AN EVALUATION OF THE ENVIRONMENTAL IMPACTS FROM PESTICIDE USE:

APPLICATIONS TO U.S. COTTON AND TOMATO PRODUCTION

by

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(Under the Direction of Jeffrey C. Mullen)

ABSTRACT

The multidimensional impacts of pesticides to consumers, farm workers, wildlife, and the environment are now an important component in policy decisions regarding agricultural production. In the quest for sustainability and safety in agriculture, various indices have been developed to help understand the hazard posed by pesticides to the various environmental components. We use the EIQ developed by Kovach et al. (1992) to estimate the overall hazards from pesticides and the pesticide impacts to workers, consumers, beneficial arthropods, birds, fish, and bees, using two case studies.

Case Study I addresses impacts from pesticides used in U.S. cotton production for the years 1981/84, 1992, 1997, and 2002 for all cotton-producing states. We estimate these impacts using the overall EIQ rating and the seasonal environmental impacts (SEI) based on total pounds, pounds per harvested acre, and pounds per treated acre. The results in this case study indicate that impacts using both EIQ ratings and SEI showed higher declines between 1997 and 2002 than between the earlier study years. The SEI results are uniform irrespective of the insecticide application rate measurement used. The main differences among them are in magnitude.

Case Study II focuses on the hazards from fumigants proposed as methyl bromide alternatives for tomatoes in Florida. The search for alternative fumigants has been ongoing since the 1991 Montreal Protocol that classified methyl bromide as an ozone depleting substance and destined it for phase-out. We determine the least toxic choice of these alternative fumigants based on their environmental impacts. Our findings indicate that Midas@98:2 is the least toxic alternative, and Telone II + Vapam is the second least toxic. Among environmental categories, workers and beneficial arthropods are the most impacted by both cotton pesticides and tomato fumigants. On the other hand, fish are the least affected by alternative fumigants, followed by consumers. Considering cotton insecticides, the least impacted categories vary by states among consumer, fish and birds.

INDEX WORDS: Pesticide use, Environmental Impacts, Environmental categories, Environmental Impact Quotient, Seasonal environmental impact, Fumigants, Methyl bromide

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DEDICATION

To the Almighty, for making this possible

and

To my Children, Alice and William

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INTRODUCTION

1.1 Background

1.1.1 Chemical use in Agriculture

A wide array of chemicals exists in agriculture and these include fertilizers and pesticides. A pesticide, according to The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) [7 USC 136] is "any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insects, rodents, nematodes, fungi, or weeds, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant." The three main categories of pesticides are herbicides, fungicides and insecticides. Pesticides have contributed much to the growth in agricultural productivity and food supply.

Pesticides are designed to target a specific pest in a specific environment, without harming other organisms. Unfortunately, pesticides are designed to kill organisms that happen to share many biochemical pathways and physiological processes with non-target species in the agro-ecosystem, including animals and humans. The biological commonalities make it difficult to develop pesticides that have ample margins of safety between the pest species and non-target organisms (Sexton et al., 2007). Since the full/total costs of pesticide application often are not borne exclusively by the farmer or firm that makes the application decision, economic theory suggests pesticides will be used in excess relative to the level preferred by society (Sexton et al., 2007). This only exacerbates the non-target effects.

The use of chemicals has greatly helped to alleviate crop losses and improve crop quality in the last several decades. Humans started using pesticides to prevent damage to their crops since before 500 BC. Since that time, crop damage from pests has been managed in a relatively effective and inexpensive manner by synthetic pesticides. Chemical-based strategies have been the preferred form of pest control in agriculture since the 1950's, when they contributed to an unprecedented growth in agricultural production and productivity (Pimentel, 1978, 1991; Pimentel and Greiner, 1997). Starting in the 1970's, however, the on-farm benefits started to be weighed against concerns over the off-farm costs of pesticide risks to human health and the environment (Travisi et al., 2006). The dangers to pesticide use were brought to the limelight with publication of Rachel Carsons' 1962 *Silent Spring*. Since then, there has been continued decline in total pesticide use, especially in the 21st century.

The discovery of chemical use is one of the greatest innovations in agriculture. Technological innovations, however, tend to result in effects and outputs other than the ones intended. These are called externalities. There are many types of externalities in agriculture. Economists use the term "externality" to describe a harmful or beneficial side effect that occurs in the production, consumption, or distribution of a particular good. Due to a lack of biophysical data and the complications involved in valuing most externalities, most studies do not include a detailed assessment of environmental impacts. As a result, some qualitative assessments are very often made in empirical impact studies.

One problem is the market model, the dominant approach to evaluating agricultural impacts, can lead to overestimation of benefits if a large proportion of the output is not marketed or if poor infrastructure results in high transaction costs. Furthermore, costs can be underestimated if the technology produces negative effects on the environment and natural resources. On the other hand, an underestimation of benefits can occur if the technology produces positive environmental and natural resource management impacts, which have not been included in the market effects (Waibel 2006). Growing concerns of land degradation, deforestation and loss of biodiversity have led to an increase in the importance of environmental impact assessments (EIA) in agriculture.

The market system is a powerful, relatively inexpensive, self-adjusting and responsive mechanism for resource allocation. Still, market failures will occur when the price mechanism fails to come up with the social optimum in resource allocation. Environmental impacts may be subject to market failure because of their public-good nature, or because of the absence of complete and coherent property rights. Public goods are those for which exclusion of potential users (beneficiaries) is difficult if not impossible, and the use by one individual does not diminish the availability for others (ADB 1999). These impacts are also dislocated in time and space, making cause and effect difficult to establish (Dixon and Pagiola 1998).

In general, markets do not exist for chemical use externalities in agriculture, which creates a rationale for government intervention to institute corrective strategies that will lead to higher social welfare. One corrective strategy in the event of such market failure is that governments have the legitimate role of instituting pesticide use regulations or imposing taxes. These can alter incentives in the marketplace so that participants will make optimal societal decisions. The Environmental Protection Agency (EPA) is in charge of pesticide use regulations.

Effective pesticide policy is, however, made difficult by a variety of characteristics of the externalities, including the multidimensionality and temporal and spatial heterogeneity of damages, the diffuse and non-point source nature of pesticide pollution, information asymmetries, and monitoring costs (Sexton et al. 2007). This multi-dimensionality makes quantifying health and environmental improvements from pesticide use quite complex in that no single parameter can perfectly represent the environment. This, therefore, makes it hard to capture the magnitude of the effects in one measure (Bonabana-Wabbi and Taylor, 2008). Impacts on environmental and human health increase the social cost of pesticides beyond the private cost facing the farmer.

The harmful effects from pesticide use have widely been identified throughout the literature to include: toxicity to humans and animals (health effects), environmental effects (water, air and soil pollution, harm to non-target insect pests - mainly beneficial biological soil organisms), and pest resistance leading to use of even more toxic pesticides. Sagar (1991) also identified secondary pest outbreaks, loss of desired pesticide effects, target pest resurgence, and phyto-toxic effects as additional pesticide effects. More specifically, the environmental contamination from pesticides ranges from the disruption of natural water, air and soil functions to the alteration of the ecosystem resulting in detrimental affects on nutrient cycles, or the toxicity of non-target organisms. These effects have been categorized by The Scientific and Technological Options Assessment-STOA (1998) into four main risk groups: occupational (worker safety problems) and consumer (food safety issues) human health, environmental quality and biodiversity, and water resources.

The environmental pollution and human health risks associated with chemical pesticide applications presented a strong case for policy intervention to achieve pesticide-use levels acceptable to society (Sexton et al., 2007). In response to these concerns, farmers began to adopt alternative practices with the goals of reducing input costs, preserving the resource base, and protecting human health. These concerns of risk posed by extensive pesticide use have motivated the development of alternative programs being promoted and incorporated into national agricultural policies in many countries around the world. The three main alternatives to pesticide use, of which several versions exist, are;

1) Organic farming – a technique that aims to enhance the health of the agro-ecosystem by prohibiting the use of synthetic pesticides and instead encouraging cultural practices like composting, crop rotations, and conservation tillage techniques.

2) Integrated pest management (IPM) – a technique that utilizes various biological, physical, and chemical control and habitat modification techniques with the intent to minimize economic, health and environmental risks. IPM works by avoiding routine spraying, but instead depends on scouting for pest problems before deciding to spray.

3) Sustainable agriculture – an integrated system of plant and animal production practices having a site specific application that will, over the long term, satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of non-renewable and on-farm resources, and integrate where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations, and enhance the quality of life for farmers and society as a whole (Congress in the 1990 Farm Bill).

There is no universal definition of IPM in the literature. Several definitions exist, but all address basically the same principle. That is, IPM is a range of management styles within the spectrum of pest management regimes. Weibers (1992) defines the spectrum to encompass such practices as; (a) scheduled application of pesticides, (b) monitoring systems (the use of pesticides applied at economic thresholds), (c) monitoring systems in combination with cultural control and expert systems, (d) “organic farming” (cultural, biological control and expert systems), and (e) “philosophical agriculture”. The University of California State-wide Integrated Pest Management Project (IPMP) defines IPM as;

> *An ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial, and non-target organisms, and the environment* (UC IPM online).

The U.S. Environmental protection Agency (EPA) defines IPM as;

> *An effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices where current, comprehensive information on the life cycles of pests and their interaction with the environment is used in combination with available pest control methods to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment. IPM programs take advantage of all pest management options possibly including, but not limited to, the judicious use of pesticides* (U.S. EPA Fact Sheets).

USDA on the other hand defines IPM as;

> *An ecologically based approach to pest (animal and weed) control that utilizes a multi-disciplinary knowledge of crop/pest relationships, establishment of acceptable economic*

thresholds for pest populations and constant field monitoring for potential problems. Management may include such practices as "the use of resistant varieties; crop rotation; cultural practices; optimal use of biological control organisms; certified seed; protective seed treatments; disease-free transplants or rootstock; timeliness of crop cultivation; improved timing of pesticide applications; and removal or 'plough down' of infested plant material" (Waldron, 1989 p. 1).

The key element of IPM, therefore, is to observe the effects of pesticides to the agro-ecosystem (i.e., the conditions of the plants, the soils, the air, populations of pests and natural enemies, etc.).

Environmental issues are now at the heart of agricultural production. In the U.S., Congress has passed legislation intended to improve air and water quality, protect endangered species, protect human and animal health while assuring continued productivity. Agricultural chemicals now face greater regulation, and those associated with environmental degradation face even more harsh regulation (restricted use) or prohibition. A good example of prohibited chemicals is methyl bromide, used as a pre-plant soil fumigant, mainly in tomato and strawberry production.

1.1.2 Pesticide Risk

Impacts from pesticide use are normally defined in terms of health risks and / or environmental degradation due either to increased contamination of soil and water resources, reduction in farmland diversity, and loss of natural habitats (Florax et al. 2005). Increased awareness about these risks has led to heightened campaigns for environmental sustainability and food safety. Such campaigns have led to advocacy for growing organic food, minimize pesticide use through the use of Integrated Pest Management (IPM), resulted in new policy instruments, such as eco-labelling of fresh produce (Govindasamy et al. 1998; Blend and van Ravenswaay 1999), more stringent rules and regulations by the U.S. Environmental Protection Agency (EPA) governing proper use of pesticides, and pesticide taxes (Swanson 1998; Mourato et al. 2000; Pearce and Seccombe-Hett 2000).

1.2 Economics of Pesticide Use

All agricultural activities impact the environment, and thus there is need for well defined property rights for sustainability. A property right is an exclusive privilege to use an asset (Perloff, 2001). According to neoclassical economics, well defined property rights ensure that an owner benefits exclusively from use of the property and wholly incurs the costs of use. Unfortunately, the costs of agricultural impacts are external to agricultural systems and markets for the final products, and thus affect the whole society (individuals and communities who are not involved in production decision making) (Tegtmeier and Duffy, 2004). This indicates a case of poorly defined property rights leading to market failures and economic inefficiencies. Because these effects occur outside the marketplace, they are called externalities. Many externalities have the characteristic of a public good (or bad), where consumption by one individual does not preclude others from consuming it (Perloff, 2001). Externalities that affect public goods, for example pesticide effects, are of greater policy interest because there are fewer defensive activities available to the victims (Tegtmeier and Duffy, 2004). To correct for market inefficiencies with regard to pesticide use, government intervention in the form of pesticide regulation is employed in an effort to ameliorate the externality costs.

Pesticide use results in both positive and negative effects. The positive effects or benefits relate to the rate at which pesticide use enhances yield, thereby increasing total production and lowering consumer prices. The magnitude of these benefits depends upon the rate at which increases in pesticide use can enhance yield – pesticide productivity. Negative effects or costs refer to costs imposed on society from pesticide use. Similar to general production, pesticide use entails both private and externality costs (Zilberman and Millock, 1997). Private costs are the costs borne by the producer in pesticide and other input purchases and application, and correspond to the area under the marginal private cost curve (MC^P), the private supply curve (Figure 1.1). Under perfectly competitive market conditions, these are equivalent to the value of resources employed in the manufacture and distribution of the pesticides. Externality costs refer to the negative effects of pesticide use, in particular, health and environmental effects, and correspond to the area under the marginal externality cost curve (MC^E), the externality supply curve (Figure 1.1). In the competitive equilibrium, producers consider only their private costs in making decisions and ignore the harm they inflict on others. Society considers both the costs of the externality and the costs of producing the output, resulting in the social marginal cost curve, MC^S . The height of the social marginal cost curve (society supply curve, MC^S) at any given quantity of output then equals the vertical sum of the MC^P and MC^E (Perloff, 2001).

