represents control initiated at first boll formation, and treatment 3 represents control initiated at 15% boll infestation.

Source: Watson et al. (1978).

Table 14. Calculated Mean Monthly Temperature for Mesa Farm's Cotton Canopy, 1978

Months	Mesa Farm Canopy Temperature[a]	Sky Harbor Air Temperature[b]	Adjustment Coefficient
June	80.0°F	89.5°F	.98
July	86.4	95.0	.91
August	87.0	92.0	.95
September	--	86.1	.985

a. Air temperatures represent means from Sky Harbor air temperature.

b. Canopy temperatures are derived directly by multiplying air temperature by adjustment coefficient.

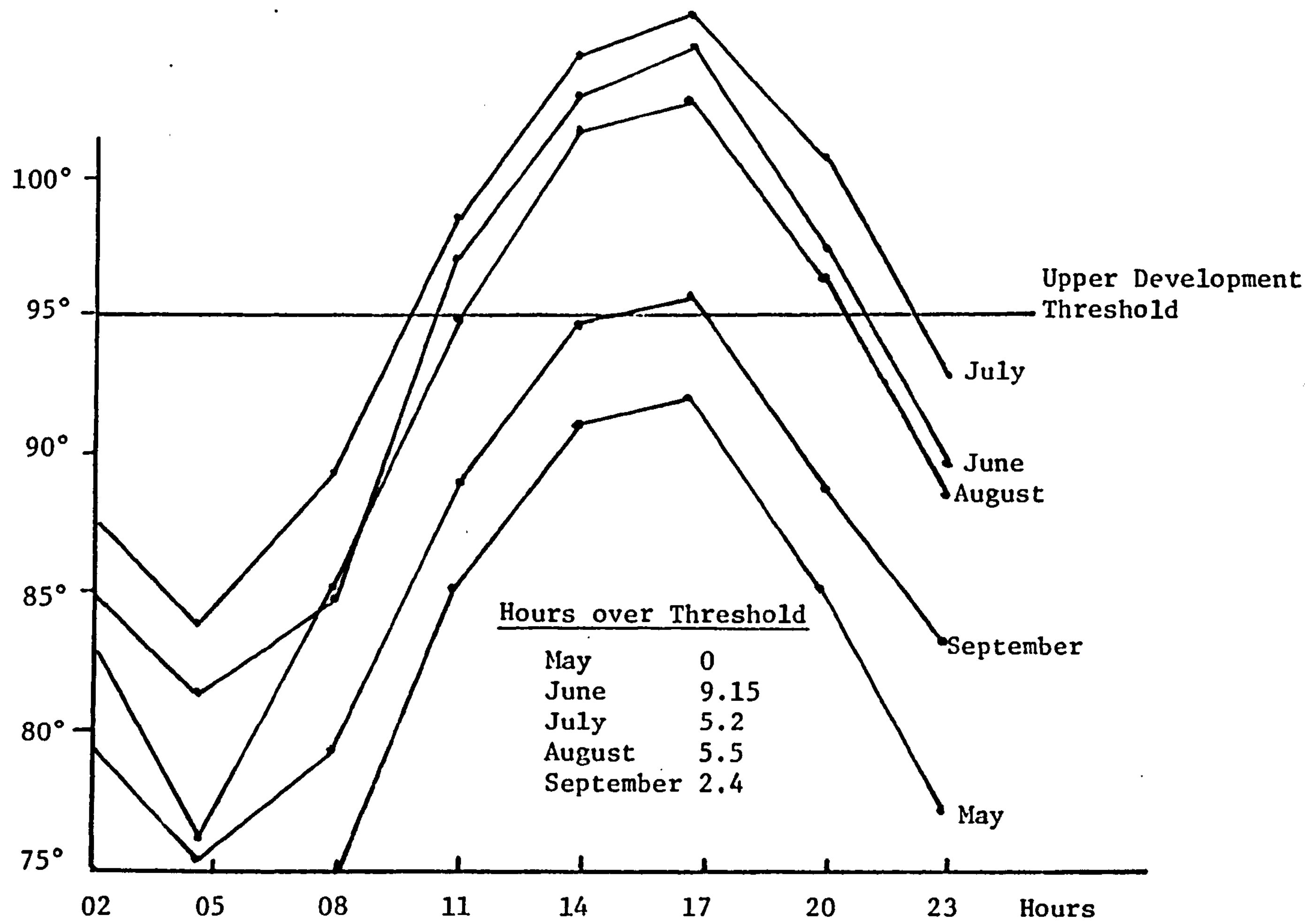

Figure 5. Mean Monthly Temperatures at 3-hour intervals, Adjusted for Cotton Canopy Temperatures, Phoenix, Arizona, 1978

Figure 5 shows the average monthly temperatures from May through September, at 3-hour intervals. The plotting of these temperatures allows for the determination of physiological days by calculating the number of daily hours over the threshold for each month. These temperatures are adjusted to reflect the temperature within a cotton canopy.

Finally, Figure 6 summarizes the relationship between physiological days and calendar days throughout the growing season, segmented by the cotton growth stages.

The data presented in this chapter represent much of the physical description of the environment in which cotton is grown. The control of insect populations is assumed to be of critical importance in growing cotton. This information on the physical data is used to provide inputs into the analysis that follows in later chapters.

The Tobacco Budworm in Arizona

The tobacco budworm (*Heliothis verescens*) and the bollworm (*Heliothis zea*), two common pests in Arizona cotton, are so similar in life cycles and feeding habits that they are often treated as a single insect complex. Until 1973, the bollworm and pink bollworm (*Pectinophera gossypiella*) were the major cause of concern to Arizona cotton producers. However, the tobacco budworm began to emerge following 1973. Within a few years it has developed into a major pest to Arizona cotton farmers. Significant efforts have been made to control the tobacco budworm. Since these control measures have been initiated, however, resistance to methyl-parathion by the tobacco budworm has increased. The number of insecticide applications per acre of cotton has been as

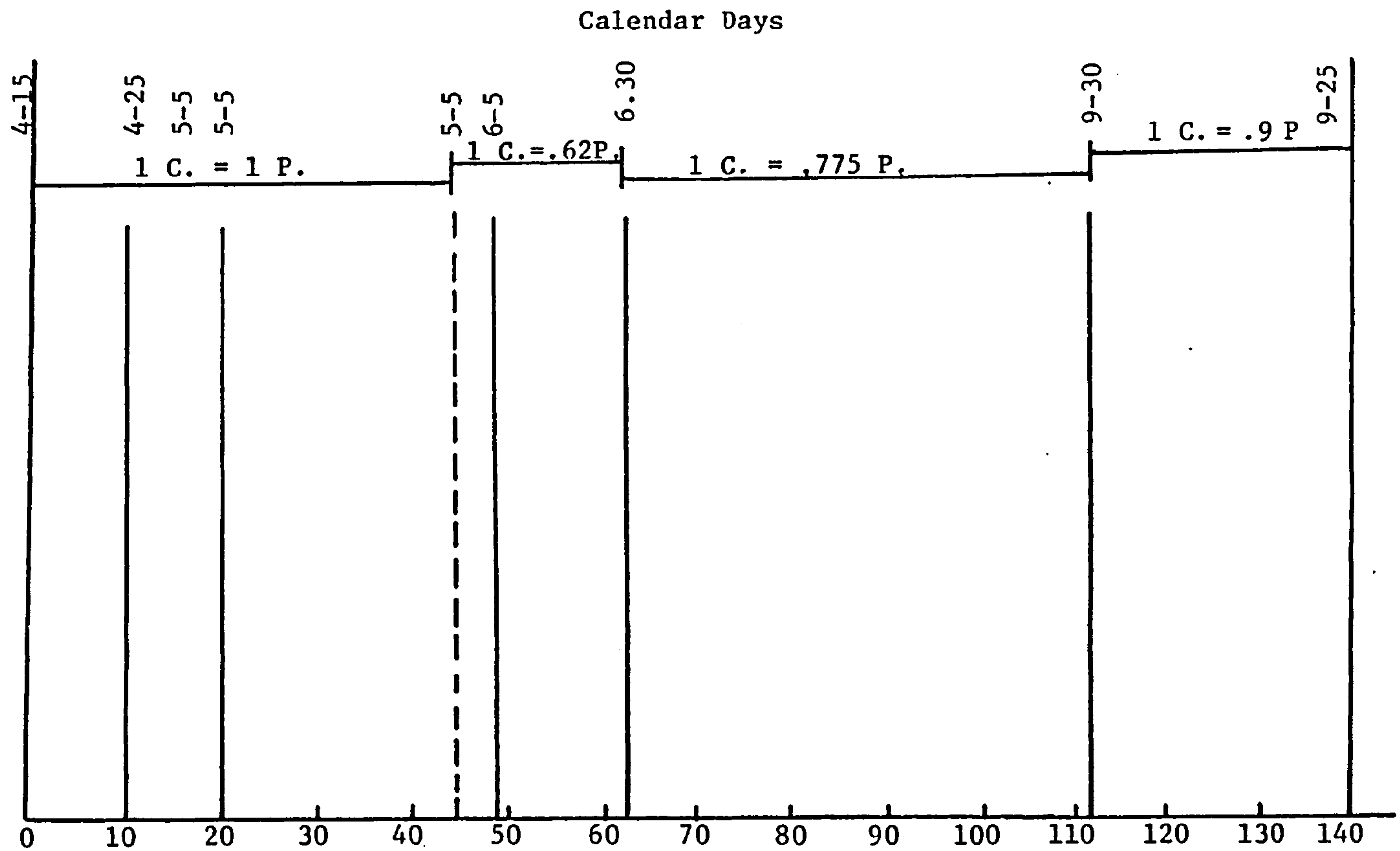

Figure 6. Physiological and calendar days of cotton growing season. -- Conversion coefficients from calendar to physiological given at specified periods.

high as 15 per season, but significant crop losses have resulted, despite the substantial use of methyl-parathion. Primarily because of the heavy control measures for the tobacco budworm, the pink bollworm and the bollworm population have been reduced to a minimal damage status in Arizona. With the recent introduction of a new class of chemicals, the synthetic pyrethroids, control of the tobacco budworm may become more effective. However, caution must be taken to avoid potential resistance to these new chemicals.

This study concentrates on the tobacco budworm. Thus, to understand the process of controlling this pest, a brief description of the insect is provided in the following paragraphs.

Growth Stages of the Tobacco Budworm

The egg stage begins the life cycle of the tobacco budworm. The newly laid eggs, which occur throughout the growing season, are cream colored and are generally found singly on cotton terminal leaves. The subspherically shaped eggs look very similar to those of the bollworm. However, because the budworm is more resistant to insecticide control than the bollworm, distinction between these pests at all stages is important. If inspected closely, the budworm eggs have fewer ridges (8-11 to the bollworm's 17-17) (Tollefson, 1979) and the "ridges terminate before they reach the tiny micropyle at the middle of the top" (Werner, Moore, and Watson, 1979). Once the eggs hatch, tiny yellowish or reddish caterpillars feed on the tender terminal leaves and pinhead squares of the cotton plant. Within a couple of days these early instars molt and begin feeding on larger squares and any availabe flowers.

Instars are specific development stages in larval growth. A total of five or six instar stages generally occur, with the latter three resulting in the heaviest damage to the cotton fruiting forms due to the caterpillar's size and feeding habits. Flowers and bolls with higher nutritional content are preferred by the insect at this stage. After the tobacco budworm passes through five or six larval instars, generally from 12-15 days, they move into the soil to pupate for an additional 9-10 days. Complete life cycles can occur in as little as 25 days during summer months and up to eight generations of budworms can occur per season.

Damage to Cotton by the Tobacco Budworm

Because the tobacco budworm is a relatively recent economic pest to cotton producers, monitored larval feeding patterns of this pest are relatively nonexistent. Two data sources are used to develop an estimate of tobacco budworm damage. However, final estimation of damage is restricted to an Arizona study. This estimate is used in following chapters of this thesis as the implications of insecticide control are analyzed.

The first source is by Kincade, Laster, and Brazzell (1967) of the Mississippi Agricultural Experiment Station. This study looks at feeding patterns of tobacco budworm larva as they are placed on the cotton plant at various times in the growing season. The second source is Scott Tollefson, an entomology graduate student at The University of Arizona, who has conducted a similar study over a slightly longer growing period, specifically in Arizona (Tollefson, 1979). Tables 15 and 16 present the studies by Kincade et al. (1967) and Tollefson.

Kincade et al. found that a single budworm larva destroyed an average of 10.1 squares, 1.2 blooms, and 2.1 bolls in a mean of 15.8 development days. Total mean damage per larva was 13.4 fruiting forms. Their study also showed that the larvae damaged more squares than blooms or bolls, due primarily to the lower nutritional content of the squares. Furthermore, early season damage to squares was greater than in the later season. Such early-season damage may be caused by a reduction in square availability (a 66 percent loss of squares per plant is expected throughout the growing season due to natural causes) and the advent of flowers and bolls, a preferred feed for the tobacco budworm.

Tollefson's findings are similar. Total fruiting form damage per tobacco budworm is shown to be 11.82 for June, decreasing to 7.64 in July, and decreasing further to 7.14 in August. However, total damage is slightly less than the study by Kincade et al. Actually, results are similar for bolls and flowers. The exception occurs in square damage. Tollefson showed a significantly smaller per larva damage to squares than does Kincade et al. (mean of 5 squares per insect vs. a mean of 10.1 squares per insect). This is due partly to average length of larval feeding periods. The Kincade et al. study assumed a 15.8 development (feeding) period while Tollefson assumed 13. By adjusting Kincade et al. average feeding period to Tollefson's, square damage in the Kincade et al. study is reduced 1.8 squares/insect, resulting in an average damage of 8.3 squares per insect. Another discrepancy of major importance between the two studies is the study area. The experiments by Kincade

Table 15. Feeding Characteristics of Tobacco Budworm Larvae Placed in Growing Cotton Plants at Various Times of the Growing Season

Date Infested	Number Plants Infested	Number Larvae Developed	Average Fruiting Forms Destroyed			Larval Devel- opment (days)
			Squares	Blooms	Bolls	
7/1/65	12	1	10.0	0.0	0.00	15.0
7/7/65	31	8	14.3	1.1	1.25	15.9
8/2/65	19	3	10.0	2.7	3.00	18.3
8/4/65	15	3	11.0	1.3	4.00	14.7
8/11/65	15	5	4.4	.8	2.80	14.4
8/16/65	11	1	6.0	2.0	.00	17.0
8/22/65	11	2	8.5	.5	2.00	17.0
Average			10.1	1.2	2.10	15.8

Source: Kincade et al. (1967, p. 1164).

Table 16. Feeding Damage by Tobacco Budworm Larvae Placed on Cotton Plants at Various Times of the Season

Means in the same row followed by same letter are not significantly different at the 0.5 level (LSD).

Infestation Period	Number Larvae Monitored	Average Fruiting Forms Destroyed				Larval Feeding Period
		Squares	Flowers	Bolls	Total	
June	17	8.82 a	1.56 a	1.41 a	11.82 a	14.88 a
July	24	4.08 b*	1.24 a	2.28 b*	7.64 b*	12.63 bc
August	28	3.46 b*	1.46 a	2.21 b	7.14 b*	11.85 b
Program August '76	8	3.75 b*	1.00 a	2.25 b	7.00 b*	12.65 bc
$\overline{X}$	77	5.00	1.30	2.00	8.40	13.00

Source: Tollefson (1979).

*Significant at .01 level.

et al. were conducted at the Delta Branch Experiment Station at Stoneville, Mississippi, Tollefson's experiments were conducted at the Unviersity of Arizona Mesa Cotton Research Farm, just east of Phoenix, Arizona. There are significant temperature differences between the two locations. The latter has significantly hotter days. Since larval feeding is inversely affected by temperature, larvae at the Mesa Farm actually had fewer feeding hours per calendar day, which may explain the discrepancy in estimated square damage. To compare larva damage from the Kincade et al. study to larva damage from Tollefson's study, physiological days should be calculated for the Stoneville area. However, due to a lack of data from the Mississippi Experiment Station, comparisons were not completed. Since this study is primarily concerned with cotton in Arizona, the Tollefson study is used to develop the damage function described in the following section. However, the similarities between the two studies illustrate the importance of considering the results of Kincade et al. as the damage function is estimated.

Square damage in the early part of the growing season is much greater than either flower or boll damage because (1) early season fruiting forms are comprised almost totally of squares (flowers and bolls are just beginning to emerge), and (2) because squares have a much lower nutritional content than either of the other fruiting forms which necessitates the need for a greater consumption of squares until alternate nutrition is available.

Boll damage by tobacco budworm larvae is a function of two major factors, temperature, as described above, and percent moisture content of the boll. Van Steenwyk, Ballmer, and Reynolds (1976) conducted a study relating cotton boll age, size, and moisture content to pink bollworm attack (the feeding habits of both tobacco budworm larvae and pink bollworm larvae are directly affected by boll moisture). The results indicate that bolls 14-21 days old are most susceptible to attack. Preferred boll moisture content ranged from 81.9 to 79.4 percent. Maximum damage occurs at the 81.9 percent moisture level with an average of 2.45 larvae/boll. By the day 28, with moisture at 73.5 percent, damage was below 0.5 larva/boll (Figure 7). Damage to bolls therefore declines toward middle and late development due to this lack of adequate boll moisture.

Both Kincade et al. (1967) and Tollefson's (1979) results agree with those of Brazzel et al. (cited by Kincade et al., 1967) who showed that, in its larval development, the budworm larva moves down the cotton plant destroying several fruiting forms. According to the Kincade et al. findings, young larvae initially feed on tender pinhead squares on the upper portion of the plant. After approximately 7 days the larvae move down to the next third of the plant feeding on larger squares, blooms, and young bolls, for 3 to 5 days. The larger larvae finally move to the lowest portion of the plant feeding on large bolls for a period of 1 to 3 days before entering the ground to pupate.

The Three Insect Damage Functions

This study assumes that damage caused to the crop by each insect per physiological day varies throughout the growing season. To relate

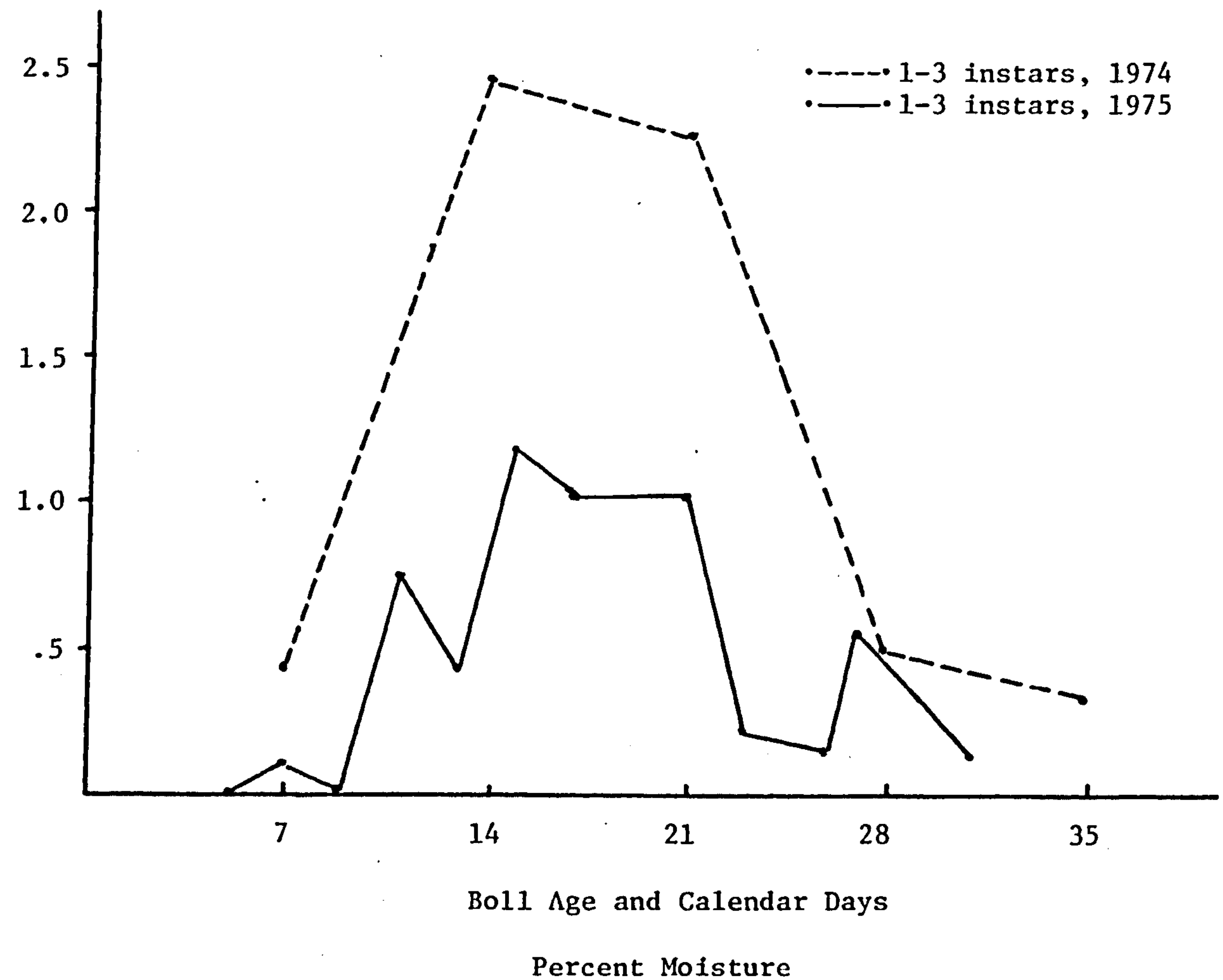

Figure 7. Relationship of boll age and percent moiture content of cotton bolls to pink bollworm infestation. -- Data points taken from Van Steenwyk et al. (1976).

fruiting form damage to yield reduction, damage must be specified for each stage of fruit form development.

In Table 16, Tollefson's data specify average fruiting forms destroyed per tobacco budworm for three infestation periods. Mean damage per budworm occurs over an average feeding period of 13 calendar days. To reduce the damage recorded by Tollefson into damage per physiological day, a data transformation is carried out. By multiplying calendar days by the physiological days coefficients (as presented in Figure 6 and in Table 17), calendar days are reduced to physiological days. For example, Tollefson's first infestation period occured in late June. Referring to Figure 6, one calendar day (C) is equal to 0.62 physiological day (P) for that growth period. By multiplying .62 by average calendar feeding days the period is reduced to physiological days (e.g., 13 • .62 = 8.06 physiological days). Now, by dividing average square damage for that period (8.82) by the physiological-day feeding period, damage per insect is reduced to a single physiological day (8.82/8.06 = 1.1 squares, as in Table 17). Repeating this process for each infestation period and each fruiting form provides the data of Table 17. Square, flower and boll damage per tobacco budworm per physiological day is graphically presented in Figure 8. Note that such damage function is directly related to its particular fruiting development pattern (compare Figures 4 and 8). Comparing the development patterns for each fruiting form, with the respective damage functions, quantity of per insect damage increases as the number of per plant fruiting forms increases. Relative damage is immediately greatest for squares because flowers and bolls are not yet present. In addition, young, 1-3 instar larvae prefer the small, tender pin-head

Table 17. Damage by Tobacco Budworm to Cotton Fruiting Forms; Converted from Calendar Days to Physiological Day Units

	June 25 1C = .72P	July 20 1C = .775P	August 10 1C = .9P
Average Square Damage			
Calendar Day	8.82	4.08	3.46
(Physiological Day)	(1.10)	(.40)	(.34)
Average Flower Damage			
Calendar Day	1.56	1.24	1.46
(Physiological Day)	(.20)	(.12)	(.14)
Average Boll Damage			
Calendar Day	1.41	2.28	2.21
(Physiological Day)	(.10)	(.23)	(.22)

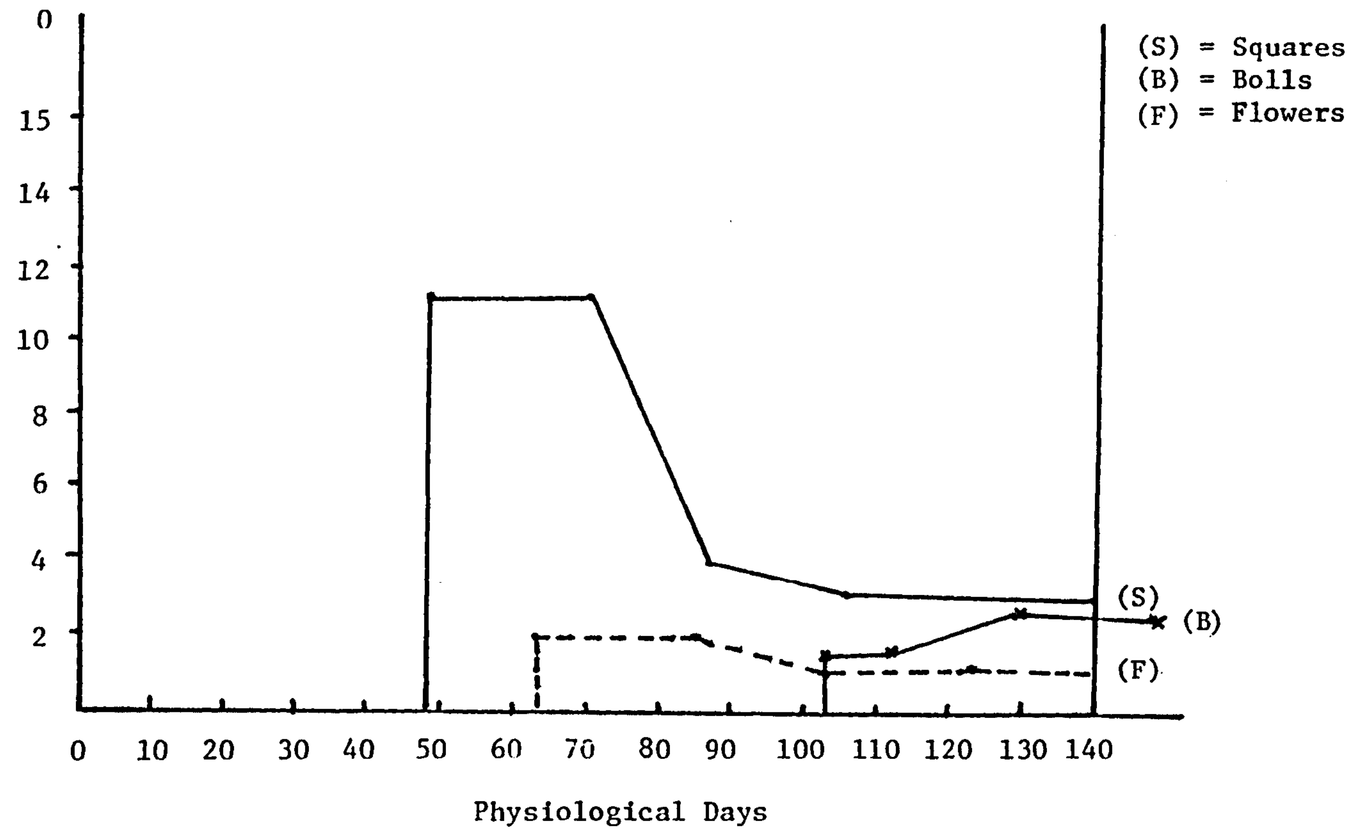

Figure 8. Time-dependent variable damage curves for cotton cotton fruiting form. -- Damage specified in physiological day units.

squares, since the larvae physiology is not sufficiently developed to cut through the thick carpel walls of the cotton boll. Finally, in Figure 8, note that boll damage per insect is greater than flower damage. Essentially, this is because boll damage peaks at day 130, or approximately 20 physiological days after boll emergency. Such damage is caused by a combination of larva size (older, 3-5 instar larvae tend to prefer boll fruit over squares and flowers), and boll moisture content, which is optimal for larvae 14-21 days after boll emergency (van Steenwyk et el., 1976).