Economics can be used to inform both private and public decision makers about trade-offs in the use of pesticides and other pest control strategies (Sexton et al. 2007). Much of the pesticide economics literature has focused on determining when pesticide use improves social welfare. Economic theory states that the social optimal input (pesticide) usage level is where the societal marginal costs equal the societal marginal benefits. The difference between the social and private optimal input use levels normally lead to the need for pesticide use regulation in an effort to minimize or eliminate the externality costs and reconcile the social and private costs. Optimal private (Q^P) and social (Q^S) pesticide use occur where the marginal private and marginal social cost curves intersect the demand curve (DD), respectively (Figure 1.1). Welfare is maximized where price equals to the social marginal cost curve but not to the private marginal cost curve. Market optimization results in the private optimum, Q^P, while welfare maximization results in the social optimum, Q^S. Consumer and producer surplus are then represented by areas A and $B+F$ at the social optimum, and by areas $A+B+C+D$ and $F+G+H$ at the market equilibrium.

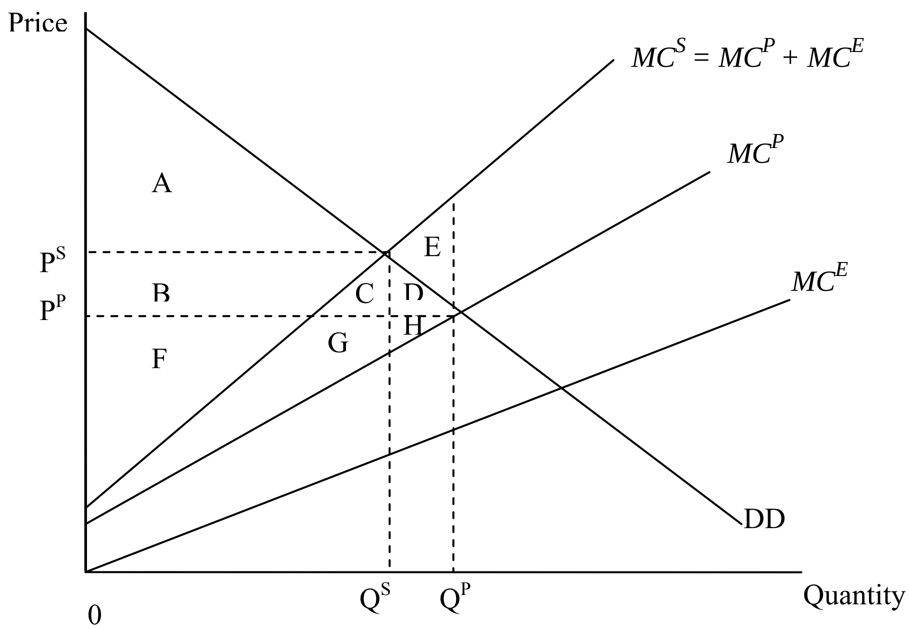


Figure 1.1: Welfare and Market Optimal Output with Externality Cost

1.2.1 Pesticide Regulation

As society has become more aware of pesticide risks, pesticide regulation has had to shift its focus from efficacy and labeling (the federal government's focus), to pesticide manufacturing, use, and disposal. Regulation of pesticides in the United States is based almost entirely on the direct effects on health and the environment (Knutson, 1999). U.S. pesticide regulation is governed by two major laws: the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). The two laws evolved from two earlier pieces of legislation: the Federal Insecticide Act of 1910 and the Federal Food and Drugs Act of 1906 (Toth, 1996). FIFRA regulates the use and sale of pesticides, while FFDCA controls the amount of pesticide residues allowed in food (food safety concerns) (U.S. EPA). Both laws require manufacturers to register every pesticide with the Environmental Protection Agency (EPA).

FIFRA gives EPA authority to require manufacturers to provide appropriate supporting chemical, toxicological, environmental, and residue studies and labels specifying active ingredients, dosage and concentration for each registered pesticide. FFDCA, on the other hand, gives the EPA the authority to establish the legal limits for pesticide residue in or on food and feed. Worker safety is regulated by the Worker Protection Standard (WPS). This gives requirements for who can apply pesticides, protective measures for workers handling pesticide treated crops, and sets minimum re-entry time after pesticide application. The Safe Drinking Water Act (SDWA) overseas water quality concerns by establishing maximum containment levels for polluting chemicals (Zilberman and Millock, 1997).

To register a pesticide, the EPA must evaluate data provided by the manufacturer and approve a label and a Material Safety Data Sheet (MSDS) for the pesticide. The label and MSDS contain information on product chemistry, physical and chemical characteristics, aquatic and wildlife toxicology, plant and re-entry protection, non-target insect toxicity, environmental fate, residual chemistry, and spray drift. They therefore provide farmers and the public with general, technical, risk and safety information about pesticides. They also serve as the legal notice of approved uses and rates (U.S. EPA).

1.2.2 Pesticide Productivity

Pesticides have been used in agriculture for centuries, but the health and environmental hazards of pesticide residues were not well known until the publication of *Silent Spring* by Rachel Carson. Her publication captured the attention of both scientists and the general public. Agricultural pesticides have since been increasingly recognized for their adverse effects. In response to these recognitions, several studies have attempted to model pesticide externalities into agricultural production analyses. Modeling these effects is, however, complicated by the multidimensionality and heterogeneity of pesticide use (Zilberman and Millock, 1997). Heterogeneity of pesticide use refers to differences in pesticide impacts that can arise from location of pesticide use, application technology (air or ground), or re-entry time after application. Multidimensionality, on the other hand, arises due to the multiple targets of pesticide use: workers (worker safety problems), consumers (food safety issues), water (surface and ground), animals (mammals, birds, bees) and beneficial arthropods.

Pesticides are classified among damage control agents or inputs. Damage control inputs do not directly increase yield, but ensure maximum potential output is realized by reducing damage caused by damage agents (pests) (Lichtenberg and Zilberman, 1986). Hence, their effectiveness depends on pest pressure. Due to this characteristic, it is not straight forward to account for the effects of damage control inputs like direct yield increasing inputs in the production function (Kuosmanen et al. 2006). For a conventional input set, X, the marginal physical product depends on its direct relationship with output, Q, which can be represented implicitly in a production function as $Q = F(X)$. In estimating the productivity of damage control inputs, you have to account both for the effects of the damage agents, *Z*, acting through the damage function *D*(*Z*), and the effects of the damage control input, *T*, acting through the control function, *C*(T). The productivity of damage control inputs should be defined in terms of their contribution to abatement services (Lichenberg and Zilberman, 1986). Hence, the marginal product of *T* depends on both the damage and control functions (Fox and Weersink).

1.3 Production economics

1.3.1 Optimization in Agricultural Production

In order to address environmental pesticide impacts, we first give a discussion on some basic production economics concepts, including optimal input use, profit maximization, and environmental externalities. Agricultural production is basically an optimization process, involving minimizing costs and or maximizing profit. Production entails determining the optimal input level for the profit maximizing output. This is represented using a production function, which expresses the relationship between the profitable amounts of output that can be realized at different levels of input for a given production technology (Wetzstein, 2005). Assuming perfectly competitive input and output markets, one variable input, *T* (pesticides), and one output, *Q*, the production function can be represented as, $Q = f(T)$. This assumes the other inputs are at their optimal levels, and hence, can be ignored in this representation. Our focus is on environmental impacts from pesticide use; hence we shall not dwell on specification issues. In the cotton case study, we consider all the cotton growing states, so that a change in output will result in a change in output price. In the tomato study, Florida is the top fresh market tomato producing state, hence, changes in its output level will affect fresh market tomato prices in the U.S. Price is therefore a function of output, $P(Q)$.

Other variable inputs in both cotton and tomato production include: labor, fertilizer, machinery, irrigation and weather variables. Assuming these inputs are at their optimal level, uncertainty in output arises from weather variables; say rainfall, temperature or both, and pest pressure. Pest pressure is also influenced by weather variables. Since pesticide use depends on pest pressure, realized output can be considered as a combination of potential output (due to conventional inputs), losses from pest damage. Following Lichtenberg and Zilberman (1986), output can be represented explicitly as:

$$Q = G(X, C(T))$$

For profit maximization, the first order conditions (F.O.C.) with respect to pesticide level must be satisfied, thus;

$$\max_{X,T} \pi = P(Q)Q[X, C(T)] - P_T T - P_X X$$

where π, $P(Q)$, P_T and P_X denote profit, output price (a function of output), pesticide price and price of other inputs, respectively. Assuming an infinitesimal change in other inputs due to a change in pesticide use, $\frac{\partial X}{\partial T} \approx 0$

$$\frac{\partial \pi}{\partial T} \equiv P(Q)\left[\frac{\partial Q}{\partial C} * \frac{\partial C}{\partial T}\right] - P_T = 0, \qquad \left[\frac{\partial Q}{\partial C} * \frac{\partial C}{\partial T}\right] = \frac{\partial Q}{\partial T} = MPP_T$$

$\equiv P(Q)MPP_T - P_T = 0$, MPP_T is the marginal physical product of T

$\equiv VMP_T = P_T$, VMP_T is the value of marginal product of T.

The F.O.C imply that for profit maximization, the optimal input level should be where the value of each additional unit of input (VMP_T) equals the input price (P_T), Figure 1.2 (b). This corresponds to optimal private input level T^* which yields optimal output Q^*, Figure 1.2 (a). This optimizing process so far does not account for externality effects of input use, hence corresponds to the producers production decisions.

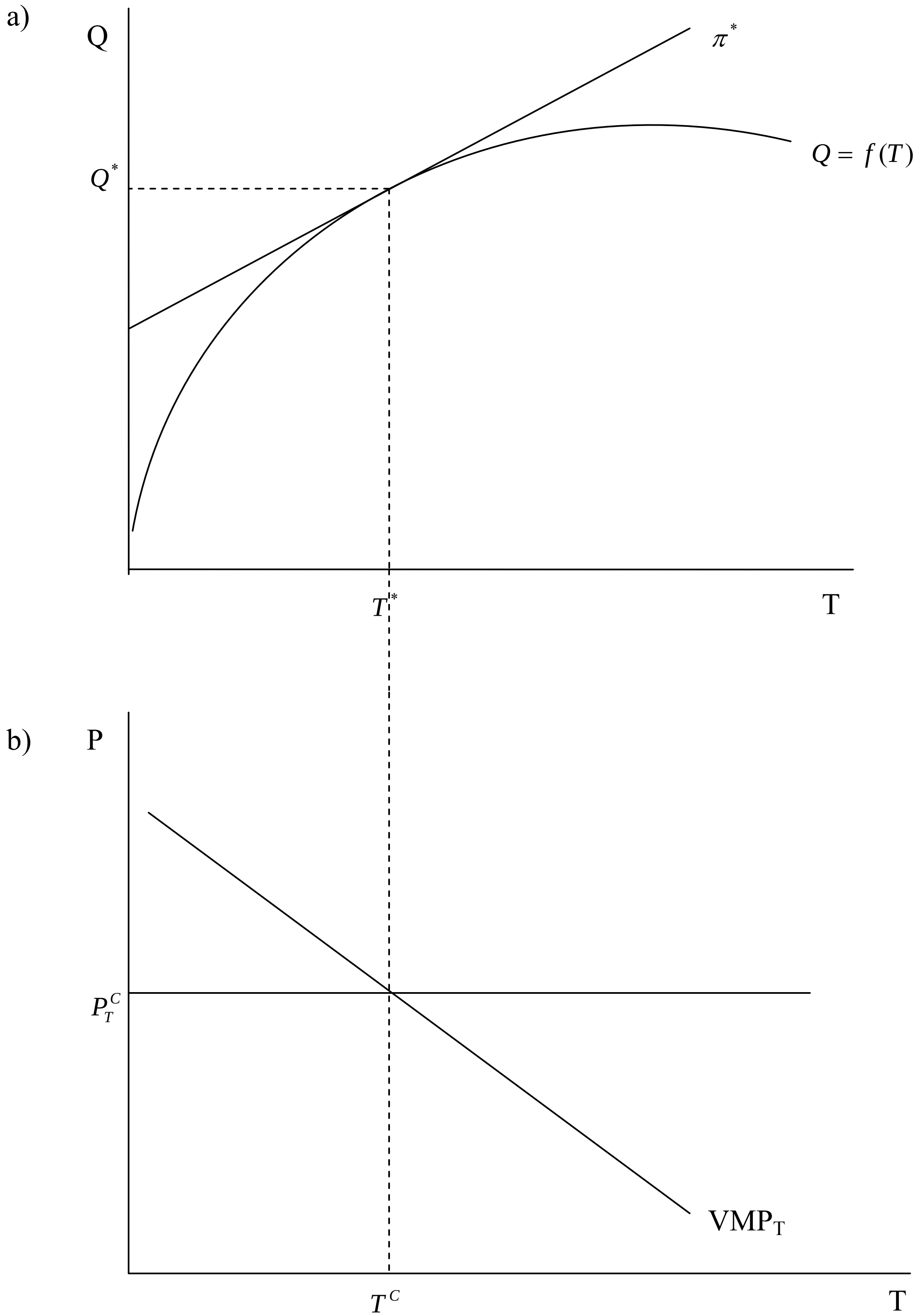


Figure 1.2: Perfectly Competitive Profit Maximization FOC in Input Market

1.3.2 Optimization with Externalities

Externality effects from pesticide use accrue negatively to society, resulting in a reduction in social welfare. The private optimization decisions illustrated above indirectly result in negative externalities, which are, therefore, a function of *Q*. If we assume the externality is *E*, then the externality function will be, $E = g(Q) = g[f(T)]$. The optimization process now entails choosing the input level to maximize profit and minimize the externality, thus:

$$\max_T \pi = P(Q)Q - P_T T - E - F$$

$$= P(Q)Q - P_T T - g(Q) - F$$

F.O.C. with respect to input level, *T* is now

$$\frac{\partial \pi}{\partial T} \equiv P(Q)\frac{\partial Q}{\partial T} + Q\left(\frac{\partial P}{\partial Q} * \frac{\partial Q}{\partial T}\right) - P_T - \left(\frac{\partial g}{\partial Q} * \frac{\partial Q}{\partial T}\right) = 0$$

$$\equiv MPP_T\left[P(Q) + Q\left(\frac{\partial P}{\partial Q}\right)\right] - P_T - g_Q * MPP_T = 0,$$

where $P(Q) + Q\left(\frac{\partial P}{\partial Q}\right)$ is the new output price, and $Q\left(\frac{\partial P}{\partial Q}\right)$ is the change in price due to *T*.