CHAPTER 4

DEVELOPMENT OF THE MATHEMATICAL MODEL

To provide an estimate of the economic impacts of regulatory actions placed on chemical insect control, some estimate for farmer response to the insect-host complex is used. This estimate is developed from a mathematical model of a profit maximizing farm that is assumed to have sunk all production costs except insect control cost.

Farmers frequently apply more insecticide than is actually needed to control cotton pests. Often the cotton producer assumes the necessity for a predetermined application schedule in which control measures are initiated at the outset of leaf or square development and continue throughout the growing season. Such action fails to take into account the host-pest-predator-parasite interrelationships and the economics that exist within the plant-pest eco-system. For Arizona farmers, such action may be especially true, particularly when considering the tobacco budworm. The tobacco budworm is normally held in check by natural predators and parasites, and does little or no damage to the cotton plant. However, other insects, particularly the stink bug (the most common being the *Chlorochroa sayi*), and the lygus bug (*Lygus hesperus* Knight) emerge in the early growing season and begin damage to the cotton. At this time the farmer is forced to initiate insecticide treatment, and thus the budworm problem emerges. The initial application destroys the beneficials, and the natural insect equilibrium is disrupted, resulting in an increased growth rate by the insecticide-resistant pest. After this initial application, treatments are implemented periodically for the remainder of the growing season to control the insect complex. Recognizing the uncertainty that exists in the control of insects, such procedure may be a rational control method. Today, however, new and more useful information being developed necessitates a look at alternative pest-control measures.

The mathematical model of Talpaz and Borosh (1974), which is used in this study as a basis for determining optimal control strategies, incorporates a kill function from Hall and Norgaard (1973) in which the insect mortality rate is independent of the size of the pest population. The kill function is of the form, $K(x, t) = P(t)F(x)$ (where x = level of insecticide and t = time) and specifies that the number of insects killed by x is linearly related to the insect population. The model also incorporates multiple insecticide applications with setup and insecticide costs throughout the growing season. The setup costs include preparation costs and fixed contract fees, which are independent of levels of x but strictly proportional to the number of treatments.

The research of this thesis made a significance change in the basic form of the damage function as used by Talpaz and Borosh. In addition, the parameters of the model were estimated to approximate conditions for Arizona cotton production.

Specifically, Talpaz and Borosh assumed a constant damage per tobacco budworm over the cotton season. Several studies referred to in Chapter 3 indicated that damage per insect varies over the growing season. Using the data from the studies on budworm damage to cotton, a time-dependent damage function is developed in Chapter 3 and incorporated into the mathematical model presented in this chapter.

Other basic parameters such as setup costs, insecticide prices, harvesting cost, and cotton prices were estimated to reflect the conditions experienced by Arizona farm firms. In addition, the "no damage" lint-cotton yield was previously estimated for Pinal County, and an assumed initial insect population are incorporated into the model. To integrate all of these variables into a single model, the cotton growing season is converted from calendar days to physiological days for Arizona. For example, the growing period of cotton is found to be 140 physiological days for Pinal County, Arizona. The short time period is due primarily to the warmer weather conditions found in central Arizona. Finally, all variables of the model were based on a single acre of cotton, assumed to be planted with all costs, except costs associated with insect control and sunk prior to decision on insect control.

Specification of Mathematical Model

This model assumes that farm production is restricted to a single field crop, cotton, and that insect infestation is limited to a single insect population of tobacco budworm. The model takes into account that the development of the insect population, and the damage it inflicts while feeding in the cotton plant depends on temperature. The cotton growing season is measured in degree-days, or specifically, physiological day units. An additional assumption is that a single insecticide, methyl-parathion is applied at equal physiological time intervals throughout the cotton growing season. Finally, the model assumes that all costs, with the exception of insecticide and setup costs, are sunk costs. Therefore, profits per acre estimated by this model are significantly greater than actual farm producers would experience since sunk costs are not subtracted from the estimated profits above insect control costs.

Insect Population Dynamics

Since insecticide treatments are applied to the cotton crop, two insect population growth rates are considered. The first is the "natural" growth rate, the rate that occurs prior to the initial insecticide application. This assumes a normal pest-predator-parasite equilibrium but without insect migration. The second is the augmented growth rate. This rate is assumed to increase due to the destruction of beneficial insects occurring after the initial insecticide application. The base model developed by Talpaz and Borosh (1974) assumes a single homogeneous birth-death process, again without migration. The birth and death rates of the budworm are, respectively, denoted by ν and μ. Subtracting death rate from birth rate provides the growth rate.

$$\rho = \nu - \mu \ ; \ \rho > 0 \ , \tag{5}$$

and the population level satisfies the differential equaltion

$$\partial P = \rho \partial t \tag{6}$$

where the population level at physiological time t is

$$P(t) = P_o e^{\rho t} \ , \tag{7}$$

the initial population represented by P_o. The population before the initial spraying is therefore denoted as P(t).

As previously mentioned, with the initiation of the first insecticide treatment, many of the beneficial insects that held the tobacco budworm population in check are destroyed. The disruption of the beneficial insect population causes an increase in the insect growth rate. The new growth rate, r, is assumed after the first application, where $\rho < r$. Specifically the respective growth rates are $\rho = .01$ and $r = .05$.

The total growing period (T) for cotton is 140 physiological days and is denoted by T, where $t_o = 0$ at the initial planting period, and $t_n = T$ which specifies Day 140, specifically, harvest time. During the T physiological days, n - 1 insecticide treatments are applied to the cotton plants. In general terms, insecticide applications are times $\frac{T}{n}, \frac{2T}{n}, \frac{3T}{n}, \ldots, \frac{(n-1)T}{n}$. With the growing season equally divided up into n periods, damage to cotton yield can be evaluated between periods.

The insect survival rate after the first treatment, denoted by ζ, and Z equals the insect survival rate after subsequent treatments. At time t, the insect population level is:

$$P(t) = \begin{cases} P_o e^{\rho t} & t_o \lesssim t < T/n \\ \zeta Z^{i-1} P_o e^{\rho T/n} e^{r(t-T/n} & iT/n<t<(i+1)^{T/n} \end{cases} \quad (8)$$

where i = 1, . . ., n-1 (i = the number of sprayings up to time t).

Mathematics representing the insect population dynamics (8) is graphically illustrated in Figure 9 for n - 1 = 5 insecticide treatments. With the insect population at $P_o e^{\rho T/n}$, the first spraying reduces the insect population level to P_1. At 2T/n , despite an augmented growth rate, the second insecticide treatment also reduces the population level to P_1. This process is repeated for all n - 1 treatments. Each application brings the population to the same level. With this the case then,

$$\zeta\, P_o e^{\rho T/n} = Z\,(\zeta P_o e^{\rho T/n})\; e^{r^{T/n}}$$

or

$$Z = e^{-rT/n}. \tag{9}$$

The decision variables are the pest survival rate ζ, and the number of treatments, n. These variables will be chosen so as to maximize profits for each farm size. The quanitity of insecticide (units of x) to be applied is a function of ζ and Z and is therefore dependent on the kill efficiency function of the insecticide (i.e., the survival rates are a function of the kill rates; the reverse is also true).

Kill Efficiency Function

Talpaz and Borosh (1974) stated that the kill efficiency function used for their model is a common one (Hueth and Regev, 1974; Knipling, 1966; and Shoemaker, (1973) of the form

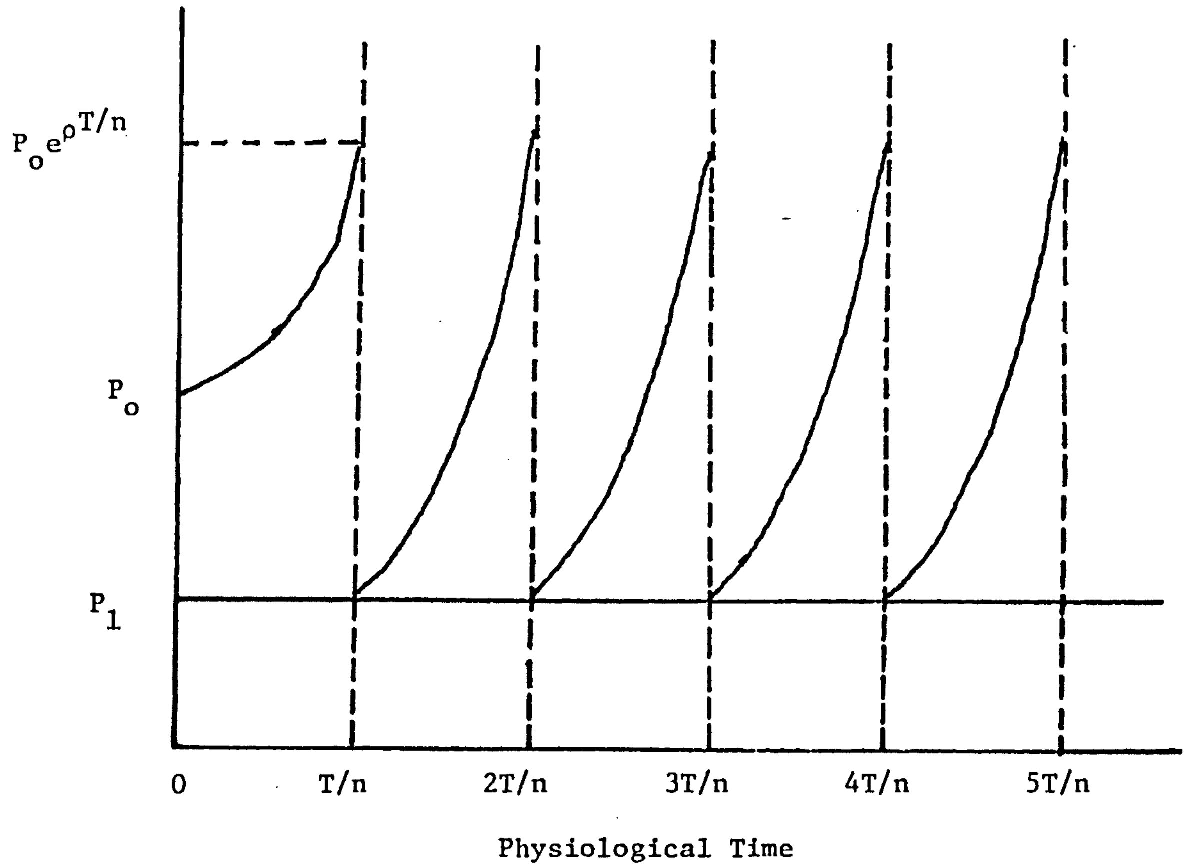

Figure 9. Pest population dynamics subject to insecticide application. -- Modified from Talpaz and Borosh (1974).

$$K(x,t) = P(t)\ F(x) \tag{10}$$

which specifies that the amount of pests killed by the level of insecticide x, at time t, increases linearly with an increase in the pest population level and, is directly related to the quantity of x used. The kill efficiency function F (x) is generally assumed to monotonicly increase with x, specifically, an increasing kill rate with low levels of x, and a decreasing kill rate for high levels of x. Theoretical studies of dosage-response (Finney, 1952) with pest resistance have yielded the following restrictions to F(x).

$$F'(x) > 0 \tag{11}$$

$$F''(x) > 0\ ,\ x \varepsilon (0,x_1) \tag{12}$$

$$F''(x) < 0\ ,\ x \varepsilon (x_1,\infty)$$

$$F\ (0)\quad 0 \tag{13}$$

$$\lim_{x < \infty} F(x) < 1 \tag{14}$$

Items (13) and (14) satisfy the boundary conditions for F(x). For the derivation of the kill efficiency function, the insect tolerance to insecticide does is assumed to have the Weibul distribution (Talpaz and Borosh, 1974, footnote 27). Talpaz and Borosh utilize the function

$$F(x) = 1-e^{-ax^{\lambda}} \tag{15}$$

where a = 1.044 and λ = 1.025 for methyl-parathion, and equation (15) satisfies the boundary conditions (13) and (14) that specify that if no insecticide is applied, zero insects will be killed and that no matter what quantity of insecticide is applied, some insects will always survive. The last condition is true only if λ is greater than 1. Figure 10 depicts an example of the kill efficiency vs. pesticide dosage function F (x). At the inflection point x^*, the survival rate of the insects is $e^{(1-\lambda)/\lambda}$. This is not the kill function for a = 1.044 and λ = 1.025 stated above.

The Profit Function

The profit function for this single-crop, single-pest, single-insecticide model is

$$\pi(\zeta_1 n) = \beta^* y - (n-1)\, c - \alpha[X(\zeta) + (n-2)\, X(Z)] - \beta D \qquad (16)$$

and where β^* represents the unit price of cotton (product price equals .56¢/pound cotton lint). $\beta = \beta^* - \gamma$ is the per unit cotton price after the harvest cost has been deducted, specifically, β = 0.5515¢ per pound cotton lint and γ equals the per unit harvest cost of 0.0085¢ per pound cotton lint. The term X (ζ) represents the quantities of insecticide applied for the first treatment and X (Z) represents the quantitites of insecticide applied for all subsequent treatments. The initial treatment is always significantly larger than subsequent treatments because of the low insect survival rate produced by the first treatment. Population levels never reach the levels prior to the first application.

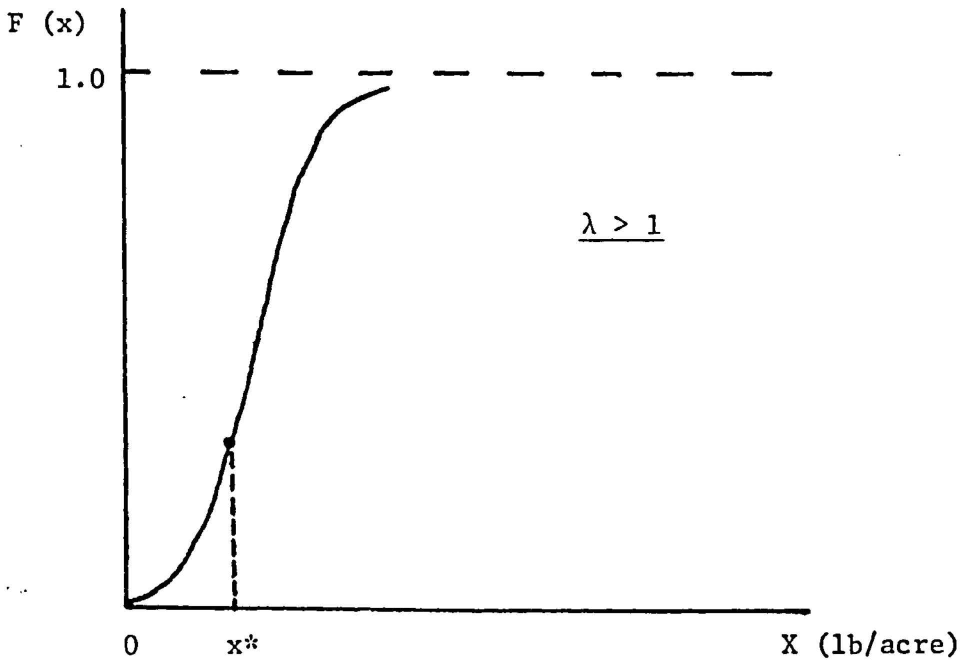

Figure 10. Specification of F(x). -- An increasing kill rate for insecticide levels below X*, a decreasing kill rate for levels above X*, asymptotically approaching 1, $F(x) = 1 - e^{ax^{\lambda}}$.

The Insecticide Cost Function

Cost parameters for insecticide are assumed to vary with farm size. Large farms receive lower costs of insecticide per unit and lower setup costs then do the smaller farms. The lower costs are the result of volume discounts. The service charge per acre, or setup costs, are also often negotiated if acreage to be sprayed is of sufficient quantity.

The cost of applying the quantity of insecticide (x) is given by

$$S\ (x) = \begin{cases} c \pm \sigma\ x & \text{if } x > 0 \\ 0 & \text{if } x - 0,\ C = 0 \end{cases} \tag{17}$$

where c is the setup cost per treatment ($2.25/acre for the small farm and $2.14/acre for the large farm) and α denotes the unit cost of insecticide ($2.90/pound active ingredients for the small farm and $2.65/pound active ingredient for the large farm). S(x) represents the functional relationship between x and the insect survival rate. Extremely low survival rates imply lower quantities of insecticide with a lower associated total cost. Higher insect survival rates imply larger quantities of insecticide with a greater per unit cost. Finally, a zero application of insecticide results in a zero cost parameter for either insecticide or setup costs, denoted as S(x) = 0.

Using the Variable Damage Function

Talpaz and Borosh (1974) in their development of a crop damage function recognized that the total damage to final yield, between two time periods, could be expressed as

$$D(t_1,t_2) = \int_{t_1}^{t_2} (t) \cdot P(t)\, dt \tag{18}$$

where $\delta(t)$ is the damage per insect as a function of time t and P(t) is the insect population at time t.

However, Talpaz and Borosh (1974) used the simplifying assumption of constant damage, that is, $\delta(t) = \delta$, for all time periods and δ is a constant.

One of the important features of the model used in this study is that damage per insect is assumed to vary throughout the growing season. Therefore, total damage between time t_1 and t_2 is assumed to be determined by equation (18) where $\delta(t)$ at anytime t is assumed to be a linear function of time, such that,

$$\delta(t) = b_t t + C_t$$

where

b_t = slope of the damage function at time t, and

C_t = the intercept constant of the damage function at time t.

The damage functions of Figure 8 in Chapter 3 were adopted to fit the format illustrated above by recognizing that "total damage" per insect resulted in insect damage to the three types of fruiting forms; the squares, the flowers, and the bolls. Under these conditions the total damage per insect (in units of lb cotton lint/insect) is defined as

$$\delta(t) = \ell \Sigma_{j=1}^{3} \sigma_j \cdot \delta_j(t) \tag{20}$$

where $\delta_j(t)$ = the damage per insect to fruiting form, j, where j = 1 for squares, j = 2 for flowers, and j = 3 for bolls (in fruiting forms/insect)

σ_j = the number of open bolls resulting from one fruiting form of type j (in units of open bolls/fruiting form), where $\sigma_1 = .44$, $\sigma_2 = .67$, $\sigma_3 = 1.0$

and ℓ = a constant which converts the number of open bolls to units of final output

= (325,000 open bolls per acre/70 open bolls per lb of seed cotton) x (.33 lb of lint cotton per lb of seed cotton). In units of lb. lint cotton/open boll.

The total damage between time periods t_1 and t_2 is therefore found by substituting Equation (20) into Equation (18) such that

$$D\ (t_1,t_2) = \ell \int_{t_1}^{t_2} [\sum_{j=1}^{3} \sigma_j \cdot \delta_j(t)]\ \ P(t)\ dt,$$

$$= \ell \sum_{j=1}^{3} \{\sigma_j \cdot [\int_{t_1}^{t_2} \sigma_j(t)\ \ P(t)dt]\}\ . \qquad (21)$$

Each of the damage functions $\delta_j(t)$ is defined in the form of Equation (19) and shown in Figure 10. Specifically, the three damage functions $\delta_j(t)$ where time, t, is measured in physiological days are defined:

1. For squares, in units of squares/insect as

$$\delta_1(t) = \begin{cases} 0, & 0 \le t < 48 \\ 1.1, & 48 \le t < 60 \\ -.04t + 3.5 & 60 \le t < 77.5 \\ -.003t + .63, & 77.5 \le t < 97.5 \\ .34, & 95.5 \le t < 140 \\ 0, & t \ge 140 \end{cases} \qquad (22)$$

2. For flowers, in units of flowers/insect as,

$$\delta_2(t) = \begin{cases} 0, & 0 \le t < 48 \\ .20, & 48 \le t < 60 \\ -.0046t + .48, & 60 \le t < 77.5 \\ .001t + .043, & 77.5 \le t < 97.5 \\ .14, & 97.5 \le t < 140 \\ 0, & t \ge 140 \end{cases} \quad (23)$$

3. For bolls, in units of bolls/insect as

$$\delta_3(t) = \begin{cases} 0, & 0 \le t < 48 \\ .17, & 48 \le t < 60 \\ .0034t - .034, & 60 \le t < 77.5 \\ .0005t + .268, & 77.5 \le t < 97.5 \\ .22, & 97.5 \le t < 140 \\ 0, & t \ge 140. \end{cases} \quad (24)$$

A major aspect of the solution process is the evaluation of the integral portion of Equation (21). These integrals can be denoted as

$$D_j\ (t_1,t_2) = \int_{t_1}^{t_2} \delta_j(t)\ P(t)\ dt \quad (25)$$

substituting Equation (19) into Equation (25) yields

$$D_j\ (t_1,t_2) = \int_{t_1}^{t_2} b_{tj}t \cdot P(t)\ dt + \int_{t_1}^{t_2} C_{tj} \cdot P(t)\ dt \quad (26)$$

where b_{tj} and C_{tj} are determined from the relationships (22), (23), and (24) according to physiological time and in accordance with Equation (19).

Using the population dynamics of Equation (8) the damage functions can be solved in closed form for the period before the initial spraying by noting that

$$D_j\ (t_1,t_2) = \int_{t_1}^{t_2} b_{tj}\quad t\cdot P_o e^{\rho t}\ dt + \int_{t_1}^{t_2} C_{tj}\cdot P_o e^{\rho t}\ dt \qquad (27)$$

Assuming that t_1 and t_2 can be chosen such that b_{tj} and C_{tj} are constant for each j across any time period, Equation (27) reduces to

$$D_j\ (t_1,t_2) = b_{tj}P_o \int_{t_1}^{t_2} te^{\rho t}\ dt + C_{tj}\cdot P_o \int_{t_1}^{t_2} e^{\rho t}\ dt$$

$$= \frac{P_o}{\rho}\ [(b_{tj}\cdot(t-\frac{1}{\rho}) + C_{tj})\cdot e^{\rho t}]_{t_1}^{t_2} \qquad (28)$$

After the initial spraying (for $t > T/n$), again assuming that t_1 and t_2 can be chosen such that b_{jt} and C_{jt} are constants for each j across any time period, Equation (27) reduces to

$$D_j(t_1,t_2) = \int_{t_1}^{t_2} b_{tj}\cdot t\cdot[\delta(e^{-r^{T/n}})^{i-1}]\cdot P_o e^{\rho^{T/n}}\ e^{r(t-T/n)}dt$$

$$= \int_{t_1}^{t_2}\ C_{jt}\ [\delta(e^{-r^{T/n}})^{i-1}]\cdot P_o e^{\rho T/n}\ e^{r(t-T/n)}dt$$

(29)

Letting $K = \delta P_o e^{\rho^{T/n}}$, a constant representing the number of surviving insects after the initial spraying, Equation (29) reduces to

$$D_j(t_1,t_2) = \frac{K}{r}\,[b_{tj} \cdot (t-1/r) + C_{tj})\,(e^{(i-1)-\frac{rT}{n}} \cdot e^{r(t-T/n)})]_{t_1}^{t_2} \tag{30}$$

where

i = the number of sprayings up to time t.

The total damage factor D of the profit function expressed in Equation (16) is defined as the integral (or sum) of the above defined partial damage functions as indicated in Equation (18) and Equation (21).

The Solution Method

Since the number of insecticide applications (n-1) must be an integer (according to model specifications) the model solution procedures utilize discrete numerical methods. Thus, n is specified and substituted into all of the components of the profit function. Specifying n divides the growing season into constant intervals of length T/n. The constants n and T/n are substituted into the damage function and into Equation (8) which represents the population dynamics and the profit function. For all values of n over a feasible range (say 0 to 15), the level of the initial survival rate (δ) which maximizes profits is selected. The selection process for ζ maximizes $\pi(\delta,n)$ assuming no resource constraints. This optimization procedure implies that ζ is selected such that

$$\frac{\partial \pi}{\partial \zeta} (\zeta, n) = 0$$

$$\frac{\partial^2 \pi}{\partial \zeta^2} (\zeta, n) \quad 0$$

The values of ζ for each feasible n which maximizes Equation (22) are found using the Bisection Method (James, Smith, and Wolford, 1977, pp. 93-96) and a computer solution which displays all of the relevant data.

CHAPTER 5

EMPIRICAL RESULTS AND ANALYSIS

Two items of interest are analyzed in this chapter. First, a comparison of the efficiency costs to farms of the implementation of two types of regulatory actions on insecticides. Second, an economic comparison of two different pest damage functions; constant damage as proposed by Talpaz and Borosh (1974) and a variable damage as developed in this study.

The initial analysis compared the standard to a taxing strategy as described in Chapter 2. Development of the analysis consists of three distinct sections: (1) efficiency effects of a standard for a small farm (Type 1) and a larger farm (Type 2), (2) efficiency effects of a tax on both farm sizes, and (3) comparing efficiency costs for each control action (tax vs. standard) by farm size.

Since a significant part of this study was the development of a variable damage function, it is compared with the constant damage function of Talpaz and Borosh (1974).

Efficiency Costs from Two Regulatory by Farm Size

Tax

Due to the negligible effect the price of insecticide has on profits, a large tax of 100 percent of the initial cost of insecticide is implemented.

As in the case of the standard, before the initiation of a tax, optimal insecticide applications are 8.83 pounds per acre for Type 1 and 8.91 pounds per acre for Type 2. A 100 percent tax reduces marginal profits at every point along the curve, thereby, shifting the respective curves to the left, Type 1 now uses 8.21 pounds of insecticide per acre while Type 2 uses 8.29 pounds of insecticide per acre. Loss in profits for each farm size is the area between the two marginal profit curves (Area A_1' = change in profit for Type 1; Area A_2' = change in profit for Type 2), where Area A_1' = \$24.61 per acre and Area A_2' = \$22.86 per acre.

A_1' and A_2' do not represent the efficiency cost of implementing the tax. For the standard, \$3.72 per acre was the implementation cost to the farmers of restricting insecticide use to 8.25 pounds per acre. The changes in profits are negative for both Types 1 and 2 farms. A tax has two components: (1) a direct cost to the farmer and (2) a gain to society in the form of a tax revenue. The tax revenue is computed as the quantity of insecticide used times its price.

For Type 1 the tax revenue is \$8.21 pounds per acre • \$2.90 pounds per acre or \$23.81 per acre. Subtracting this from A_1' provides the actual cost of implementing the tax, which is \$.80 per acre. The \$23.81 per acre is a monetary "gain" to society. For Type 2, the generated revenue is \$22.13 (8.29 pounds per acre • \$2.67 per acre) and the implementation cost is \$.73 per acre. The total cost of implementing the tax is \$.80 + .73) equal to \$1.53 for the two farm sizes.

Change in profits for each farm size is the sum of the implementation costs and tax revenues. As previously specified, this is area

A_1' for Type 1 and A_2' for Type 2, or a percentage change in profits of .0295 percent and .9273 percent respectively, where $A_1 > A_2$.

Standard

A standard is initiated to restrict total per acre insecticide use. Restrictions are the same for each farm size, specifically 8.25 pounds of insecticide per acre, for a total of 16.5 pounds for the two farms.