Let $g_Q * MPP_T = g_T$, then

$$\frac{\partial \pi}{\partial T} \equiv VMP_T - P_T - g_T = 0$$

$$\equiv VMP_T = P_T + g_T$$

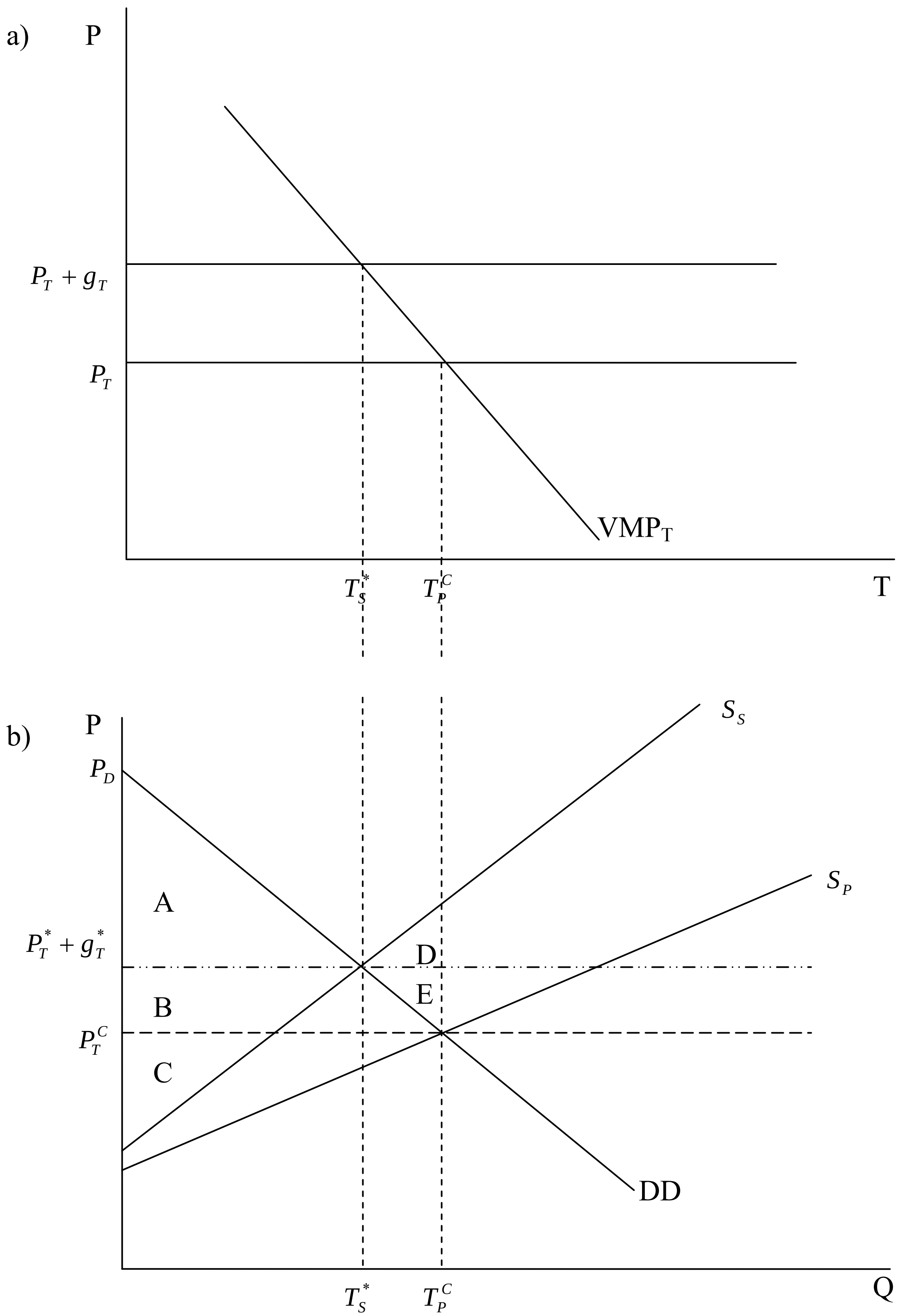


Figure 1.3: Externality Effects on Social Welfare

This results in a new optimal output level T_S^* where $VMP_T = P_T^* + g_T^*$. Social welfare corresponding to this new output level is area $A + B + C$, where area $B + C$ is producer surplus and area A is consumer surplus. Area $D + E$ is the cost due to the externality, which is deadweight loss (Figure 1.3).

The strategy to reduce pesticide use effects, either through reducing application rates or applying less toxic pesticides, is aimed at reducing this deadweight loss and increasing social welfare. In our current study, the boll weevil eradication program in cotton and the methyl bromide phase-out in tomato production were aimed at achieving this objective. The ultimate intended effect is to achieve a shift to the right, in both the social and private supply curves, to S_S^1 and S_P^1 respectively. The costs due to the externality translate into benefits as positive shifts in the supply curves.

1.4 Problem Statement

Concerns over environmental and health effects from pesticide use have been at the forefront of policy decisions in agriculture since the advent of the Green Revolution. Agricultural production decisions have now to be made with positive and negative effects of pesticide use in mind. Efforts to curb pesticide overuse have included stringent regulations, banning some pesticides, imposing pesticide taxes, recommending less toxic alternatives, integrated pest management, and reducing application rates and number of applications. Such efforts led to development of the boll weevil eradication program in cotton to help eradicate the boll weevil, which was responsible for increased use of pesticides and secondary pest outbreaks. This resulted in banning of some very toxic pesticides and use of alternatives requiring low application rates. Similar efforts resulted in a phase-out of the broad spectrum fumigant, methyl bromide. In response to the phase-out, several alternatives have been proposed for use in various crops. For these reasons, this study focused on evaluating the environmental impacts from cotton pesticide use since the inception of the Boll Weevil Eradication Program, and the impacts of the proposed methyl bromide alternatives for Florida tomatoes.

1.5 Objectives

This study analyzes the impact of pesticides in U.S. cotton production and Florida tomato fumigation. The main objective was to determine if the cotton industry has experienced an improvement in pesticide impacts since the beginning of the BWEP, if the proposed fumigants perform better than methyl bromide, and to highlight the components of the environment most affected by these pesticides. Specifically, the research objectives are;

1. To identify pesticides used in U.S. cotton production since the early 1980's and the alternatives proposed for methyl bromide in tomato production.
2. To estimate overall and environmental component impacts from pesticide use in U.S. cotton production to determine the change in impacts with the boll weevil eradication program.
3. To estimate overall and component environmental impacts of alternative fumigants to methyl bromide in tomato production in Florida.

1.6 Organization of Study

The dissertation consists of six chapters. This current chapter addresses some introductory aspects of pesticide use in agricultural production. This chapter also outlines the problem statement and objectives of what we propose to do. Chapter 2 gives a review of previous studies that have estimated impacts from pesticide use. These studies are summarized and limitations pointed out. Chapter 3 presents the methodology that is employed in estimating the environmental impacts. Chapter 4 and 5 are Case Studies, focusing on a subject as outlined in the last two objectives. Chapter 4 addresses the estimation of environmental risks from pesticides used in U.S. cotton production to six environmental categories for the periods: 1981-84, 1992, 1997, and 2002. This chapter investigates the trend in impacts from The Boll Weevil Eradication Program. Chapter 5 considers the environmental impacts from the Methyl Bromide phase-out program in Florida tomato production. This is achieved by comparing the impacts between methyl bromide and its proposed alternatives. Finally, chapter 6 gives a summary and concluding remarks from the research.

CHAPTER2

LITERATURE REVIEW

2.1 Pesticide Impact Determination Issues

External costs of pesticide use refer to the costs of damage imposed on society and the environment due to using pesticides in agricultural production but that are not accounted for in the market price either through the cost of pesticides or the price of agricultural products. The lack of markets for health and environmental services means that, unlike man-made products, they are not explicitly priced, so their monetary values cannot be readily observed. Several methods have been used in assigning an economic value to pesticide impacts. Such methods include: remediation cost, lost productivity, and willingness-to-pay to avoid pesticide risk. Willingness-to-pay, which is commonly used, does not measure the existence or extent of an environmental problem, rather it measures the attitude toward a problem, and whether the problem bothers a particular stakeholder enough to pay for an alternative (Levitan et al., 1995).

Accurately determining the actual damages of pesticide use is always difficult, due to the high cost of monitoring and measuring the extent of such damages. Despite these difficulties, an extensive empirical economic literature now exists on pesticide risk valuation. Previously, environmental impacts of pesticide use were commonly proxied through variables such as pounds of active ingredient (a.i.) applied or dollars spent on pesticides (Brethour and Weersink, 2001). The disadvantage, according to Brethour and Weersink (2001) is that both these measures assume environmental damage is directly correlated with the quantity of pesticide used, regardless of the specific chemical and formulation. As Stenrød et al. (2008) point out, the increased availability of low-dosage alternatives make the argument more clear that weight and volume measures are not adequate proxies for assessing pesticide risk.

2.2 Impact Studies

Several studies have looked at the various aspects of pesticide use. Some have evaluated the economic impacts from pesticide use; others have looked at the benefits of pesticide use, and others have evaluated reductions in pesticide risks. Some of the studies that reiterate the importance of pesticides include Knutson et al. (1990), who examined pesticide benefits in terms of the possible effects on the U.S. society of a hypothetical complete ban of herbicides, insecticides and fungicides. They concluded that farming in the U.S. without chemical inputs would lead to reduced yields and hence high prices, reduced exports of grain and cotton, and will also affect incomes.

Helmers et al. (1990) looked at pesticide effects in terms of the resource use and production that would be expected over a 4-6 year period of restricting the use of chemical inputs. They found that U.S. agriculture could adjust (mainly in the labor and other non-chemical inputs) to a reduction in the use of chemicals without causing significant reductions in farm production, or major changes in prices and other performance indicators, and that market prices would rise only modestly. Some other estimates indicate that losses to pests would increase to ten percent if no pesticides are used at all and crop losses would range from zero to nearly 100 percent (Pimental et al., 1992). Other studies (Buzby et al., 1995; Roosen et al., 1998) have looked at the reduction or banning of a specific pesticide compound. Buzby et al. used willingness-to-pay (WTP) to estimate the benefits of banning sodium ortho-phenyphenate

(SOPP), a post harvest pesticide that was used in Florida fresh market grapefruit packinghouses. They found that benefits of banning SOPP far outweighed the costs.

Studies abound in literature on the evidence of health and environmental risks associated with chemical exposure. Pesticide use effects are known to be multidimensional, which poses measurement issues (Travisi et al., 2006). For this reason, most of the earlier studies measured the impact of pesticide use on the environment in qualitative terms: risk of human and animal exposure to toxic chemicals; preserved species diversity; reduced runoff and leaching potential, hence less ground and surface water contamination; reduced fish poisoning and preservation of beneficial insects (Bonabana-Wabbi and Taylor, 2008). Progressively, however, studies have emerged that have quantified and even valued these impacts.

An example is Kovach et al.'s widely known Environmental Impact Quotient (EIQ) study, which expressed the impact of pesticides on the environment by scoring their effects on a set of environmental categories (Kovach et al., 1992). EIQ is a model that transforms the environmental impact information of pesticide active ingredients to a single value. The environmental impact was determined based on the effects of the active ingredient on the three principal components of agricultural production systems: a farm worker, a consumer, and an ecological component. The EIQ assigned a number to the active ingredient (a.i.) based on 11 characteristics of the ingredient, although they did not assign an economic value to the differences in EIQ's.

Using EIQ numbers, Kovach was able to compare impacts on the environment of different pest management options (based on the amount of active ingredients in pesticide formulations), with small numbers indicating less impact on the environment, even though weights across categories were arbitrary, and no monetary values were associated with these impacts. To evaluate the impacts of a pesticide-use reducing program on the environment, the changes in health and the environment have been expressed in monetary terms using non-market valuation techniques. Expressing benefits in monetary terms is a convenient means of expressing the relative values that society places on different uses of resources.

Most of the studies have focused on valuing the human health effects, especially for farmers and consumers. Such studies include: Misra et al., 1991; Ravenswaay and Hoehn, 1991a,b; Baker and Crosbie, 1993; Eom, 1994; Pingali et al., 1994; Crissman et al., 1994; Antle and Pingali, 1994; Buzby et al., 1995; Govindasamy and Italia, 1997, 1998; Roosen et al., 1998; Thompson and Kidwell, 1998; Blend and Ravenswaay van, 1999; Fu et al., 1999; Wilson, 2002. Wilson (2002) was more concerned with health risks to farmers. Relatively fewer studies have looked at the environmental / ecological effects / impacts of pesticide use: Higley and Wintersteen, 1992; Kovach et al., 1992; Beach and Carlson, 1993; Mullen et al., 1997; So¨derqvist, 1998; Lohr et al., 1999; Foster and Mourato, 2000; Brethour and Weersink, 2001; Cuyno et al., 2001; Schou et al. 2002.