The results of this analysis are shown in Figure 11 for farm Types 1 and 2. These graphs show profits and marginal profits as a function of total per acre insecticide use in an unrestricted case. The profit and marginal profit curves have very little difference between the two farm types and are therefore combined. Type 1 has a maximum profit of $833.96 per acre with a corresponding optimal insecticide use of 8.91 pounds per acre. The difference between the two optimal profits is $2.26. Considering the size differential for Types 1 and 2, the $2.26 is an insignificant amount, especially when considering farm size, as in Chapter 2. Three reasons exist for this discrepancy. First, the sole criterion for farm size is insecticide use. With the base price of methyl-parathion at $2.90 per pound active ingredient and total per acre use at just over 8 pounds, profit curves are only incrementally affected, despite the 8 percent price discount for Type 2. The second contributing factor is a combination of the insect population growth rate (0.01 before first treatment, 0.05 for all subsequent treatments) and the pest survival rate. The pest population grows so rapidly that within a short time there are more insects than cotton available for feeding. To

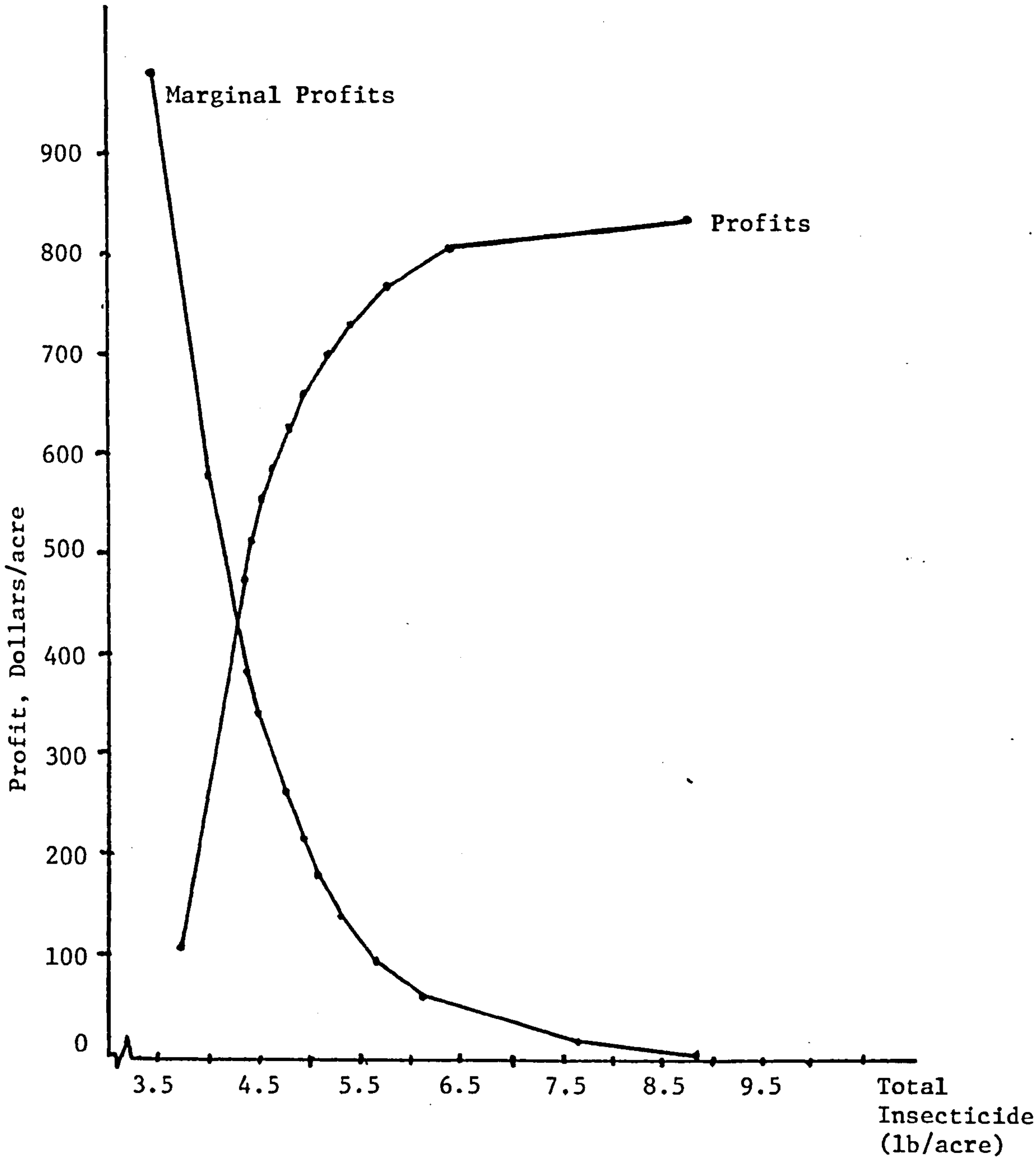

Figure 11. Profit and marginal profit curves for types 1 and 2 farms

correct this, an unrealistically low pest survival rate is computed (0.00069 for Type 1 and 0.00064 for Type 2, where n = 3 for both farms, and, using the variable damage function). Using constant damage (Talpaz and Borosh's survival rate is .00416 with n = 7) per insect over the growing season, results initially appear to be satisfactory. However, constant damage is an unreasonable assumption, since the tobacco budworm does not cause damage to fruiting forms until square emergence, nearly 1½ months after planting. Given growth rates of p = .01, r = .05, a survival rate of 0.00069, and the incorporation of variable damage function, the optimal number of applications are reduced from 10 (Talpaz and Borosh, constant damage) to 3. Between the pest growth rates, the very low survival rate, and a small number of insecticide treatments, profit differentials between farm Types 1 and 2 are not significant.

Before the initiation of a standard, each farm type administered optimum amounts of insecticide, 8.83 pounds per acre for Types 1 and 8.91 pounds per acre for Type 2, on the point where marginal profits equal zero. Referring to Figures 12 and 13, graphical depictions for each farm size are represented. Two items need mentioning when referring to these marginal profit curves. First, that the levels of insecticide use, 8.83 pounds per acre for Type 1 and 8.91 pounds per acre for Type 2, represent optimal, unrestricted levels of insecticude use. Second, when referring to the standard, it is these unconstrained levels of insecticide use in which the analysis occurs. The marginal profit curves to the left of these unconstrained levels represent the reduction in marginal profits and insecticide use due to the implementation of a

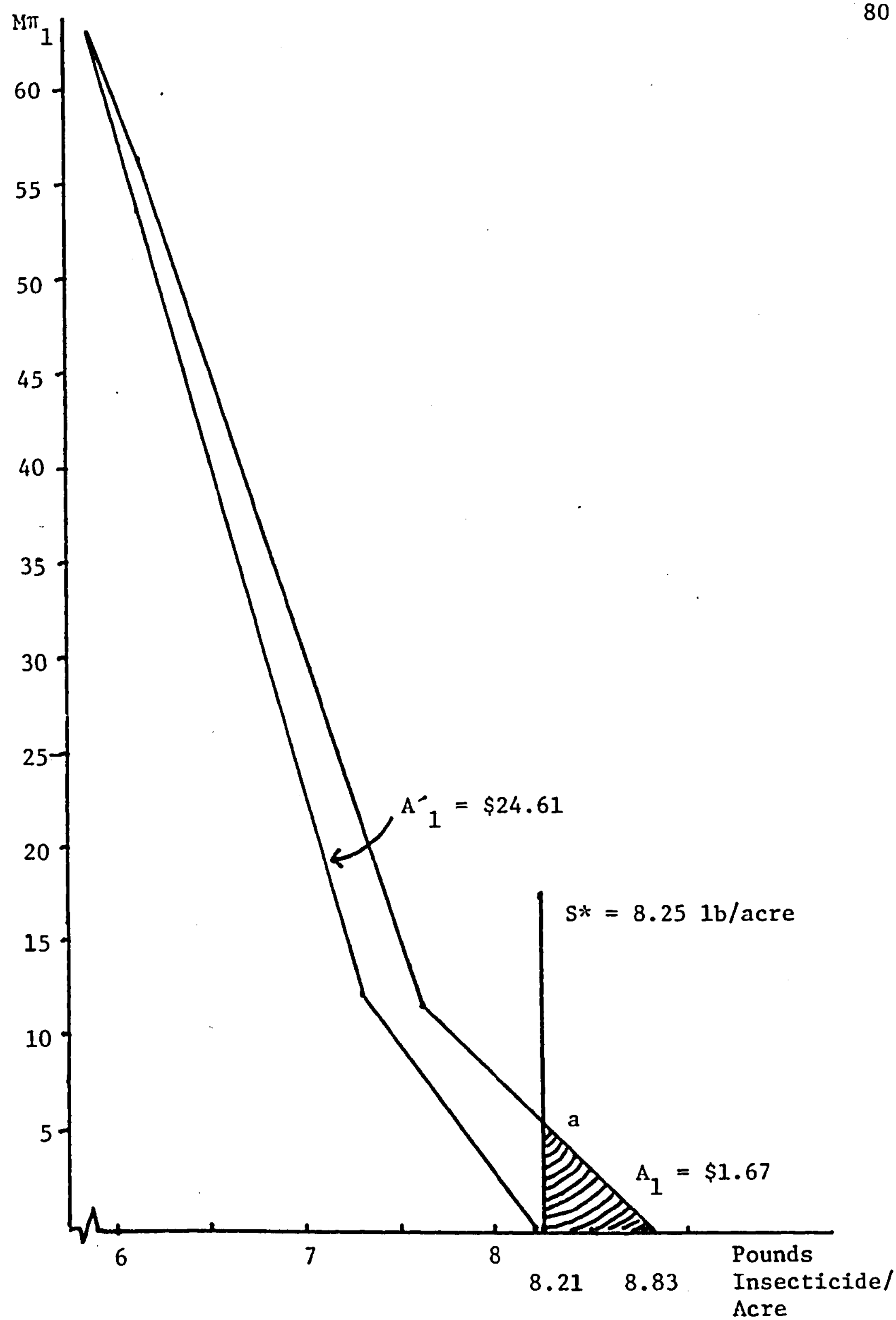

Figure 12. Marginal profit curves for type 1 farm. -- Depicted are effects of a standard (S*) and tax on farm profits.

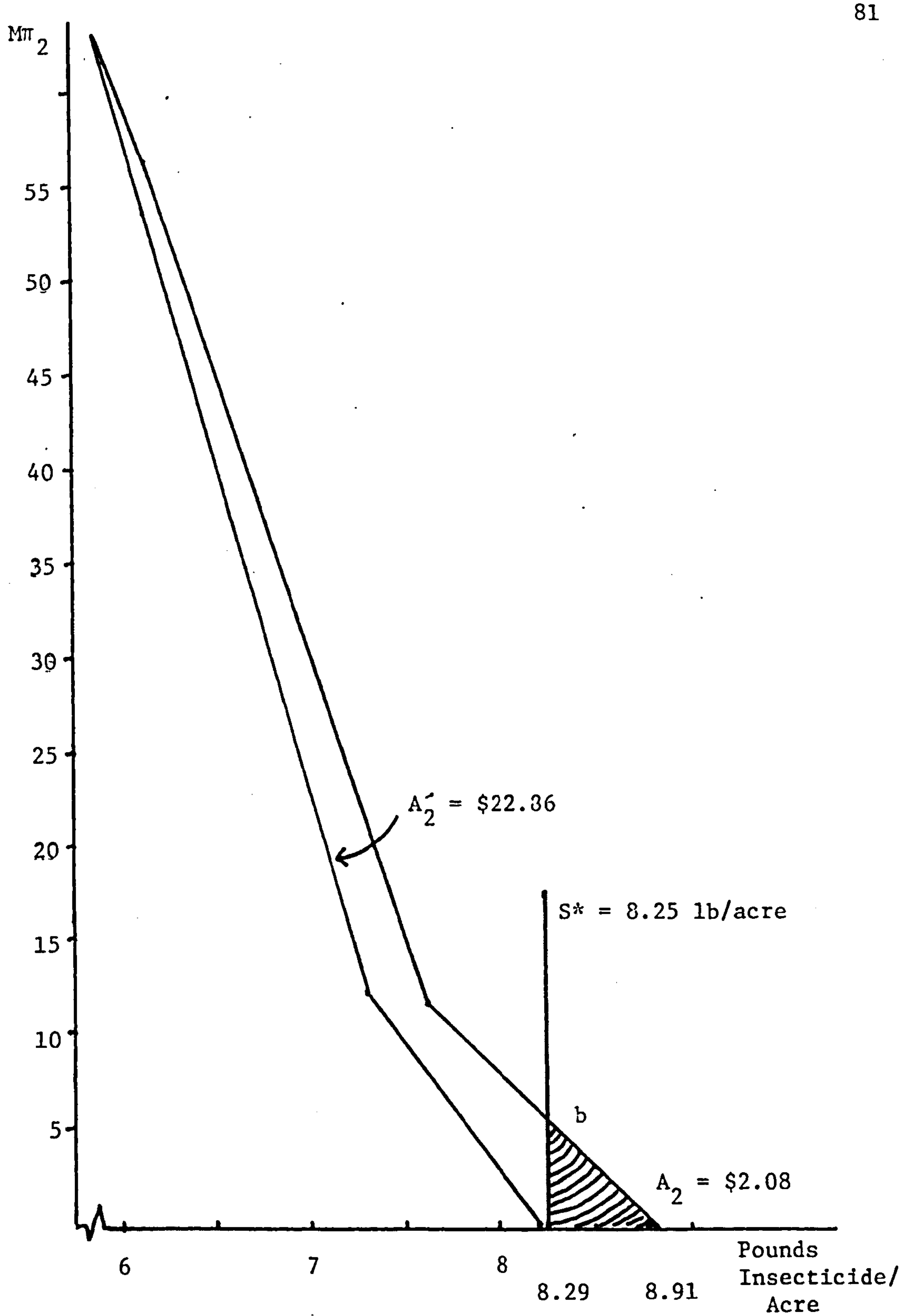

Figure 13. Marginal profit curves for type 2 farm. -- Depicted are effects of a standard (S*) and tax on farm profits.

tax. The areas between the two curves represent the respective loss in profits for each farm size.

Each marginal profit curve ($M\pi_1$ = marginal profits for Type 1, and $M\pi_2$ = marginal profits for Type 2) represents optimal insecticide treatments (n-1). For both farms, optimal n = 3, or two (n - 1) actual applications. An assumption of the model is that treatments be divided equally throughout the 140 physiological days, for this case, 46.67 physiological days apart, providing three distinct periods. The first treatment kills 0.99936 percent of the pest population on farm Type 1, a figure so low that only one additional treatment is required to maximize profits.