Brethour et al. (2001) and Mullen et al. (1997) analyzed the non-market benefits of a program of Integrated Pest Management (IPM) using a consumer survey in the U.S., and Ontario, Canada, respectively. Owens et al. (1998) and Cuyno et al. (2001) studied farmers' WTP for reducing the negative effects of pesticides in the U.S. and in the Philippines, respectively. All these studies valued changes in integrated pesticide risk management on the environment in addition to acute and chronic human health toxicity for farmers. These studies valued environmental effects of pesticides, considering health as one of several environmental categories. They all used contingent valuation to obtain the willingness-to-pay to reduce pesticide risks. Respondents had to value their WTP in a sequence of scenarios for the different environmental and human health categories. Similarly, Foster and Mourato (2000), and Schou et al. (2002) analyzed environmental and human health pesticide use risks, but used contingent ranking techniques to determine WTP to reduce human health effects and loss to farmland diversity.

Cuyno et al. (2001) used an approach that looked at both the health and environmental benefits from using IPM. They assigned the risks posed by specific pesticides (they considered 44 pesticides) applied to onions in the Central Luzon region of the Philippines by assigning one risk level for each active ingredient for each environmental category. They categorized the environment into impacts to humans (chronic and acute health effects), mammalian farm animals, aquatic species, birds and beneficial insects. They then used these risk levels to calculate an eco-rating score for each active ingredient and environmental category, with and without IPM.

The difference between with and without IPM scores was used to represent the amount of risk avoided due to using IPM (or benefits). To value these benefits, they obtained willingness-to-pay (WTP) to prevent those risks through a survey of onion farmers in the region. The economic benefits per person were then obtained as the product of percent reduction in risk due to using IPM and the WTP value. They found that using IPM practices on onions reduced the use of specific pesticides from 25 to 65 percent, depending on practice. They also found that estimated economic benefits varied from 231 to 305 pessos per person per cropping season.

Mullen et al. (1997) developed an approach for estimating the economic values of the environmental benefits of IPM using the Virginia peanut IPM program. Their premise was based on the fact that previous studies had just focused on assessments of the economic impacts of pesticide use on human health or environmental risks, economic benefits of IPM induced cost reductions or yield changes, but none had assigned an economic value to these impacts. They used eight environmental categories: groundwater, surface water, acute human health, chronic human health, aquatic species, birds, mammals, and arthropods, and developed risk levels for 130 pesticide active ingredients used in Virginia.

To determine the economic value of the IPM program, they obtained society's WTP (based on a U.S. national survey) to reduce the risks due to pesticide use, in addition to estimating the proportional changes in pesticide use induced by adoption of the IPM program. The advantage of their study is that all their WTP values and some of the risk levels for specific pesticide active ingredient can be applied to evaluation of IPM programs in other states. Their study estimated annual environmental benefits resulting from adoption of the peanut IPM program of about $844,000 for the eight southeastern Virginia counties that constituted the study area.

Brethour and Weersink (2001) followed an approach similar to Mullen et al. (1997) to value environmental benefits associated with changes in the levels and types of pesticides applied in Ontario agriculture from 1983 to 1998. They estimated the reduction in external costs from changes in pesticide use to be about US$ 188 per household. Higley and Wintersteen (1992) measured the value to farmers of avoiding environmental risks caused by pesticides by considering the risks to surface water, groundwater, aquatic organisms, birds, mammals, beneficial insects, and humans. Higley and Wintersteen (1992) and Mullen et al., 1997 differed from Kovach et al. (1992) in that they used eight criteria to characterize environmental risks in calculating the adjusted EIQ's.

CHAPTER 3

METHODOLOGICAL FRAMEWORK

3.1 Introduction

Environmental impacts/effects have first to be quantified and then valued in monetary terms before they can be included in economic analyses. Environmental implications become difficult to value when they do not pass through regular pricing mechanisms (the market). Many environmental goods and services do not enter markets, or do so only imperfectly. The difficulties this causes for valuation are compounded by the empirical limitation that available data are often scarce or of poor quality (Dixon and Pagiola 1998).

The economic literature offers two alternative approaches to environmental risk valuation: the human capital (HC) approach and the willingness-to-pay (WTP) approach. The former is more suited to valuing health effects, while the later can be used for both health and environmental risks. These methods are illustrated in Figure 3.1. The monetary value of a decrease in pesticide usage and the associated risks can be expressed as the aggregate individuals' willingness-to-pay for a pesticide risk reduction or, alternatively, the willingness-to-accept (WTA) a compensation for exposure to increased risk levels (Travis et al. 2006). This is based on the premise that the valuation in changes in pesticide risk will reflect the preferences of the economic actors exposed to the risk. The actors in this context are farmers, farm workers and consumers.

WTP values are normally obtained using Contingent Valuation Survey methods (CV) that have been suggested and applied as a means for valuing health and environmental effects (Higley and Wintersteen, 1992; Mullen et al, 1997; Cuyno et al., 2001; Brethour and Weersink, 2001). This general method has, however, received criticism, due to several potential biases including vehicle, strategic, hypothetical, starting point, and information biases (Bonabana-Wabbi and Taylor, 2008). This notwithstanding, WTP can provide information on the level of environmental protection and human health risk that is socially acceptable and within a cost-benefit framework, the expected level of potentially excessive costs in terms of both private and public expenditure (Travisi et al., 2006).

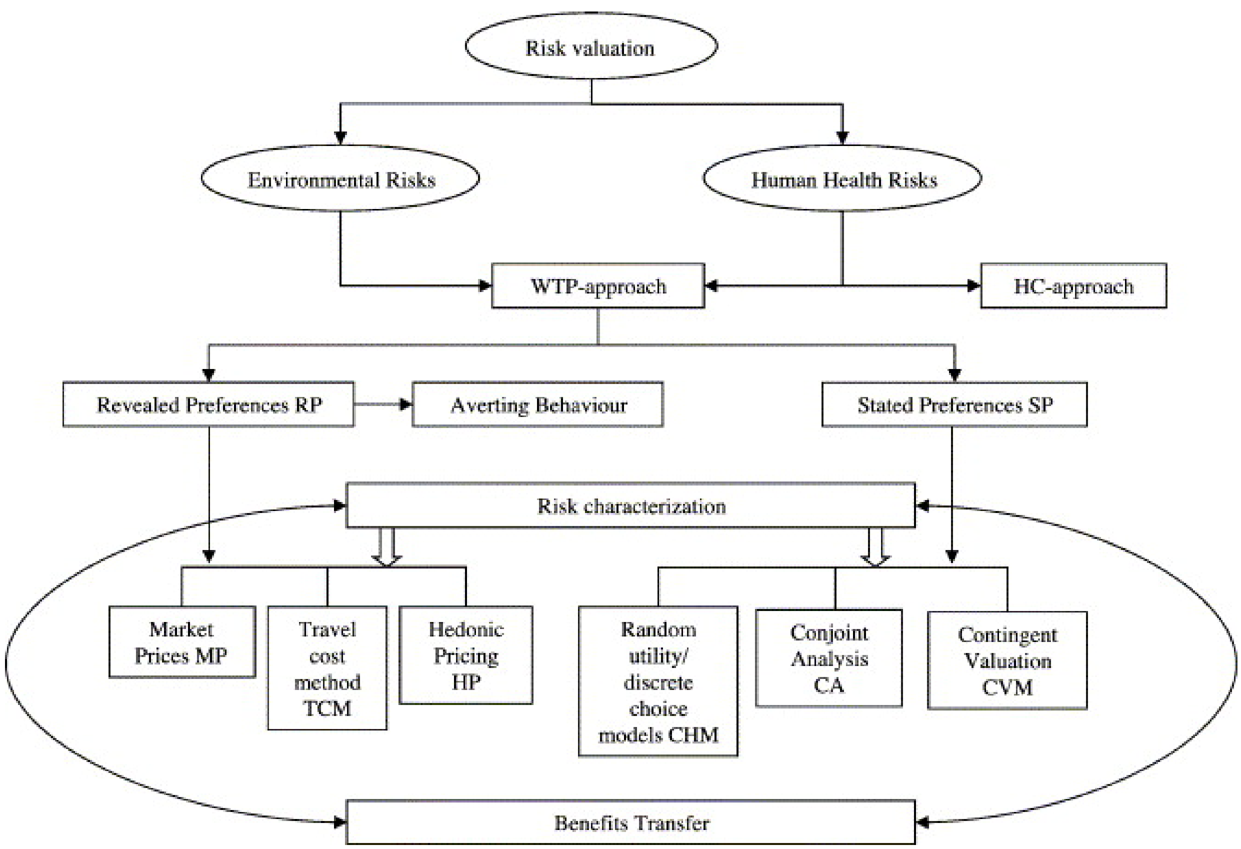


Fig.3.1. Available valuation techniques for environmental and human health risk changes (Adapted from Travisi et al., 2006)

To value environmental effects due to BWEP and MeBr phase-out, we followed the EIQ criterion proposed by Kovach et al (1992) to estimate pesticide impacts. Additionally, we used the environmental criteria similar to Mullen et al (1997). Thus, the valuation involved:

1) Categorizing the environmental impacts from pesticide use
2) Identifying pesticides used to control the weevil in cotton production before and after the BWEP, and, similarly, pesticides proposed as MeBr alternatives
3) Establishing the risk level for each pesticide active ingredient to each environmental category identified in (1) above
4) Estimating each pesticide's overall EIQ value and the EIQ to each environmental category
5) Estimating the total seasonal environmental impact for all pesticides used in each study year for each State, and determine the percent change in impacts between the study years.
6) Estimating the seasonal impact for methyl bromide and its alternatives to determine the least toxic choice.

3.2 Environmental Impact Categories

The nature and extent of pesticide impacts on the environment, on non-target species and human beings, vary to a great degree depending on their inherent chemical properties and the manner in which these chemicals are incorporated into the environment. The environmental behaviour (mobility and persistence) and toxicity profiles of most pesticides differ from each other too. Kleter et al. (2008) observed therefore that merely reducing the amount of pesticides applied to crops may not provide sufficient insight into their environmental impacts. Thus, even though pesticide risk to the environment is related to the amount of active ingredient applied, total pounds of active ingredient applied per year is not the best indicator of risk (Mullen et al., 1997). The interplay among these three factors, together with the degree of exposure of organisms to the chemicals dictates the degree of pesticide impacts. In addition, climatic conditions, soil properties, topography, and many other site-specific factors also influence pesticide behavior, consequently affecting risk and hazard levels (Cuyno, 2001).

To value pesticide risks, we used the EIQ approach proposed by Kovach et al (1992). This approach is quite popular and has been used by several authors to estimate impacts from pesticide use. It is attractive due to its simplified data requirements compared to the WTP approach. We used environmental categories similar to Mullen et al (1997). In their study they divided the environmental pesticide impacts into eight categories based on the non-target species and the natural environment affected into; acute human health, chronic human health, aquatic species, birds, other mammals, arthropods, groundwater, and surface water. This categorization accounts for the dual problem that a given pesticide is likely to pose different levels of risk or impact (j) to different environmental components ($i = 1,2,...8$) and, for a given environmental component, some pesticides will pose greater risks than others.

3.3 Cotton Pesticides and their Risk Levels

Due to the fact that cotton farmers used many of the pesticides present at the time for controlling the boll weevil**,** we used the entire list of pesticides used on cotton for the study years (Appendix Table A.1). To establish the risk level for each pesticide active ingredient to each environmental category, we first need to define the basis for rating pesticide impacts. Following Hornsby et al. (1996), pesticide impacts can be measured as the product of hazard (or toxicity level / rating or numeric index of toxicity) of the pesticide a.i. and the degree of exposure of the organism to the toxic substance. Pesticide impacts can be classified using qualitative categories: low, moderate, high, or using a numeric index: 1 to 5, where 5 is the highest degree of impact. Toxicity refers to the property of a chemical which causes damage to the body of a living organism and is normally measured based on toxicological and/or eco-toxicological thresholds.

3.4 Measuring toxicity and exposure levels

3.4.1 Toxicity

Toxicity with regard to human health is normally categorized as acute or chronic. Acute toxicity refers to exposure to a single dose of a toxin which produces symptoms within a short period of time after the exposure (Diane 2002). Acute toxicity can be scored / rated using either the EPA (Table 3.1) or WHO (Table 3.2) criteria. EPA criteria use signal words warning of dangers of acute toxicity on pesticides labels. These label signal words are based on a system which breaks pesticides into categories and specific ratings of toxicity. The specific ratings are described in terms of LD_{50}, which is the lethal dosage of a compound necessary to kill 50 percent of a population of test organisms (rats, mice, etc.) and eye and skin effects. The LD_{50} is assessed based on the mode of exposure, thus we have oral, dermal, and inhalation LC_{50}. The higher the LD_{50} rating, the lower the toxicity level. According to the WHO criteria, pesticides are grouped into 5 hazard categories using oral LD_{50} and dermal LD_{50} and, whether the pesticide formulation is in liquid or solid form.

Chronic toxicity is used to describe the potential long term effects which could result from exposure to small amounts of a toxin over time (Diane 2002). This type is scored based on tests for teratogenicity (deformities in unborn offspring), mutagenicity (permanent changes in hereditary material), and carcinogenicity (tendency to cause cancer) for each pesticide. The results from these tests can be classified as: “negative”, “no evidence”, “inconclusive”, “data gap”, “possible”, “probable” or “positive”. The EPA terms these classifications as Weight of Evidence (WOE) of carcinogenicity (Table 3.3). From results to these three tests, a pesticide can be rated as high risk if it has one or more “positive” outcomes, moderate if it has one or more “data gap”, “possible” or “probable”, and low risk if all three tests result in either “negative”, “no evidence” or “inconclusive” (Table 3.4). Chronic toxicity may impact different parts of the body than acute toxicity (Diane 2002).

Toxicity levels for aquatic species are rated based on LC_{50} / 96 hr, which is the concentration of a chemical (in mg/l or ppm) necessary to kill 50 percent of the organisms in a 96 hour test. LC_{50} / 8-day are used to measure toxicity levels for birds (avian species). Since toxicity data are not the same for all aquatic or avian species, the risk score for the aquatic and avian species category are determined by the highest level of risk a pesticide poses to any of the species in the category (Cuyno et al. 2001, Mullen et al. 1997). Beneficial insect’s toxicity levels are assigned following the same criteria as Mullen et al., 1997. Other mammals are rated using the same criteria as for human health. These toxicity ratings are shown in Table 3.5.

Pesticide risk levels for groundwater were classified as high, moderate or low based on the Pesticide Leaching Matrix developed by USDA’s Soil Conservation Service, and on Gustafson’s Groundwater Ubiquity Score, GUS (for pesticides without the pesticide leaching rating). The matrix assigns risks based on the soil leaching rating and on the pesticide leaching rating. GUS for each pesticide is given as:

$$GUS = \log_{10}(t_{1/2}^{soil}) \times [4 - \log_{10}(K_{oc})], \qquad (3.1)$$

where $t_{1/2}^{soil}$ is the soil half-life of the pesticide and K_{oc} is the pesticide’s soil adsorption index. Based on GUS, groundwater risks are assigned as low, moderate or high if $GUS < 2.8$,

$1.8 < GUS < 2.8$ or $GUS > 2.8$, respectively. Surface water risk levels were based on the Surface Runoff Matrix and for pesticides without this rating, the risk levels were evaluated based on three pesticide characteristics; water solubility, soil Koc and soil half-life, using U.S. EPA's 'red flag' values for these characteristics (Table 3.5).

3.4.2 Exposure Levels

The degree of potential exposure / exposure ratings for a particular species to an a.i. is determined by evaluating the mode of exposure. Exposure to pesticides normally occurs through: residues in food, groundwater and surface water contamination, air pollution, the frequency of chemical applications and mobility of species (Cuyno, 2001). The exposure level of beneficial insects is measured using pesticide plant surface residue half-life, and that for avian species is measured using both pesticide half-life in the soil and on plant surfaces. Half-life is defined as the time required for half of the chemical residue to lose its analytical identity whether through dissipation, decomposition, metabolic alteration or other factors. The levels for aquatic species are obtained using the runoff potential score. All these ratings are shown in Table 3.5. Table 3.6 gives a definition of the toxicity indicators used for various environmental categories.

Pesticide risk has no market value; therefore, some other mechanism has to be used to assign a value to pesticide risk in order to incorporate the risk in economic analysis. This mechanism is contingent valuation, which is a type of non-market valuation. The idea behind non-market valuation is that agents will assign a value (economic value) to a good or service based on their preferences or the utility derived from that good or service or the avoidance of that "bad", where the economic value of something is a measure of its contribution to human well-being. Put differently, the economic theory of value is based on the ability of things to satisfy human needs and wants or to increase the well-being or utility of individuals (Champ et al. 2003). Without the market to assign this value, therefore, each agent is assumed to be the best judge of how well off they are in any given situation. That is, each agent acts in self-interest and will rank alternative states based on their well-being in each state. The economic value obtained using contingent valuation is called willingness-to-pay.

Table 3.1: EPA Signal Words and Relative Risk Levels (Acute Toxicity)

Signal word	Relative Risk	Relative Toxicity Ranking	Oral LD_{50} (mg/kg)	Dermal LD_{50} (mg/kg)	Inhalation LC_{50} (mg/kg)	Eye Effect	Skin Effect
Danger, Danger/ Poison (I)	High	Highly toxic	≤ 50	≤ 200	≤ 0.2	Corrosive	Corrosive
Warning (II)	Moderate	Moderately toxic	50-500	200-2,000	0.2-2	Irritation for 7 days	Severe irritation
Caution (III)	Low	Slightly toxic	500-5000	2,000-20,000	2-20	Irritation reversible w/in 7 days	Moderate irritation
Caution (IV)	Non-toxic	Relatively non-toxic	>5000	>20,000	>20	No irritation	Mild, slight irritation

Adapted from Mullen et al. 1997

Table 3.2: WHO Acute Toxicity Classification of Pesticides by Hazard

Class	Hazard	LD_{50} for the rat (mg/kg body weight) Oral		Dermal	
		Solids	Liquids	Solids	Liquids
Ia	Extremely hazardous	≤ 5	≤ 20	≤ 10	≤ 40
Ib	Highly hazardous	5 – 50	20 – 200	10 – 100	40 – 400
II	Moderately hazardous	50 – 500	200 – 2000	100 – 1000	40 – 4000
III	Slightly hazardous	> 500	> 2000	> 1000	> 4000
IV	Unlikely hazardous	Not given			

Source: The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification, 2004

Table 3.3: EPA Carcinogenicity Classification Using Weight of Evidence (WOE) from Epidemiological and Animal Studies

Group	WOE of Carcinogenicity	Classification
A	Sufficient evidence in humans	Human carcinogen
B1	Limited evidence in humans	Probable human carcinogen
B2	Sufficient evidence in animals with inadequate or lack of evidence in humans	
C	Limited evidence in animals and inadequate or lack of human data	Possible human carcinogen
D	Inadequate or no evidence	Not classifiable as human carcinogen
E	No evidence in adequate studies	Not a human carcinogen

Source: Cuyno et al. 2001

Table 3.4: Assignment of Human Chronic Toxicity Risk Levels

Indicator / Classification of Test Results	Risk Level
Existence of one or more positive test results or conclusive evidence of teratogenicity, carcinogenicity, or mutagenicity	High
Data gaps, Possible, Probable evidence of teratogenicity, carcinogenicity, or mutagenicity	Moderate
Existence of negative test results, inconclusive results, or no evidence of teratogenicity, carcinogenicity, or mutagenicity	Low

Source: Cuyno et al. 2001

Table 3.5: Toxicity Rating Using Impact Scoring System

Impacts	Indicators	Score		
		High risk = 5	Moderate risk = 3	Low risk = 1
Human health				
Acute toxicity	Pesticide class (WHO criteria)	Ia: Ib	II	III
	Signal word (EPA criteria)	Danger/poison	Warning	Caution
Chronic toxicity	Weight of Evidence (WOE) of chronic effects	> 1 +ve conclusive evidence	Data gap possible probable	-ve inconclusive evidence
Exposure				
Leaching potential	Ground water ubiquity score	GUS > 2.8	0.8 > GUS > 2.8	GUS < 1.8
	Leaching potential score	High	Moderate	Low
Runoffs potential	Number of Red Flags exceeded for the ff:	> 2 red flags	1 red flag	0 red flag
	Soil adsorption (Koc)>300			
	Soil half-life > 21 days			
	Water solubility >30ppm			
	Surface loss potential	High	Moderate	Low
Air contamination	Henry's law constant			
	Place of Application	Aerial	Crop/soil surface	Soil
Food residues	Systemicity		Systemic	Non-systemic
	Time of application		Post-emergent	Pre-emergent
	Plant surface half-life	> 4 weeks	2-4 weeks	1-2 weeks
Aquatic species				
Toxicity	96h LC50 (fish) mg/l			
	Other aquatic species	> 10 ppm	1-10 ppm	< 1 ppm
Exposure	Runoffs potential score	High	Moderate	Low
Beneficial insects				
Toxicity	Beneficial effects score (BENE)	BENE > 50	25 < BENE < 50	BENE < 25
Exposure	Plant surface half-life	> 4 weeks	2-4 weeks	1-2 weeks
Mammalian farm animals (same as human health				
Birds				
Toxicity	Bird toxicity ratings	High/extreme	Moderate	Low
	8-day LC50	1-100 ppm	100-1000ppm	>1000ppm
Exposure	Soil half-life	>100 days	30-100 days	<30 days
	Plant surface half-life	> 4 weeks	2-4 weeks	1-2 weeks

Source: Cuyno et al. 2001

Table 3.6: Definition of Toxicity Indicators by Environmental Category

Environmental Category	Indicator	Definition
Acute human toxicity	Oral LD_{50} (mg/kg)	The orally ingested dose (number of mg of toxicant per kg of body weight) required to kill 50% of a large population of test animals
	Dermal LD_{50} (mg/kg)	The dose of a pesticide applied to the skin which kills 50% of the test population animals
	Inhalation LC_{50}	The concentration of a pesticide in air over a predetermined period of time that kills 50% of the test population animals
Chronic human toxicity	Weight of Evidence (WOE)	WOE of test results are classified with respect to the following levels: negative; no evidence; inconclusive, data gap, possible, probable, positive
	Carcinogenicity	The ability of the toxic substance to encourage the growth of cancer
	Teratogenicity	The ability of the toxic substance to cause deformities in unborn offsprings
	Mutagenicity	The ability of the toxic substance to cause permanent changes in hereditary material such as genes and chromosomes
	Other tests	Potential reproductive effects; Impacts on human organs; Sub-lethal effects
Aquatic Species	95-hr LC50 (mg/L)	The concentration of active ingredient that kills half of the test population within 95 hours
Beneficials	Beneficial Effect Score	The score is based on the EIQ developed by Kovach et al.; scores reflect risk of pesticides to beneficial arthropods
Insects	Insect toxicity	Ratings from past studies and toxicity databases
Birds	8-day LC50	The concentration of active ingredient that kills half of the test bird population within 8 days
	Bird toxicity ratings	Ratings from past studies and toxicity databases

Source: Cuyno et al. 2001

3.5 Estimating Effects of BWEP and MeBr Phase-out on Pesticide Use

Pesticide risk has been defined in the literature as the hazard of the active ingredient: that is, its inherent potential to cause harm, and the likelihood of exposure to the active ingredient to actually cause harm. Numerous pesticide risk indicator models exist for the calculation of environmental pesticide risk. These models differ in four main aspects: components of the analysis including pesticides considered, variables assessed, and the choice of specific measurable endpoints as the indicators of impacts on these variables; the mathematical structure of the model (relative weighting of variables and scoring of the results); method for filling data gaps and whether usage data were factored into the equation (Walter-Echols and van der Wulp, 2008). With the continued interest and emphasis on pesticide risks, those indicators in existence are continually updated while many more are developed. For example, van Bol et al. (2002) listed 95 different pesticide indicators compared to Levitan et al's (1995) list of 51 indicators. Cornell University's Environmental Risk Analysis Program identified eight of the indicators as being widely used worldwide, namely; EPRIP, EYP, PERI, SYNOPS, SyPEP, EIQ, CHEMS1 and MATF (Table 3.7). Of these, the last three indicators were developed in the U.S.

Estimation of pesticide effects is a complex process because pesticides impact several categories of the environment differently. For example, a particular pesticide may be highly toxic to one category, but non-toxic to another. Labelling such a pesticide as having a high, or low impact on the environment would be erroneous. To fully capture these effects from pesticide use, it is imperative to address effects to all environmental categories.

Table 3.7: Examples of Pesticide Indices

	EPRIP	EYP	PERI	SYNOPS	SyPEPS	EIQ	CHEMS1	MATF
Pesticide application rate	X	X	X	X	X	X	X	X
Pesticide toxicity values	X	X	X	X	X	X	X	X
Pesticide chemical	X	X	X	X	X	X	X	X
Field size	X	X	X	X	X	X	X	X
Soil data	X	X		X				
Weather data	X	X		X	X			
Bodies of water	X			X	X			
Pesticide health impacts						X	X	X
Impact on pesticide								X
a.i. pre-existing in environment							X	

EPRIP = Environmental Potential Risk Indicator for Pesticides, Italy; EYP = Environmental Yardstick for Pesticides, Netherlands; PERI=Pesticide Environmental Risk Indicator, Sweden; SYNOPS = German environmental indicator model; SyPEP=System for Predicting the Environmental Impact of Pesticides, Belgium; EIQ=Environmental Impact Quotient, USA; CHEMS1=Chemical Hazard Evaluation for Management Strategies; MATF= Multi-Attribute Toxicity Factor, USA

Source: Walter-Echols and van der Wulp, 2008

To determine the environmental impacts from cotton pesticide use, we employed the Environmental Impact Quotient (EIQ) criteria developed in 1992, maintained, and frequently updated by Cornell University. This universal indicator, developed by Kovach, Petzoldt, Degni, and Tette (1992) and updated annually, effectively integrates the various environmental impacts of individual pesticides into a single field value per acre. The EIQ is a comparatively general indicator that estimates a given pesticide active ingredient's impact/toxicity by accounting for the effects to the farm worker (applicator and harvester), consumer (exposure potential plus potential groundwater effects) and ecology (effects to fish, birds, honeybees and other beneficial insects).