To adequately show the differences a standard and a tax have on insecticide use, insecticide levels had to be summed for the two farms sizes. In other words, implementation of a 100 percent tax reduces Type 1 to 8.21 pounds per acre, while Type 2 is reduced to 8.29 pounds per acre. The sum of insecticide for the two farms is 16.5 pounds. Exactly half that amount, or 8.25 pounds per acre, becomes the per acre allowable insecticide use for the small and large farm under a standard.

Therefore, restricting insecticide to 8.25 pounds per acre for each farm, Type 1 is restricted only 0.58 pounds, while Type 2 is restricted 0.66 pounds. Loss in profits due to the standard at S^* in Figures 15 and 16 are the areas to the right of S^* and under the respective marginal profit curves. Type 1 loses area A_1 which equals \$1.67 per acre and Type 2 losses are a A_2, which equals \$2.08 per acre. This represents a percentage change in profits of 0.2 percent and 0.25

percent, respectively. Under the standard, percentage change in profits for Type 1 are <u>less</u> than the percentage change in profits for Type 2. Finally, the efficiency cost of establishing a standard at S^* is the sum of the areas $A_1 + A_2$, or (\$1.64 per acre + \$2.08 per acre) equal to \$3.72, which represents the total efficiency cost of restricting insecticide use to 8.25 pounds per acre.

Tax vs. Standard

In analyzing the effects of a tax and standard, it is essential that each control action reduce total levels of insecticide use equally. However, a distributional difference in levels of use will vary between a tax and a standard, as this is an important part of the analysis. Therefore, not only per acre restrictions for each farm size is looked at, but also total restrictions for the two farm types.

In contrasting the two regulatory strategies, three basic criteria are analyzed, all in the form of costs. The first criterion is the direct cost to the farm firm, shown as a change in profits or percentage change in profits. The second criterion deals with the cost of implementing each control action. The final cirterion more of an implicit cost, contrasts the actual allowable insecticide levels under the respective strategies. It, too, is analyzed from an efficiency point of view. Table 18 presents the figures, classified by farm size and the specific control action.

Comparing change in profits due to a standard or a tax shows a large difference for each farm type. However, when referring to profits in this analysis, it is important to recognize that profits per acre

Table 18. Effects of Two Regulatory Actions, Standard and Tax, by Farm Type

Regulatory Action	Farm Type	Change in Profit ($/acre)	Percent Change in Profits	Allowable Insecticide (lb/acre)	Implementation Cost ($/acre
Standard	1	$ 1.67	0.20	8.25	$1.67
	2	$ 2.08	0.25	8.25	$2.08
Tax	1	$24.61	2.95	8.21	$ .80
	2	$22.86	2.73	8.29	$ .73

recognize only the cost of insecticide, setup costs, and harvest costs. Other costs in cotton production (i.e. labor and machinery, water, herbicide and defoliant, hauling, ginning) are assumed to be sunk costs. Profits for each farm size in this analysis must therefore be recognized as being larger than would ordinarily occur in cotton production. The standard has a negligible effect on farm profits (0.20 percent for Type 1 and 0.25 percent for Type 2) while the tax has a larger effect (2.95 percent for Type 1 and 2.73 percent for Type 2). Costs to the farmer for meeting the insecticide target (8.25 pounds per acre on each farm) are significantly lower using the standard.

Referring again to Table 18, three results should be carefully considered, essentially, they are the distributional changes in costs and insecticide use. First under a standard, insecticide use is restricted equally (8.25 pounds/acre) between farms. However, the cost associated with the equal restriction is larger for Type 2. A tax reverses the costs, Type 1 now experiencing the larger percentage loss in profits. Second, even though the tax meets the total allowable use of insecticide (16.5 pounds for thw two farms), the distribution is different. The tax allows the larger, more efficient producer to use more insecticide (8.29 pounds per acre) than the smaller (Type 1 = 8.21 pounds per acre) farm while still reducing total use between farms equal to restriction under the standard (8.29 pounds per acre + 8.21 pounds per acre = 16.50 pounds for both farms). This agrees with the theory of tax efficiency discussed in Chapter 2, the more efficient producer is allowed to use more of the restricted input insecticide per acre. Third, a comparison of the implementation costs reveal a change in impacts between the standard and the tax. Under a standard, Type 2 experiences the greater cost while under a tax Type 1 realizes the greater cost. In addition, the cost of implementing the standard is more than twice that for a tax (T = \$1.53 per acre; S = \$3.75 per acre). Again, the less efficient farm is penalized for actually being "inefficient" in procurement of inputs for crop production.

Economic Comparison of the Two Damage Functions

A significant part of this research effort is the development of the variable damage function described in Chapters 3 and 4. Incorporating variable damage into the model of Talpaz and Borosh is an attempt at more closely approximately real world conditions. The following analysis compares the two different damage functions and examines their effects to farm firms. Tables 19 and 20 present data for analysis.

Inspection of Tables 19 and 20 show fairly significant differences when comparing damage functions for a particular farm size, but insignificant differences when contrasting across farms. Analysis, therefore, restricted to the Type 1 farm. Figure 14 depicts profit and marginal profit curves using variable damage for Type 1 farm, while Figure 15 depicts similar curves for the same farm incorporating constant damage. The major difference between the curves lies in their responsiveness to insecticide applications. Profits, or marginal profits of the variable damage curve show large responses to low levels of insecticide, while the curves with constant damage show less response to low levels of insecticide Both profits ane marginal profits become less sensitive to increases in insecticide with the large quantities of use. Reasons for this marked difference in insecticide responsiveness necessitate referral to Tables 19 and 20. In these tables, the profit differential (Type 1) is just over 5 percent between the two damage functions. In other words, Type 1 farm incorporating the variable damage function realizes a 5 percent increase inchange in profits over the Type 1 farm using constant damage.

The profit and marginal profit curves with constant damage (CD) utilize 9 insecticide treatments while the profit/marginal profit curves for variable damage (VD) utilize only two treatments. Furthermore,

Table 19. Effects of Constant and Variable Damage on Profits, Optimal Quantities and Number of Applications of Insecticide per Acre by Farm Type

Farm Type	Profits	Optimal Levels of Insecticide use (lbs)	Optimal Number Applications	Initial Insecticide Application (lbs)
Constant Damage				
Type 1	$790.15	9.93	10	4.51
Type 2	$793.43		10	4.59
Variable Damage				
Type 1	$833.96	8.83	3	6.41
Type 2	$836.22	8.91	3	6.72

Table 20. Comparison of Constant and Variable Damage to Changes in Profits and Insecticide Quantities per Acre

Farm Type	Change in Profit	Percent Change in Profit	Change in Insecticide (lbs)	Percent Change in Insecticide
Type 1 (Constant → Variable	+ $43.81	+ 5.3	-1.1	-11
Type 2 (Constant → Variable	+ $42.79	+ 5.1	-1.09	-11

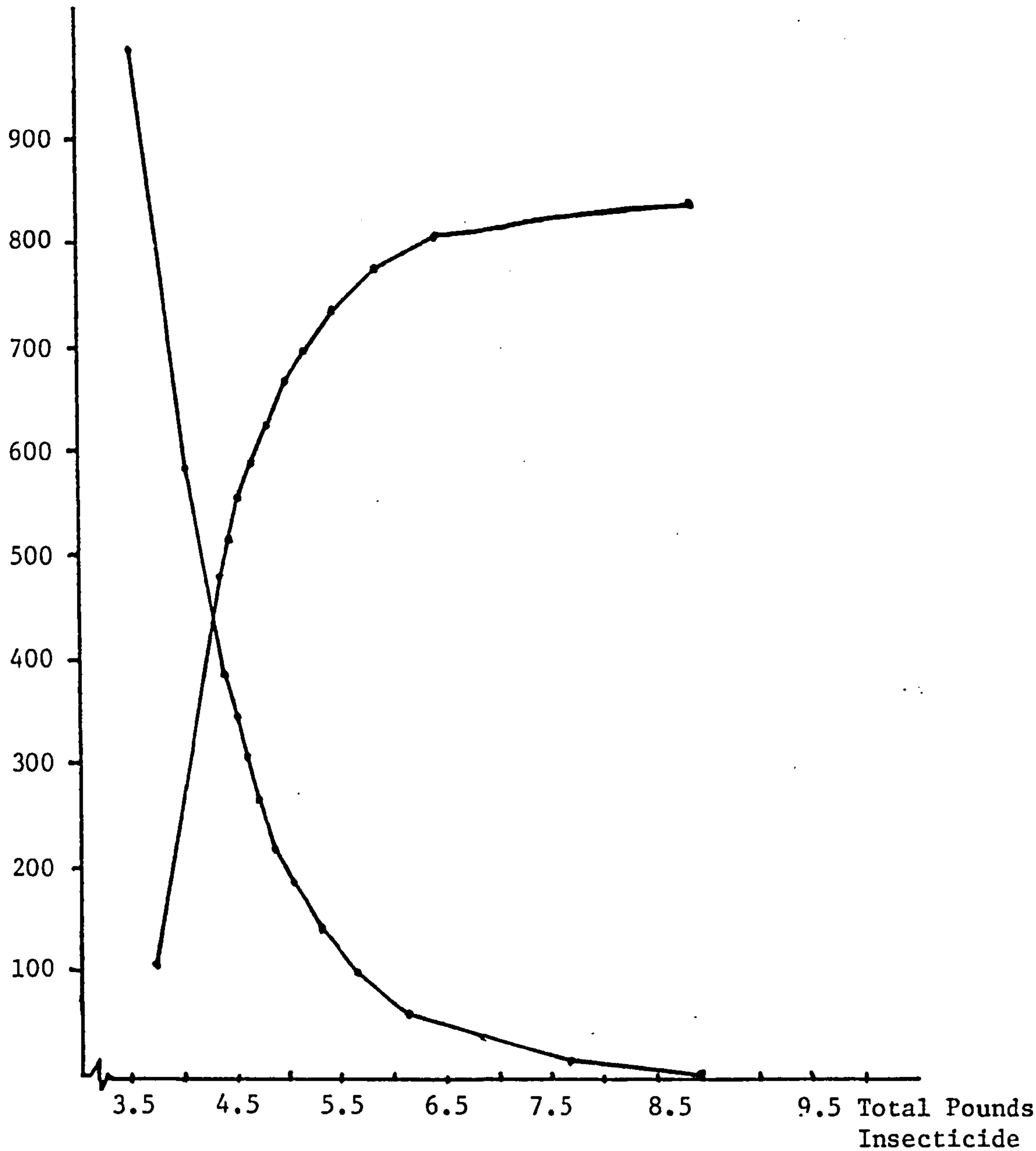

Figure 14. Profit and marginal profit curves for type 1 farm with variable damage. Optimal Applications at N = 3.

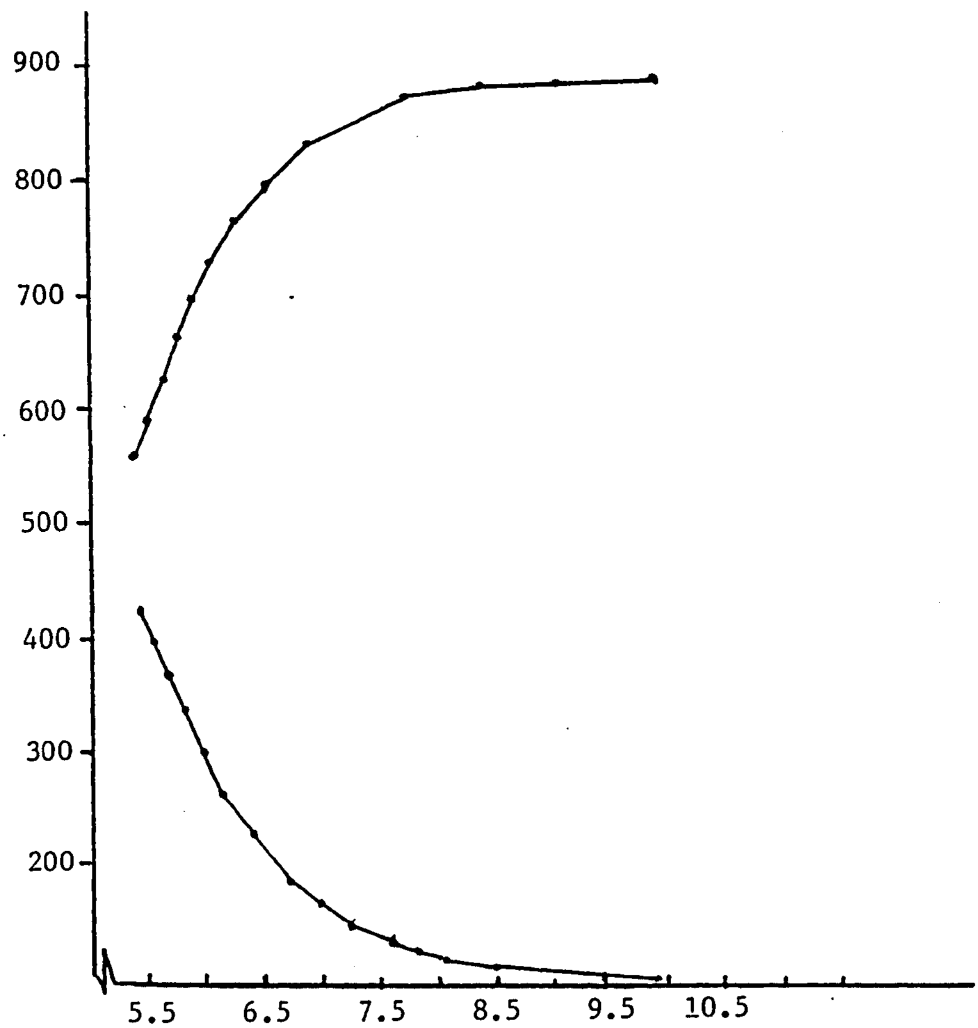

Figure 15. Profit and marginal profit curves for type 1 farm with constant damage

despite the large differences in number of treatments, total insecticide is fairly similar (9.93 pounds per acre for CD and 8.83 pounds per acre for VD).