The indicator thus accounts for occupational, food safety and environmental contamination. The EIQ value is calculated using the formula below, according to Kovach et al. (1992).

$$EIQ = \frac{1}{3}\{[c((dt*5)+(dt*p))]+[\frac{1}{2}(c*(s+p)*sy)+L]+ \\ [(f*r)+(\frac{1}{2}(d*(s+p)*3))+(z*p*3)+(b*p*5)]\} \tag{3.2}$$

The various toxicity impact categories as represented by the various components of the above equation are outlined in Table 3.8. Table 3.9 gives a definition of the symbols used in equation (3.2) and the ratings for scoring the toxicities for each environmental category.

Table 3.8: EIQ Value Components

Component	Equation
Farm worker (Applicator + Harvestor)	C*((DT*5)+(DT*P))
Consumer (exposure + groundwater effects)	(C*(S+P)/2*SY)+(L)
Ecology (fish, birds, honeybees, other beneficial insects	(F*R)+(D*(S+P)/2*3)+(Z*P*3)+(B*P*5)
Total EIQ = Farm worker + Consumer + Ecology	{[C(DT*5)+(DT*P)] +[(C*(S+P)/2*SY)+(L)] + [(F*R)+(D*(S+P)/2*3)+(Z*P*3)+(B*P*5)]}/3
Field Use EIQ	EIQ * % active ingredient * rate (lbs/acre)

Source: Kovach et al. 1992

The EIQ criterion has been used widely to assess the environmental impact of various IPM programs. This criterion has been used in comparing the environmental impact (relative risk) between pesticides or different pest management programs (Kovach et al. 1992). The comparison between pesticides arises in situations where different pesticides can be used in controlling the same pest. Using the EIQ which measures the environmental impact of each pesticide, we then obtained their toxicity, referred to in this study as the Field Use EIQ rating. In such cases, the pesticides can be compared by using their field use EIQ rating. Field use EIQ is used to account for different formulations of the same active ingredients and different use patterns. The pesticide with the least Field use EIQ rating is the best choice. This was the criteria employed in assessing the methyl bromide alternatives. A pesticide Field Use EIQ is obtained as the product of the EIQ value, pesticide formulation (percent active ingredient in the formulation) and the rate of application (active ingredient per acre). Thus;

$$\text{Field Use EIQ } = EIQvalue * a.i./acre * Rate \quad (3.3)$$

Table 3.9: Definition for Symbols and Ratings for Each Toxicity Category in Equation (3.2).

Environmental Category	Symbol	Score 1	Score 3	Score 5
Long-term health effects	C	Little-none	Possible	Definite
Dermal toxicity (Rat LD50)	DT	>2000 mg/kg	200-2000 mg/kg	0-200 mg/kg
Bird toxicity (8 day LC50)	D	>1000 ppm	100-1000 ppm	1-100 ppm
Bee toxicity	Z	Non-toxic	Moderately toxic	Highly toxic
Beneficial. Arthr. Toxicity.	B	Low impact	Moderate	Severe impact
Fish toxicity (96 hr LC50)	F	>10 ppm	1-10 ppm	<1 ppm
Plant surface half-life	P	1-2 weeks (pre-emerg. Herbic.)	2-4 weeks (post -emerg. herbic.	>4 weeks
Soil residue half-life ($T_{1/2}$)	S	<30 days	30-100 days	>100 days
Mode of Action	SY	Non-systemic; all herbicides	Systemic	
Leaching potential	L	Small	Medium	Large
Surface runoff potential	R	Small	Medium	Large

Source: Kovach et al. 1992

On the other hand, different pest management strategies can be compared by using the total seasonal environmental impact for each strategy. The seasonal environmental impact for each pesticide is obtained as the product of its Field Use EIQ rating and the number of applications. The total seasonal impact then is the sum of the seasonal impacts for all the pesticides used in the management strategy. As noted earlier, the boll weevil eradication program is a form of IPM, thus the EIQ criterion can be applied in determining the environmental impact of pesticide use in cotton production. This was achieved by obtaining the total seasonal environmental impacts for pesticides used on cotton in 1981-84, the boll weevil pre-eradication period, and those used in 1992, 1997, and 2002.

Multiplying Field use EIQ by number of applications to obtain seasonal impact, however, raises some issues. This assumes the pesticide concentration is cumulative across applications, a case which is not necessarily true. Repeat applications are based on the fact that the previous application's concentration of active ingredient has declined to levels that are ineffective on the target pest, hence the need to boost the level. Since we were not able to obtain data on the residual concentrations from prior applications, we chose to consider the impact from a one time application

EIQ values for each a.i. used in cotton production were either obtained from Kovach et al. 1992 at (http://nysipm.cornell.edu/publications/eiq/default.asp), or calculated based on the chemical's toxicological and physical properties using equation (3.2), as outlined in Kovach et al. (1992). The chemical toxicological and physical properties information was obtained from various sources including: IUPAC (The International Union of Pure and Applied Chemistry); EXTOXNET (Extension Toxicology Network), a Pesticide Information Project maintained cooperatively by Cornell University, Michigan State University, Oregon State University, and University of California at Davis; U.S. Environmental Protection Agency (EPA); CDMS (Crop Data Management System) that maintains a comprehensive label and MSDS data for various pesticide products by manufacturer.

From the literature, pesticides have different effects on different environmental categories. Based on this, we estimated the impacts by environmental category as defined in the

EIQ index: worker, consumer, fish, birds, bees and beneficial arthropods related to the eight environmental categories used in our study. These categories encompass groundwater, surface water, aquatic species, acute and chronic human health, birds, mammals and artificial arthropods. This was achieved by multiplying the impact quotient for each category (obtained from its respective component in the EIQ formula) (Table 3.8) by the percent active ingredient and rate (pounds/harvested acre) or total pounds.

CHAPTER 4: CASE STUDY I

EVALUATION OF ENVIRONMENTAL EFFECTS FROM PESTICIDE USE: AN APPLICATION TO THE BOLL WEEVIL ERADICATION PROGRAM IN THE UNITED STATES COTTON INDUSTRY

4.1 Introduction

Cotton is grown in over 80 countries around the world. The five largest cotton-producing countries are China (People's Republic), India, Pakistan, U.S.A and Uzbekistan, which together produce 70 percent of the total crop. Cotton was first introduced into the United States (U.S.) from India. The U.S. cotton growing region (Figure 4.1), is comprised of the 17 states spanning the southern half of the nation from California to Virginia, covering more than 21,000 square miles (The World of Cotton). U.S. is among the three main cotton producers in the world, alternating in second and third places between India and China. The three countries provide over half the world's cotton.

The U.S. produces two main types of cotton; Upland and American Pima. This study focused on upland cotton, which is also the main type grown. The Upland cotton growing area is comprised of four main regions; the Southeast, Mid-South, Southwest and West. The South-eastern region includes Alabama, Florida, Georgia, North Carolina, South Carolina and Virginia, and accounts for about 22 percent of the total Upland production. About 34 percent is grown in the Mid-South, which includes the states of Arkansas, Louisiana, Mississippi, Missouri and Tennessee. The Southwest region is comprised of Kansas, Oklahoma and Texas and accounts for

35 percent of the crop. Arizona, California and New Mexico make up the West region, which accounts for about 9 percent of Upland production. American Pima is grown in Arizona, California, New Mexico and Texas (CCI – Cotton USA).

There are five major cotton producing areas ("hot spots"): the Mississippi Delta, the high plains of West Texas, the southern tip of Texas, the arid desert region of southwest Arizona, and the Southern Valley of California. All the five have different climate, precipitation and soil types which result in differences in weed and insect pressures, runoff and leaching potential and this necessitates applying different types and amounts of pesticides (Thurman et al. 1998).

The cotton industry is one of the major contributors to the U.S. Gross Domestic Product (GDP). The average U.S. crop provides more than $25 billion in products and services annually, and also generates about 400,000 jobs in industry sectors from farm to textile mill, making it the number one value added crop in the U.S. Cotton is the single most important textile fiber in the world, accounting for nearly 40 percent of total world fiber production (USDA-ERS, 2008).

Cotton production, however, has always faced many challenges, especially related to pests. Numerous pests have been associated with cotton. The main such pest is the boll weevil. One of the significant challenges in cotton production is to control insects with minimum use of pesticides. There have been more concerns about insecticides than other pesticides, and cotton-producing countries throughout the world wish to get away from pesticide-intensive production practices (Chaudhry, 2006). Several other techniques have been utilised to deal with these damaging pests (Georgia Cotton Commission). These include:

1. Utilizing integrated pest management (IPM), a multifaceted approach that relies on natural populations of beneficial insects to suppress damaging pests.
2. Cultural practices to improve earliness

3. Bio-technological improvements to make the plants resistant to certain worms

4. Genetic modification to make the cotton crop less attractive to insects, e.g. Bt cotton. Currently, genetically engineered (GE) cotton is either resistant to specific herbicides or resistant to bollworms. The U.S. is the largest producer of GE crops and GE cotton

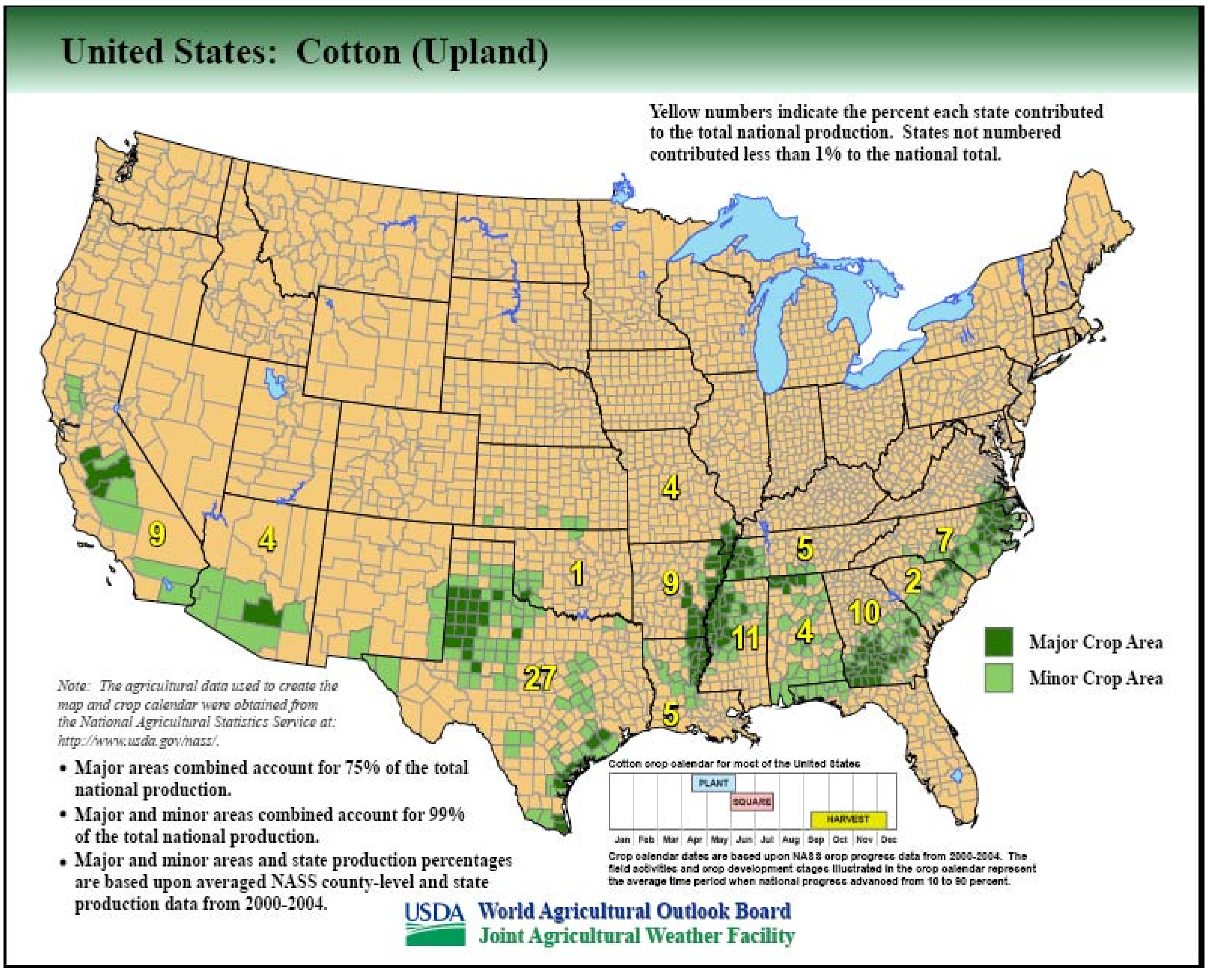


Figure 4.1: U.S. Upland Cotton Producing Regions

4.2 Boll Weevil History and Control Efforts

The main threat to the U.S. cotton industry was the arrival of the boll weevil (*Anthonomus grandis Boheman*), a native of Mexico and Central America. The pest spread rapidly to the rest of the cotton-producing states after its first appearance in the United States in 1892 near Brownsville, Texas (Parencia 1978). The after effects were devastating to the rural economies that depended on cotton.

Numerous cultural control methods were tested and reported from as early as 1904 to help curb the boll weevil menace. Short-season, early maturing cotton varieties, early planting, improved fertilization, constant cultivation, destruction of green cotton at least three to four weeks before time of first killing frost, crop diversification, were the most effective methods of insect control up untill 1918. This was termed the cultural control era. This was followed by the Inorganic Insecticide era (1919-1944), which was characterized by dusting with calcium arsenate. Scouting also evolved during this period. Next was the Organic Insecticide era that began with the advent of DDT in 1946, followed by other chlorinated hydrocarbons: Toxaphene, BHC (benzene hexachloride), Chlordane, Aldrin, Heptachlor, Dieldrin, Endrin and others during World War II period, 1945-1983. These were used as dusts initially and were very effective early on, especially if applied at intervals of four to seven days.

The chlorinated hydrocarbons were, however, quickly abandoned for organophosphates in 1964, due to boll weevil resistance (King et al. 1996). Another issue with chlorinated hydrocarbons was their short-term effectiveness, but long-term effects on the environment, animals and fish. The most used organophosphates included methyl parathion, parathion, azinphos methyl (Guthion) and malation, used as sprays. These chemical methods were coupled with the use of traps. Despite these efforts, yield losses attributed to the boll weevil, the cost of insecticide control, environmental considerations, infestation of secondary insects and insect resistance were enormous and thus called for a better and more aggressive belt-wide strategy for controlling the boll weevil in the United States. The last of the boll weevil control eras is the eradication era from 1984 to present (Dickerson et al. 2001).

Apart from yield losses and high control costs, the boll weevil eradication program was motivated by anxiety over boll weevil resistance to insecticides (Dickerson et al. 2001). Initial efforts to developing an eradication program began with the cooperative boll weevil experiment in southern Mississippi and in parts of Louisiana and Alabama, in 1971. The experiment entailed use of an integrated control approach that included chemical treatment, release of sterile males, mass trappings and cultural control. This led to a three-year eradication trial initiated in 1978 on 32,500 acres in 29 counties of northeast North Carolina and southeast Virginia, the success of which led to creation of the South Western and South Eastern boll weevil eradication programs.

The Southwest Boll Weevil Eradication Program was implemented in 1985 to eradicate the boll weevil from about 233,000 acres in western Arizona, southern California and northwest Mexico. The program was expanded to include 320,000 acres of cotton in central Arizona in 1988. Eradication was completed in southern California and western Arizona in 1987 and in central Arizona in 1991. The Southeast Boll Weevil Eradication Program was designed to eradicate the boll weevil from about 500,000 acres of cotton in the remaining part of North Carolina and in northern South Carolina. This was followed in 1987 with a program in the remainder of South Carolina and in Florida, Georgia and southern Alabama. The Southeast program also maintained previously eradicated areas in Virginia and the Carolinas as part of a post-eradication plan. A buffer zone on the western edge of the eradication area was also maintained to prevent boll weevil populations from returning to eradicated areas. The Southeast program then expanded to eastern Mississippi, middle Tennessee and the remainder of Alabama.

The start and end dates for boll weevil eradication for the various States are shown in Table A4.1, while Figure 4.2 shows the current status in boll weevil eradication.

While the boll weevil has been regarded as the number one cotton pest, other pests of economic importance to cotton include; thrips, cutworms, bollworms, tobacco budworms, beet armyworms, stink bugs, spider mites, cotton aphids, plant bugs, whiteflies, fall armyworms, and loopers (Suguiyama and Osteen, 1988). Pesticide applications to cotton became complicated by the presence of these other pests; hence, we included all insecticides used on cotton in our analysis. Appendix Table A4.2 shows the list of chemicals used for control of the boll weevil and other insects and mites in cotton before the eradication era.

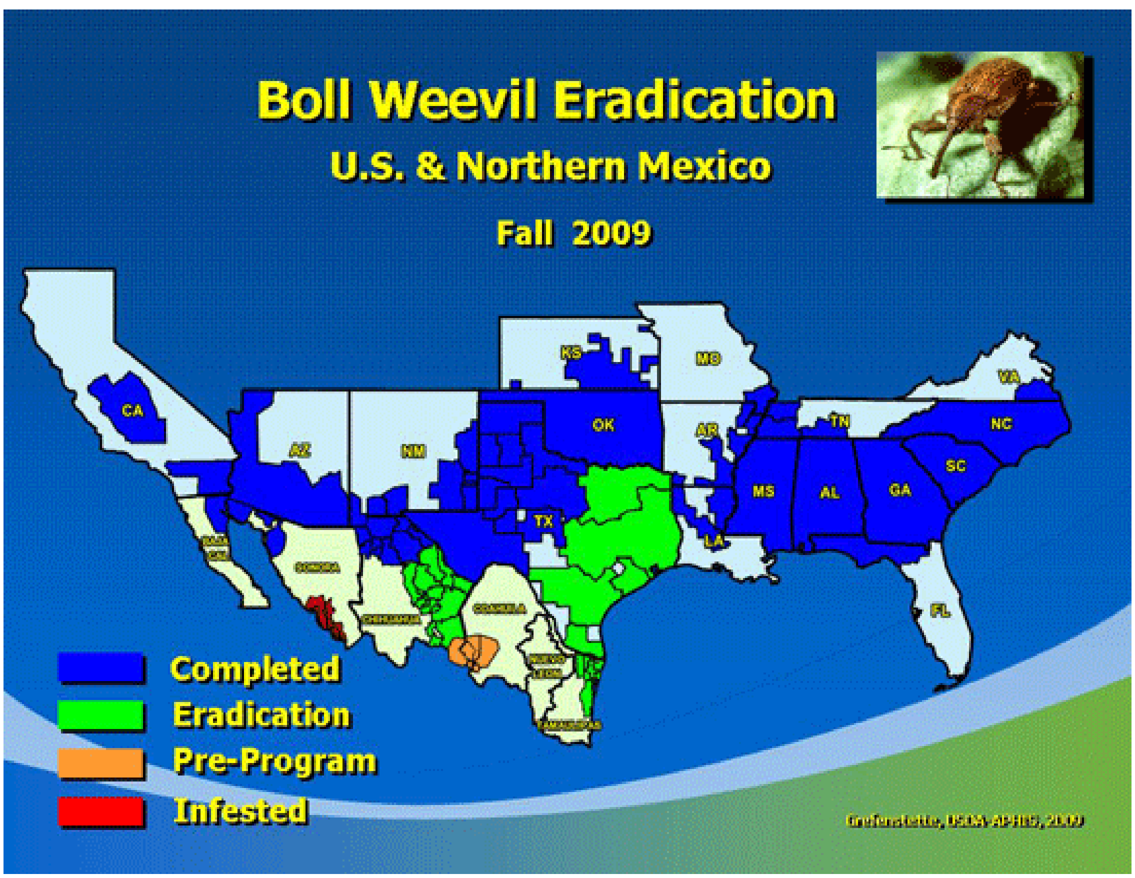


Figure 4.2: U.S. Boll Weevil Eradication
Source: National Cotton Council of America- Boll weevil eradication program

4.3 Use of IPM programs on cotton

Nearly one third of the insecticides used in U.S. agriculture have been used to control the boll weevil in cotton (Cross, 1973). This chemical overuse resulted in the development of resistance to insecticides, high control costs and unacceptable levels of chemical insecticide contamination in the environment. The boll weevil eradication program was instituted, in part, in an attempt to curtail the adverse environmental effects of traditional boll weevil control practices. The boll weevil eradication program uses a system of carefully controlled spraying of malathion, trapping and monitoring. Malathion is an insecticide in the organophosphate group of chemicals that is widely used on many different kinds of food crops.

This extensive use is supported by extensive studies by the U.S. Environmental Protection Agency (EPA) and others that have found malathion to pose little human health or environmental risks (USDA-ARS, 2002). The boll weevil accounted for most of the chemical use on cotton, so eradication greatly reduced the amount of pesticides applied to cotton. Eradicated areas have realized a 40 to 90 percent reduction in insecticide use on cotton (National Cotton Council of America). In Georgia, for example, insecticide applications were reduced from 14.4 per acre (pre-eradication) to 5.4 (post-eradication). In 1996, as the weevil was being eradicated in Alabama, cotton growers there used the fewest pounds of pesticides since World War II. The reduced pesticide use enables "beneficial" insects to multiply and prey on other cotton insect pests, which lessens further the need for insecticides, including the organophosphates. This results in a significant enhancement to the environment.

4.4 Justification

Several studies agree to the presence of environmental benefits from reduced pesticide use; therefore, quantifying these benefits is an important policy formulation. Moreover, the importance of cotton to the economies of the growing states and the fact cotton is grown on a wide area with very diverse climatic conditions has resulted in lots of different pesticides used. Benefits from such pesticide use reduction may therefore be substantial.

4.5 Objectives

The purpose of this study was to evaluate environmental impacts associated with changes in the levels and types of pesticides applied to U.S. cotton. The overall objective was to conduct an assessment of the boll weevil eradication program-induced reduction in environmental risks posed by pesticides in cotton production. The specific objectives of the study included:

1. Obtain insecticides used on U.S. cotton for the years 1981/84, 1992, 1997, and 2002
2. Determine each insecticide's risk levels and estimate the environmental impact quotient (EIQ)
3. Determine total impacts from all insecticides in each of the study years using application rate measured as total pounds, pounds per harvested acre, and pounds per treated acre

4.6 Data

Pesticide use data; providing acreage treated, rate of application and total pounds for each active ingredient were obtained from the National Center for Food and Agricultural Policy (NCFAP)and, from USDA-NASS Agricultural Chemical Use Database. NCFAP has the most comprehensive pesticide use data for 1992 and 1997.Data for 2002 was obtained from CropLife Foundation's National Pesticide Use Database (NPUD). The 1981/84 pesticide use data came from Suguiyama and Osteen (1988). The risk levels (Table A.1) for each pesticide to each of the eight environmental categories was determined from various sources including EXTOXNET, a Pesticide Information Project of Cooperative Extension Offices of Cornell University, Michigan State University, Oregon State University, and University of California at Davis; The International Union of Pure and Applied Chemistry (IUPAC); U.S. Environmental Protection Agency (USEPA); PAN, and from Mullen (1995).

Some Environmental Impact Quotient values were obtained from Kovach et al. (1992), and others were imputed using risk level information and the formula proposed by Kovach et al. These risk levels were used to calculate each pesticide's risk index, which helps us to measure the overall impact of a pesticide on the environment. Some of the pesticides used in cotton production have since been discontinued; hence, we are not able to determine the difference in their individual usage and toxicity. Our main concern is on the overall impact from all pesticides used, and to compare changes in impact across the years. Estimation of the seasonal environmental impacts was carried out following the methodology outlined in Chapter Three.

4.7 Results and Discussion

4.7.1 Pesticide Use

Pesticide use among the cotton growing States was represented by the number of active ingredients, Table 4.1, and total pounds applied, Table 4.2 and Figure 4.3. There was a general increase in number of active ingredients from 1981/84 to 1992, and a general decline between 1997 and 2002. The period between 1981/84 and 1992 coincides with active boll weevil eradication for most States. 1997-2002 pesticide use for California does not conform to expectations, because it finished eradication in 1991. The increase could be due more to a surge in other pests than the boll weevil since we included all insecticides used in each State. The outcome could be more pronounced for California because it is prone to high pest pressure due to its weather conditions. Exceptions were California and Tennessee, which had a steady increase in all the study years. The outcome for Tennessee was expected since it has been in eradication phase up to 2009.

Pesticide use based on total pounds, measuring total impacts, indicates that four States; Arizona, California, New Mexico and Texas had a percent decline in pounds applied between 1981/84 and 1992. This number increased to seven states between 1992 and 1997, and except three States; Arkansas, North Carolina and Tennessee, all the others registered a decline in pounds used between 1997 and 2002. Over the entire study period, half the states had a decline in pounds applied. Percent changes in pounds of active ingredient are in agreement with eradication time for most States, with the exception of CA, NC, NM, and TN.

Table 4.1 Number of Active Ingredients Applied

					% Change		
STATE	81/84	92	97	2002	81/84-92	92-97	97-2002
AL	13	25	27	10	92	8	-63
AR	8	19	25	23	138	32	-8
AZ	18	29	29	23	61	0	-21
CA	26	29	27	34	12	-7	26
FL	16	26	22	12	63	-15	-45
GA	17	21	28	13	24	33	-54
LA	14	25	27	23	79	8	-15
MO	9	15	17	13	67	13	-24
MS	16	27	28	21	69	4	-25
NC	13	17	13	12	31	-24	-8
NM	11	14	16	8	27	14	-5
OK	15	23	23	18	53	0	-22
SC	20	26	22	16	3	-15	-27
TN	9	15	26	28	67	73	8
TX	22	23	22	21	5	-4	-5

Table 4.2: Total Pounds of Active Ingredients Applied

	Pounds Applied (10,000)				% Change			
STATE	81-84	92	97	2002	81/84-92	92-97	97-2002	81/84-2002
AL	103.02	131.31	58.88	26.86	27	-55	-54	-74
AR	55.8	93.86	134.18	181.5	68	43	35	225
AZ	289.17	198.03	105.2	39.68	-32	-47	-62	-86
CA	348.6	210.84	303.49	130.56	-40	44	-57	-63
FL	11.29	35.45	18.66	7.11	214	-47	-62	-37
GA	65.98	114.17	108.48	69.55	73	-5	-36	5
LA	133.61	227.87	225.93	109.6	71	-1	-51	-18
MO	12.06	25.28	50.24	29.43	110	99	-41	144
MS	233.82	579.87	403.5	192.23	148	-30	-52	-18
NC	13.53	34.73	50.01	75	157	44	50	454
NM	5.47	1.47	9.49	8.57	-73	548	-10	57
OK	15.05	31.74	50.9	18.62	111	60	-63	24
SC	33.98	41.32	46.3	14.97	22	12	-68	-56
TN	15.02	67.74	60.38	82.31	351	-11	36	448
TX	301.68	199.4	321.75	274.83	-34	61	-15	-9

4.7.2 Cotton Yield

Cotton yields (Table 4.3 and Figure 4.4) show that almost all states experienced an increase in yield between 1981/84 and 1992, except Arizona and South Carolina. Eleven states had an increase in yield between 1992 and 1997, while only eight experienced increased yields in 1997 and 2002. Overall, 12 states recorded increased yields between 1981/84 and 2002.