Differences in profits, treatments and total insecticide use are all explained by the two divergent damage functions. Results with CD initially appear to more closely approximate the actual crop-pest conditions. However, this is because of the simplifying assumptions used in that model (e.g., constant per insecticide damage over the growing season and a .9924 percent kill).

The first significant aspect which affects insecticide quantity, and, therefore, profits is the number of insecticide treatments (refer to Table 19). Constant damage utilizes 9 sprayings, the first treatment appearing at 15.5 days as opposed to VD with 2 spraying and the initial treatment at 46.67 days. Treatment at 15.5 days implies a smaller pest population which in turn implies less initial insecticide (4.51 pounds). Subsequent treatments require relatively small amounts of insecticide (.67 pounds) due to a low pest population with constant damage. Variable damage initiating treatment at 46.67 days (or just before damage begins at square emergence on the forty-eighth day), implies a much larger pest population necessitating more initial insecticide (6.41 pounds). By destroying the population before cotton damage occurs, only one additional treatment of 2.42 pounds per acre is required to maximize profits. This occurs on the ninety-third day.

The second significant aspect affecting insecticide quantity and profits are the differences between the two damage curves. Constant per insect damage, across the growing season, as assumed by Talpaz and

Borosh, is less than the sum of the three variable damage functions developed in this study. Greater damage to cotton translates directly to a larger per treatment amount of applied insecticide.

From the information provided above, an important result emerges. Assuming that the incorporation of variable damage into the economic model more closely approximates actual cotton growing conditions, it becomes clear that, if farm profits are to be maximized, recommendations on the number of insecticide treatment should stress fewer amounts.

CHAPTER 6

SUMMARY AND MODEL LIMITATIONS

Utilizing two farm sizes, a comparison of the efficiency costs due to imposition of a tax and standard is analyzed. In addition, the results of incorporating into a methematical model a variable damage function as opposed to an instant damage function is considered.

An objective of this study has been to show the different impacts on profits for smaller and larger farms due to the accessibility of volume discounts for the larger farms. Results showed little difference in farm profits, specifically, the larger farm realized a $2.26 per acre gain over the smaller farm. There are two primary reasons for this small difference. First, in themathematical model, only insecticide use determines the profit differential between farm sizes. Secondly, by assuming variable damage in the model, optimal insecticide applications are limited to two per acre thereby directly reducing tota quantities of insecticide per acre.

Unrestricted insecticide use allowed optimal levels of 8.83 pounds per acre for the smaller farms and 8.91 pounds per acre for the larger farms. Imposing a standard restricts insecticide use to 8.25 pounds per acre. Associated profit losses under a standard are $1.68 per acre for the smaller farm (-0.2 percent) and $2.08 per acre for larger farm (-0.25 percent), or a total profit loss of $3.72 per acre for the two farms. In addition, the $3:72 per acre is also the cost of imposing the standard. The efficiency cost (the cost of implementing the standard minus the cost of imposing a tax) of the standard is $2.22 per acre for the two farms.

A tax reverses the distribution in costs and insecticide use. The smaller farm now loses a larger percentage change in profits (2.95 percent) whereas larger farm loses 2.73 percent. With a tax, the larger, more efficient producer is allowed to use more insecticide per acre (8.29 lb/acre) than the smaller farm (8.21 lb/acre). Since a tax is the criterion for evaluating efficiency, it has a zero efficiency cost, however, the loss in profits for each farm with a tax is much greater than with a standard.

When comparing constant versus variable damage, overall differences are summarized in the varied profits and marginal profits for a particular farm size, for this case, smaller farm. Profit differentials on the smaller farm are just over 5 percent between the two damage functions (a difference of $43.21/acre). Optimal insecticide treatments for constant damage are 9 while optimal treatments for variable damage are only 2. Constant damage sprayings occur every 15.5 days as opposed to 46.67 days for variable damages. Spraying on the Day 47 implies a large insect population which necessitates a larger quantity of insecticide for the initial treatment (6.41 lb/acre). Insecticide quantity for the initial spraying with constant damage is 4.51 pounds per acre. Subsequent treatment requires relatively small amounts of insecticide.

Another significant aspect affecting insecticide and profits are the differences between the two damage curves. Constant, per-insect damage over the 140 physiological days is less than the total of the variable damage of fruiting forms developed in this study. For the optimal solution, a greater per-insect damage necessitates a larger per-treatment quantity of insecticide, which in turn affects the level of profits.

Model Limitations

Talpaz and Borosh (1974) presented a multiple treatment pest control model. A kill function is estimated using a hypothetical distribution of pest tolerance to methyl-parathion. Frequency of application and quantities of insecticide are selected by way of mathematical-numerical optimization. Maximization of profits are the criterion for selection of number and quantity of insecticide applications.

The model as presented appears to provide reasonable information. When used as a base for this study, significant problems emerged when applying the model to actual crop-pest conditions. Five basic limitations restrict the applicability of this model.

First, the kill function estimated by Talpaz and Borosh used for this study, permits survival rates to fall below those achieved in the real world. This low survival rate is the result of applying infeasible amounts of insecticide (4-6 pounds active methyl-parathion per acre for initial treatment compared to current recommended 1 pound (University of Arizona Cooperative Extension Service, 1979). Levels of insecticide recommended by the model's optimal solution would cause severe damage to the crop-pest eco-system and to the local environment.

Second, there is no feedback loop that relates plant damage to insect growth. The model as used in this study does not limit insect population growth to available food supplies. If insecticide treatments are not initiated frequently and in sufficient quantity, insect population levels expand to levels that exceed available cotton fruiting forms. The third limitation is the simplifying assumption of constant damage in the original model. The combination of constant damage and low survival rates lead to the greatest amount of damage which always occurs in the time period before the initial spraying. Use of the more realistic variable damage function (where no damage occurs until square emergence) may result in a very low, initial damage. This condition occurs if the first application of insecticide comes before the onset of damage. The surviving pest population (according to the model's optimal solution) is so low that damage is at an unrealistic level of approximately five pounds per acre.

Fourth, the inability to constrain the quantity of insecticide after the first application is also a limitation. The definition of the survival rate for the treatments subsequent to the first is equation (9):

$$Z = e^{-r\,T/n},$$

which follows from the assumption that the pest level is reduced to the same level after each treatment. This makes it impossible to place internal constraints on the quantity of insecticide per application, after the first treatment within the current model structure. Amounts of insecticide after the initial spraying are independent of Z (survival rate after the initial spraying) which is fixed once the number of treatments are fixed.

Fifth, the constrained conditions for timing of applications currently in the model permits no strategy for timing of insecticide sprayings except intervals of equal length in physiological days.

Distributive Considerations

This analysis compares the costs to farm firms and benefits to society of restricting insecticide levels under a standard or taxing strategy. Long-run effects of these costs are considered. In studying the analysis, a number of items should be considered. First, that profits in this study refer to net returns above variable costs, where variable costs include only insecticide costs, setup costs, and harvest costs. All other production costs are assumed to be sunk costs. Secondly, all factors considered (profits, insecticide levels, and application rates) are the result of incorporation of a variable damage function into the model. Model results are significantly different when utilizing a constant damage function. Finally, it is assumed there is no substitutability of insecticides. Therefore, the cases examined represent the "worst" case a farm producer might encounter.

Because in this study profits are strictly a function of insecticide levels, profit differentials between farm sizes are small. Specifically, larger farm realized an increase in profits of $2.26 per acre over smaller farm, or a percentage gain of 0.27 percent. With the difference in profits so small for the two farms, advantages due to economies of size are negligible and therefore do not affect long-run farm survival.

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Table 21 presents the relevant information to compare effects of a standard and a tax on the two farm types. A distinction should be made between the imposition cost of a tax or standard and the efficiency cost shown in Table 21. A tax does not have an efficiency cost because the tax is the least cost way of implementing a control. However, the tax does have an implementation cost. A tax is cost efficient because it maximizes net benefits to society (i.e., the revenue from the tax is returned to society). In this case, benefits are a function of insecticide levels. As the quantity of insecticide increases, benefits also increase for the crop producer, but only up to the point where too much insecticide is applied and diminishing returns occur. Eventually, if large overdoses of insecticide are applied, harm can occur to the cotton plants causing negative returns to insecticide inputs. The tax seeks the optimal quantity of insecticide where the marginal benefits equal zero. At this point the net benefits of insecticide use are a maximum.

A standard does have an efficiency cost in addition to the cost of imposing the control measure, which is derived by subtracting the cost of levying a tax from the cost of imposing a standard. Since the nature of a tax is to be least-cost, the tax becomes the criterion for measuring other regulatory methods. Both the efficiency cost and imposition costs are effective ways to analyze regulatory actions.

Referring again to Table 21, the costs of restricting insecticide to 8.25 pounds per acre, for each farm size under a standard is $1.67 for the Type 1 farm and 2.08 for the Type 2 farm. A tax allows

Table 21. A Comparison of the Benefits and Costs to Farms and Society Due to Restricting per Acre Insecticide Levels via a Standard and a Tax

Effects of Regulatory Action	Imposition Cost (per acre)		Insecticide Use (lb/acre)	
	Standard	Tax	Standard	Tax
Type 1	$ 1.67	$24.61	$ 8.25	$ 8.21
Type 2	2.08	22.86	8.25	8.29
	3.75	47.47	16.50	16.50
Gain in Tax Revenue	0	-45.94	---	---
Total	$ 3.75	$ 1.53	$16.50	$16.50
Efficiency Cost	$ 2.22	0		

the Type 2 farm to use 8.29 pounds per acre at a cost of $22.86 per acre while Type 1 is restricted to 8.21 pounds per acre at a cost of $24.61 per acre. The total cost of implementing a standard is $3.75 for the two farms, which represents the cost of restricting insecticide use to 16.5 pounds for both farm sizes. A tax, on the other hand, realizes a total implementation cost of $1.53 for the two farms while restricting total insecticide use equivalent to that of the standard (16.5 pounds). By subtracting the imposition cost of the tax from that of the standard, the efficiency cost of implementing a standard is derived ($2.22 per acre for Type 1 and 2 farms). Since a tax is the most efficient control method, the tax has a zero efficiency cost. In summary, both control actions restrict total insectivide use equally. However, the standard does so at an efficiency cost of $2.22 per acre while the tax has a zero efficiency cost.

Essential characteristics are now exposed for the two regulatory actions. The standard reduces insecticide levels equal to that of a tax. It imposes a relatively small cost to each farm size, yet has the attribute of inefficiency, specifically at $2.22 for Types 1 and 2 farms. A taxing strategy realizes no efficiency cost in reducing insecticide use, produces an additional "benefit" to society in the form of tax revenue ($45.94 from the two farms), yet does so at a cost to the farms in the form of significant, per acre profit reductions. Such large profit losses may adversely affect the long-run survival of both the large and small farms.

Decision makers must decide between imposing an inefficient standard with relatively small effects to farm sizes, or the efficient tax, which generates revenue but also heavily penalizes both farm sizes. Before any such decision could be made, basic economic questions should first be analyzed.

First of all, how shall the policy be carried out? Should it be an across the board regulation in which all farms are equally restricted in the use of the insecticide in question? Perhaps the location of the farm to busy urban areas, water supplies, or important wildlife refuges should be considered. Why restrict a farm community which does minimal damage? Also, to be considered, is the economic impact due to the regulation as far as production losses in important agricultural commodities is concerned. This could have significant tradeoff considerations--less chemical pollution, but at what cost? Should control measures vary by geographic regions? A taxing scheme implemented where few insecticides are used will not have the same impact as one implemented with the use of intensive agricultural on control measures. Political feasibility may be jeopardized but the economics may justify such an action. What about "marginal" farms? If this forces them out of business, should they be given special consideration? Should production efficiency always be the criterion for a firm's existence?

Today, more than ever, it has become apparent that regulatory actions are directly affecting the survival of businesses of all types in our "free market" economy. Chemical restrictions can be seen as another of these control measures that will affect long run farm survival. Consumers are concerned for their welfare as longer run consequences of science and technology begin to emerge. This concern is valid, but care must be taken to avoid over-reaction, obstructing the hand that feeds us. America's agricultural production is unmatched in the world today, yet if regulations are implemented without careful considerations, irreversibility could significantly affect future food supplies. Already prime agricultural lands are being transformed into business, urban, and industrial areas. If the need arises, how easily could these areas be reverted back to agricultural production? Chemical restraints may be seen as another catalyst in restricting farm output. Our desire for "safe" production methods should be encouraged, in all areas, including the farm, but the decisions should be made only after careful deliveration as totheir long-term affects on the agricultural producer and to society as a whole.

CHAPTER 7

CONCLUSION AND FUTURE RESEARCH NEEDS

Two basic objectives are analyzed in this research. The first compares the efficiency costs large and small farms would likely experience under a taxing strategy or the imposition of a standard with a variable damage function. The second contrasts the effects of incorporating a variable damage function into the economic model with the constant damage function used by Talpez and Borosh.

Both the tax and the standard reduce total insecticide use to 16.5 pounds per acre for the two farms. However, distributional differences exist when comparing profits and insecticide use between farms. A standard restricts insecticide use for each farm size equally (8.25 lb/acre) while the tax allows the large farm to use more insecticide (8.29 lb/acre) than th- smaller farm (8.21 lb/acre). This is due to the efficiency effects of a tax, which equates across marginal cost curves.

An efficiency cost exists with a standard ($2.22 per acre for both farms) in addition to an implementation cost of $1.53 per acre. A tax realizes only an implementation cost. However, a tax has a much larger effect on farm profits, despite the fact that the two control actions restrict insecticide use equally. Farm Type 1 loses $24.61 per acre due to a tax while experiencing only a $1.67 per acre loss in profits from a standard. Farm Type 2 loses $22.86 per acre from a tax and only $2.08 per acre due to a standard. Tax revenues account for the majority of the costs experienced in the small and large farms.

Taking into account that the standard and tax reduce insecticide levels equally, decision makers should choose between the efficient tax, which significantly affects farm profits for both farm sizes, and the less efficient standard, which costs the farmer much less and will therefore have reduced long-run implications to farm firm-survival (a standard does necessitate the need for monitoring farm use of insecticide, a cost not experienced with a tax, and no considered in this study).

A comparison modeling results of using constant and variable damage functions in the economic model produces significant differences in profits, insecticide levels, and optimal application rates between the two. Analysis betweeen large and small farms shows little differences, therefore, comparisons were restricted to the small farm.

When changing from constant to variable damage, profits increase $43.81 per acre for the small farm or just over a 5 percent increase in profits. Comparison of the profits and marginal profit curves show that the model using variable damage function is more responsive to insecticide levels than is the model which utilizes a constant damage function. This response is primarily due to the low number of sprayings that occur with a variable damage function. Assuming that variable damage function more closely approsimates real world conditions for crop producers, suggests that farms tend to spray more frequently than is actually required if per acre profits are to be maximized.

Future research is needed in a number of areas. As specified in this study, the only costs considered are insecticide costs, setup costs and harvest costs, which produce profits in excess of those that would be experienced in real-world cotton production. Incorporation of additional production costs such as labor, fuel, water, herbicides, defoliants, fertilizers, and ginning, should be included into the economic model.

The model itself is based on a dynamic framework. To more closely approximate actual crop-pest dynamics, the biological model could include insect resistance to insecticides, and the affect of insect migration on insect populations.

Additional field data on insect damage, effects of actual insecticide treatments on insect populations, and the relationship of these variances to crop yields would be helpful. Such data requires close cooperation between plant scientists, university entomologists, and county extension agents. By using more actual field data, empirical results could be of more worth to decision makers and to crop producers.

APPENDIX A

THE RPAR PROCESS

Recently there has been growing concern over the potential environmental impacts of pesticide use. Due to this increased interest the Environmental Protection Agency (EPA) was assigned, under the 1972 FIFRA (Federal Insecticide, Fungicide, & Rodenticide Act) the task of re-registering all pesticides. The process developed for this purpose became known as Rebuttable Presumption Against Registration (RPAR). Specifically, RPAR was formed to save chemical company's time and money by not placing their products on the re-registration list, unless a reasonable chance of their failure to pass the specified standard existed.

There are four basic procedures to the RPAR process:

1) Pre-RPAR review - if one or more studies of proven scientific worth finds a pesticide compound environmentally hazardous, that compound will be published in the RPAR list of the Federal Register.

2) Rebuttal Period - a 45 day rebuttal period is provided for the registrant or any other interested party. Rebuttal is based on invalid scientific study or studies, or that exposure effects are not as described. In addition there is an initial listing of the compounds benefits for the purpose of risk/benefit analysis.

3) Risk/Benefit Analysis - compiled data on the risks and benefits of the compound are submitted to the EPA which in turn is given to the USDA for review. Simultaneously USDA Assessment Teams provide information on the number of acres treated, efficacy of treatment, conditions of use and alternative compounds. All of this data is given to an EPA working group to decide if:

   a) all or some uses should be registered/re-registered

   b) cancel all or some uses

   c) suggest the restriction of the pesticide

4) External Review - the provisional decision along with all compiled data are sent to the USDA and the EPA Scientific Advisory Panel for review. The panel's recommendation is sent to the EPA administrator who makes the final decision. The decision, along with the EPA and USDA comments are published in the Federal Register. If some pertinent group feels the final decision is faulty, a public hearing may be requested.

APPENDIX B

DEFINITION OF TERMS

Abort	To fail to develop completely after fertilization
Acid delinting	Removal of linters from cottonseed after ginning, by use of sulfuric or other inorganic acid.
Anther	The upper sac-like part of the stamen containing pollen.
Axil	A point at the base of the angle between a leaf or branch and the stem from which it arose.
Boll	A fruit of a cotton plant containing seed and lint.
Bract	A modified leaf that subtends a flower.
Bud	A structure containing an undeveloped leaf, flower, or stem.
Calyx	Chlorophyll bearing structure of the flower. In cotton the five sepals are fused together (making a five-lobed calyx).
Carpel	In cotton, one unit of a compound pistil.
Cell	A miscroscopic unit of structure in the plant containing protoplasm surrounded by a cell wall.
Cellulose	Carbohydrate that is the principal constituent of lint and linters. Also major component of cell walls.
Chalaza	The place in an ovule or seed from which the integuments diverge.
Convolutions	Turns or twists of a lint fiber that occur after opening of mature boll.
Cotyledons	First leaves developed by the embryo, sometimes called seed leaves.

Cross-pollination	Transfer of pollen from one plant to the stigma of another.
Cultivar	Group of individual plants within a species that differ in certain characters from others within the species.
Defolination	Removal of leaves from a plant.
Dormant	A period in the life of a seed plant or plant part when physiological activities are slowed to a minimum.
Embryo	Young plant within a seed. Produced from a fertilized egg within an ovule.
Emergence	In cotton, appearance of arched hypocotyl above soil surface.
Epicotyl	The part of the embryo or young seedling above the cotyledons.
Epiderman hair	An outgrowth of an epidermal cell.
Epidermis	Outer layer of cells.
Fertilization	(1) The union of male and female gametas. (2) Application of elements or compounds to the soil to provide nutrients for plants.
Filament	The part of the stamen that supports the anther.
Flower	Reproductive structure of a seed producing plant.
Gamete	Male or female reproductive cell.
Germination	Early growth and development of the embryo.
Ginning	Removal of lint from the seed.
Glandular hair	An outgrowth of a specialized epidermal cell.
Hull	See Seed Coat.
Hypocotyl	Part of seedling between the radicle and the cotyledons.
Integument	A covering of the ovule that later becomes part of the seed coat.
Internode	That part of a stem or branch between two nodes.

Lateral root	Root that develops from the tap root.
Lint	Epidermal hair of a cottonseed.
Linters	Short lint fibers remaining on seed after ginning.
Lipid	Fatty acid stored in cottonseed.
Lobe	Part of cotton leaf blead.
Lock	The seed and lint produced in a carpel.
Locule	Compartment in ovary.
Meristem	Undifferentiated thin walled cells that may develop into specific plant parts.
Mesophyll	Cells containing chlorophyll in the interior of a leaf. Such cells may be elongated and in a compact layer (palisade parenchyma) or loosely arranged with many intercellular spaces (spongy parenchyma).
Mote	Fertilized ovule that has failed to mature.
Microphle	Opening in the integuments through which the pollen tube passes.
Morphology	The study of the structure of plants.
Node	A slightly enlarged place on a stem (joint) from which buds arise. Place from which leaves and branches have their origin.
Ovary	Enlarged part of pistil containing the ovules.
Ovule	The part of a flower containing the female sex cell that usually develops into a seed after fertilization.
Palisade parenchyma	See Mesophyll
Petal	Showy part of cotton flower surrounding pistil and stamens. Collectively the petals (five) are corolla.
Pistil	The stigma, style and ovary of the flower.
Pollen grain	Male sex cell produced in anther.
Pollination	The transfer of pollen from anther to the stigma.

Protein	One of the classes of organic compounds. Composed of amino acids.
Radicle	Rudimentary root of the embryo. Located below hypocotyl.
Saline	Soil containing excessive amounts of soluble salts.
Seed	Mature ovule.
Seed Coat	Outer layers of cells surrounding the embryo.
Self-pollination	Transfer of pollen from anther of a given plant to stigma of any flower produced on the same plant.
Sepal	See Calyx.
Shedding	Loss of squares, flowers or bolls from the plant.
Soul compaction	Condition that exists when soil is densely packed or massed firmly.
Species	Subgroup of a genus having one or more characters in common by which they may be differentiated from other species.
Spongy parenchyma	See Mesophyll.
Spur	Short, stubby shoot.
Square	Unopened cotton flower bud together with surrounding bracts.
Stamen	The anther and filament of the flower.
Staminal column	Structure surrounding the style from which stamens develop and are supported.
Staple	Length of cotton fiber.
Stigma	The uppermost part of the pistil that receives pollen at pollination.
Stoma	An opening in the surface of a leaf that permits passage of gases and water vapor. Plural - stomata.
Style	The part of the pistil between the stigma and the ovary.

Tap root	A single primary root from which lateral roots develop.
Transpiration	Evaporation of water from a living plant, primarily through stomata.
Variety	See Cultivar.
Vascular bundle	Specialized cells that function in the transport of liquids in roots, stems and leaves.

REFERENCES

Adkisson, P. L., J. R. Brazzel, and J. C. Gains. "Yield and Quality Losses Resulting from Pink Bollworm Damage to Cotton." Austin Texas Experiment Stations, MP-632, 1963, 8 pp.

Arizona Crop and Livestock Reporting Service. Arizona Agricultural Statistics, 1978. Phoenix, Arizona, 1979.

Baumol, W. J., and W. E. Oates. The Theory of Environmental Policy. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1975.

Brazzel, J. R., L. D. Newsom, J. S. Roussel, C. Lincoln, F. J. Williams, and G. Barnes. Bollworm and Tobacco Budworm as Cotton Pests in Louisiana and Arkansas. Louisiana Technical Bulletin No. 482, 1953.

Briggs, R. E., and L. L. Patterson. Written communication. Cotton Research Center, Phoenic, Arizona, 1979.

Buxton, D. R., L. L. Patterson, and R. E. Briggs. "Fruting Pattern in Narrow-row Cotton," Crop Science, Vol. 19, (Jan-Feb.) 1979, pp. 17-22.

Finney, D. J. Probit Analysis, Ed. 2. Cambridge, Mass., Cambridge University Press, 1952.

Hall, D. C. and R. B. Norgaard. "On the Timing and Application of Pesticides." American Journal of Agricultural Economics, Vol. 55, No. 2, pp. 198=201, May 1973.

Huber, R., Personal communication. Department of Entomology, University of Arizona, Tucson, 1979.

Hueth, D., and Uri Regev. "Optimal agricultural pest management with increasing pest resistance." Am. J. Agri. Econ., vol. 56, pp. 543-552.

James, M. L., G. M. Smith, and J. C. Wolford. Applied Numerical Methods for Digital Computations with FORTRAN and CSMP, Ed. 2. New York, Harper & Row, 1977.

Kincade, R. T., M. L. Laster, and J. R. Brazzel. "Damge to Cotton by the Tobacco Budworm." Jour. Econ. Entomology, Vol. 60, 1967. pp. 1163-1164.

Knipling, E. F. "Some basic principles in insect population suppression. Ent. Soc. America Bull., Vol. 12 (March), 1966, p. 7-15.

Lucas, Kenneth. "Heat Units, Synthetic Budworm Attractant Tested in State This Years." Farmer-Ranchman, Vol. 58, No. 5, 1979, pp. 6-14.

National Oceanic and Atmospheric Administration. Local Climatological data. National Weather Service, Sky Harbor International Airport, Phoenix, Arizona, 1978.

Shoemaker, Christine. "Optimization of agricultural pest management. III. Results and extensions of a model." Mathematical Bioscience, Vol. 18 (Oct), 1973, pp. 1-22.

Stults, H. M. Predicting farmer response to a falling water table: An Arizona case study. Unpublished Ph.D. dissertation, University of Arizona, Tucson, 1968.

Talpaz, Hovav, and Itshah Borosh. "Strategy for Pesticide Use: Frequency and Application." Amer. Jour. Agri. Econ., Vol. 56, No. 4, 1974, P. 769.

Tollefson, Scott. A Study of the Biology and Ecology of Larval, Pupal, and Adult Stages of the Tobacco Budworm. M.S. thesis, University of Arizona, December 1979.

U.S. Bureau of the Census. Arizona State and County Data, In 1974 Census of Agriculture, Vol. 13, Part 3, 1977.

U.S. Department of Agriculture. Regional Cotton Variety Tests, 1972. ARS-S-62, 1975.

U.S. Department of Agriculture, Economic Research Service. "Farmer's Use of Pesticides in 1972. Agriculture Economic Report No. 252, 1975.

U.S. Department of Agriculture, Economic Research Service. "Farmer's Use of Pesticides in 1976." Agriculture Economic Report No. 418, 1978.

U.S. Soil Conservation Service. General Soil Map, Pinal County, Arizona. Portland, Oregon, 1971, 2 sheets.

U.S. Soil Conservation Service. "Water Supply Outlook for Arizona, 1977-1978." Phoenix, Arizona, 1977.

University of Arizona Cooperative Extension Service. "1979 Insect Pest Management for Cotton." Bull, Q 11 R, 1979, p. 4.

University of Arizona Cooperative Extension Service and Agricultural Experiment Stations. "Growth and Development of the Cotton Plant in Arizona." Bull. A-64, December 1969, p. 25.

University of Arizona Council for Environmental Studies. "Results of Arizona Pesticide Sales Survey, 1973-1978." College of Agriculture, Tucson, Ariz., 1978.

Van Steenwyk, R. A., G. R. Ballmer, and H. T. Reynolds. "Relationship of Cottom Boll Age, Size, and Moisture Content to Pink Bollworm Attack," Jour. Econ. Entomology, Vol. 69, No. 5, 1976.

Watson, T. F., and D. G. Fullerton. "Timing of Insecticidal Application for Control of the Pink Bollworm." Jour. Econ. Entomology, Vol. 62, No. 3, 1969, pp. 682-685.

Watson, T. F., D. T. Langston, E. B. Jackson, and D. G. Fullerton. "Pink Bollworm Suppression through Crop Termination." Jour. Econ. Entomology. Vol. 71, No. 4, 1978, pp. 638-641.

Watson, T. F., and M. C. Sconyers. "Comparison of Insecticide Application Schedules for Control of Cotton Insects." Jour. Econ. Entomology, Vol. 58, No. 6, 1965, pp. 6-7.

Werner, Floyd, Leon Moore, and Teho Watson. "Arizona Cotton Insects." University of Arizona Cooperative Extension Service, Bull. A23 R, 1979, 16 pp.

38

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