Table 4.3: Cotton Yield (pounds/acre)

					% CHANGE			
STATE	1981/84	1992	1997	2002	81/84-92	92-97	97-2002	81/84-2002
AL	607	731	597	507	20	-18	-15	-16
AZ	1204	1077	1255	1381	-11	17	10	15
AR	586	823	837	871	40	2	4	49
CA	1045	1359	1202	1469	30	-12	22	41
FL	671	701	577	439	4	-18	-24	-35
GA	600	783	646	557	31	-17	-14	-7
LA	656	717	728	717	9	2	-2	9
MS	722	761	901	808	5	18	-10	12
MO	505	792	695	796	57	-12	15	58
NM	618	616	676	816	0	10	21	32
NC	552	596	652	421	8	9	-35	-24
OK	263	320	462	557	22	44	21	112
SC	651	565	688	314	-13	22	-54	-52
TN	492	651	662	741	32	2	12	51
TX	344	441	474	538	28	7	14	56
VA	502	621	659	465	24	6	-29	-7

4.7.3 Environmental Impact Results

We analyzed hazards from pesticide use in cotton production using the overall EIQ and the Seasonal Environmental Impact (SEI). The EIQ is an index that gives the hazard level for each pesticide. Use of overall EIQ therefore enables us to determine the inherent hazard in the insecticides before actual use. The overall EIQ was obtained as the sum of the EIQ values for all insecticides used in each State in the given study year. It is, however, more realistic to obtain the hazard based on actual usage. This was obtained using the SEI, which is obtained as the summation of the Environmental Impacts (EI) for all insecticides used in each State in a given year. EI is given as the product of the EIQ, percent active ingredient in each pesticide, and the rate and number of applications per growing season. The SEI was estimated using three different usage measurements; total pounds, pounds per harvested acre, and pounds per treated acre.

Results for the overall EIQ ratings and their percent changes between 1981/84 and 2002, and between 1997 and 2002, are shown in Table 4.4 and graphically in Figure 4.5. The EIQ ratings show great variations among States between the study years. The ratings for 1981/84 appear lower than expected since this coincides with a time of intensive pesticide use. The reason could be that pesticide use was not well reported for that time. Percent changes in EIQ ratings reveal that half of the States experienced declines in impacts between 1981/84 and 2002, while 87.5 percent (14 States) experienced declines between 1997 and 2002. The declines between 1997 and 2002 are relatively larger than those between 1981/84 and 2002. This is mainly due to increases in ratings between 1981-84 and 1997. EIQ ratings depend on the toxicological information of the pesticides rather than usage, hence not a good representation of field impacts.

Table 4.4: Impacts using overall EIQ Rating

	Overall EIQ Rating				% change			
STATE	1981-84	1992	1997	2002	1981/84-1992	1992-1997	1997 - 2002	1981/84-2002
AL	561.3	983.8	953.3	436.9	75.3	-3.1	-54.2	-22.2
AR	332.4	641.6	942.3	871.5	93.0	46.9	-7.5	162.2
AZ	679.2	989.5	1117.4	731.5	45.7	12.9	-34.5	7.7
CA	1008.1	1152.4	981.9	1197.5	14.3	-14.8	22	18.8
FL	639.0	1003.3	817.5	413.8	57	-18.5	-49.4	-35.2
GA	676.2	802.5	1078.5	445.7	18.7	34.4	-58.7	-34.1
LA	454.1	1018.1	998.8	874.1	124.2	-1.9	-12.5	92.5
MO	317.9	634.6	680.6	485.0	99.6	7.2	-28.7	52.6
MS	589.6	1072.7	1005.1	814.5	81.9	-6.3	-19	38.1
NC	568.0	731.9	568.1	503.9	28.9	-22.4	-11.3	-11.3
NM	388.3	388.3	62.0	255.5	0	61.7	-59.3	-34.2
OK	537.7	913.8	862.0	641.6	69.9	-5.7	-25.6	19.3
SC	773.5	1022.7	817.9	612.8	32.2	-20	-25.1	-20.8
TN	354.4	634.6	938.2	990.4	79.1	47.8	5.6	179.5
TX	869.5	907.1	877.1	728.6	4.3	-3.3	-16.9	-16.2
VA	571.1		350.2	175.8	-100		-49.8	-69.2

4.7.4 Seasonal Environmental Impacts

Overall seasonal environmental impacts (SEI) for the study years by State are shown in Table 4.5 and graphically in Figure 4.6, 4.7 and 4.8, using rates measured as pounds per harvested acre, pounds per treated acre, and total pounds. These impacts encompass the effects to all the six environmental categories considered in this study, hence a composite measure. Based on pounds per harvested acre in 1981/84, Florida had the highest impact of 134.57, while Oklahoma had the least impact, 6.03. The highest impact in 1992 was 137.68, again in Florida, which is also the highest impact across all the study years, and the lowest impact was 5.72, in North Carolina.

Mississippi recorded the highest impact for 1997, 80.17, while New Mexico had the least, 8.09. 51.53 was the highest impact in 2002, in Louisiana, and 5.82 as the lowest impact, in South Carolina. Across the study years, and in particular, from 1992, we observe a general decline in per harvested acre impact of 59.3 percent between the highest rates and 3.5 percent between the lowest rates. By state, the impacts are quite variable. Three states; Arizona, Georgia and South Carolina recorded an overall decline over the study years. Alabama, Florida, Mississippi and Tennessee showed a decline in impacts starting from 1992. The rest of the states showed variable impacts; the impacts declined, then rose or increased and then declined.

Impact results using pounds per treated acre indicate that Arkansas and Tennessee had a general impact increase, eight states (Alabama, Arizona, California, Florida, Georgia, Mississippi, South Carolina and Texas) had a general decline, and three states (Louisiana, Missouri and New Mexico) had fluctuations. Louisiana and Missouri had an increase in 1997 followed by a decline in 2002, while New Mexico had a decline in 1997 but an increase in 2002. In this case, nine states had the highest impacts in 1992, with California registering the highest overall impact per treated acre of 426.85. Again, the trend across the years indicates a general decline in impacts from 1992 to 2002.

Impact results using total pounds show a slightly different scenario from the one above. The highest overall impact across the study years was in Mississippi, and the lowest was in North Carolina, when we exclude Virginia. In this case, two states (Arizona and New Mexico) registered a general increase, while only one state (Arizona) maintained a general decline in impacts. AL, FL and MS maintained the decline after 1992, with GA and LA joining this group, while TN fluctuated. Despite the magnitude, the difference in the charts using total pounds and pounds per harvested acre in each year's impacts can be attributed to the fact that total pounds are based on varying harvested acres. The difference in magnitude between impacts using pounds per harvested acre and pounds per treated acre is attributed to the fact that treated acres are only a fraction of the harvested acres, thus impacts measured on a per treated acre basis will be higher than on a per harvested acre.

4.7.5 Percent Change in Impacts

Changes in impacts using the three application rate measures show similar results, with a few discrepancies (Table 4.6). Impacts using pounds per harvested acre show an improvement in impacts, as evidenced by an increase in the number of States recording impact declines between the study years. Eight States recorded increased impacts between 1981/84 and 1992, six between 1992 and 1997, and only two between 1997 and 2002. On average, twelve States experienced a decrease in pesticide impacts over the entire study period. Half of these had declines above 50 percent, and while one third had declines above 80 percent. The largest impact declines were recorded between 1997 and 2002. Worth noting is that impact increases were of a relatively higher magnitude than the declines. This could be that the increases in impacts were attributable to some unusual pest outbreaks that led to increased pesticide use beyond the normal levels. This can be seen in the fact that except for Arkansas, Louisiana and Oklahoma, that had an increase in impacts between all the years, the other States had these increments amidst other years with declines. Even though missing the 1981/84 values, changes calculated using rate as pounds per treated acre gives a better picture. Most States had declines in impacts between the study years.

4.7.6 WTP Weighted Seasonal Environmental Impacts Changes

WTP for each environmental category were obtained using WTP values from Mullen (1995) and risk levels for each pesticide to each of the environmental categories. These were then summed across the categories to obtain a WTP value for each pesticide. The SEI for each pesticide was then weighted using this obtained WTP values to obtain WTP-SEI. The weighted SEI's were totalled across all pesticides used in each state in each study year, again using the three different rate measurements. We then determined the percent changes in the WTP-SEI (Figure 4.9 and 4.10). Positive changes indicate an increase in pesticide impacts. Similar to the SEI results, 1981/84-1992 indicates that most States experienced increased impacts within that period, as shown by the positive percentage changes in impacts. 1997-2002 shows that only North Carolina and Arkansas had an increase in impacts within this period, the rest of the States had a decrease in impacts. Overall, the WTP-SEI show declines in impacts across the study years for all States, except Arkansas and North Carolina.

4.7.7 Impacts by Environmental category

Results of impacts by environmental category for each State are presented in Figures 4.11-4.26. Using both total pounds and pounds per harvested acre, results show that workers and beneficial arthropod categories experienced the highest impacts in all States except California, across the study years. California workers experienced almost the same level of impacts as fish and bees. Consumers had the least impacts across most States and study years, with a few slight exceptions where fish or birds show the least impact. In cases where fish or birds had the least impact in a given year, the difference from the consumer impact was very small. Bees show the third highest impacts.

Table 4.5: Seasonal Environmental Impacts by State

	Using Pounds/Harvested Acre				Using Pounds/Treated acre			Using Total Pounds (100,000)			
STATE	1981/84	1992	1997	2002	1992	1997	2002	1981/84	1992	1997	2002
AL	63.2	67.8	50.3	11	270.8	205.8	107.1	186.4	276.6	218.1	57.5
AR	25.1	14.6	21.7	41.7	123	257.2	269.9	107.1	143.3	208.4	384.3
AZ	126.7	84.1	43.9	27.3	340.6	324.1	253.5	564.3	357.4	145.7	60.9
CA	70.5	40.2	50.9	22.9	426.9	369.6	314.7	925.6	444.1	527.8	158.7
FL	134.6	137.7	45.9	6.8	389.7	284	45.1	20.5	68.2	42.9	6.9
GA	78.6	33.9	10	7.4	362.3	273.7	54.7	121.8	154.4	136.6	94.1
LA	32.7	42.1	55.1	51.5	298.1	357.3	276.7	191.4	366	356.8	244.7
MO	20	22.3	22.8	10.3	164	214.9	76.7	29.5	73.1	88.6	40.8
MS	39	89.1	80.2	37.6	396.1	372.8	227.1	379.6	1200	774.8	435
NC	33.2	11	8.1	23.1	179.6	100.8	114.8	25.4	41.3	49.1	205
NM	14.5	5.7	25.1	25.1	54	171.7	42.2	10.5	2.8	17.1	13.3
OK	6	16.3	62.7	22.8	218.3	226.4	179.4	26.6	54.2	111.3	39.3
SC	67.8	27	20.9	5.8	256.2	192.7	102.1	65.4	55.3	60.7	13.1
TN	9.3	29	26.3	21.2	155.6	190.3	210.7	25.5	183.6	132.7	142
TX	10.3	11.7	12.6	12	257.8	186.9	168.9	507.8	418.3	659.8	558.4

Table 4.6: Percent Impact Changes

STATE	% Change on Impacts using lbs/harv acre 1981/84-1992	1992-1997	1997-2002	1981/84-2002	% Change using lbs/treated acre 1992-1997	1997-2002	1992-2002	% Change using total pounds 1981/84-1992	1992-1997	1997-2002	1981/84-2002
AL	7.2	-25.7	-78.2	-82.6	-24	-48	-60.5	48.4	-21.1	-73.6	-69.1
AR	-41.8	48	92.6	66	109.1	5	119.4	33.8	45.5	84.4	258.8
AZ	-33.6	-47.8	-37.8	-78.4	-4.8	-21.8	-25.6	-36.7	-59.2	-58.2	-89.2
CA	-43	26.7	-55.1	-67.6	-13.4	-14.9	-26.3	-52	18.9	-69.9	-82.8
FL	2.3	-66.7	-85.2	-95	-27.1	-84.1	-88.4	232.1	-37.1	-84	-66.5
GA	-56.9	-70.5	-25.6	-90.5	-24.5	-80	-84.9	26.8	-11.5	-31.1	-22.7
LA	28.7	31.1	-6.5	57.7	19.9	-22.6	-7.2	91.2	-2.5	-31.4	27.8
MO	11.3	2.2	-54.8	-48.6	31	-64.3	-53.2	147.6	21.2	-54	38.1
MS	128.6	-10	-53.1	-3.5	-5.9	-39.1	-42.7	215.7	-35.3	-43.8	14.6
NC	-67	-26.1	185.9	-30.3	-43.9	14	-36	62.1	19	317.7	705.6
NM	-60.5	339	-0.2	73.1	217.8	-75.4	-21.8	-72.9	500.6	-22.2	26.8
OK	171	283.6	-63.6	277.9	3.7	-20.8	-17.8	103.8	105.3	-64.7	47.7
SC	-60.2	-22.6	-72.1	-91.4	-24.8	-47	-60.1	-15.5	9.9	-78.4	-80
TN	212.5	-9.2	-19.4	128.7	22.3	10.7	35.5	619.7	-27.7	6.9	456.5
TX	13.2	8.4	-5	16.5	-27.5	-9.6	-34.5	-17.6	57.7	-15.4	10

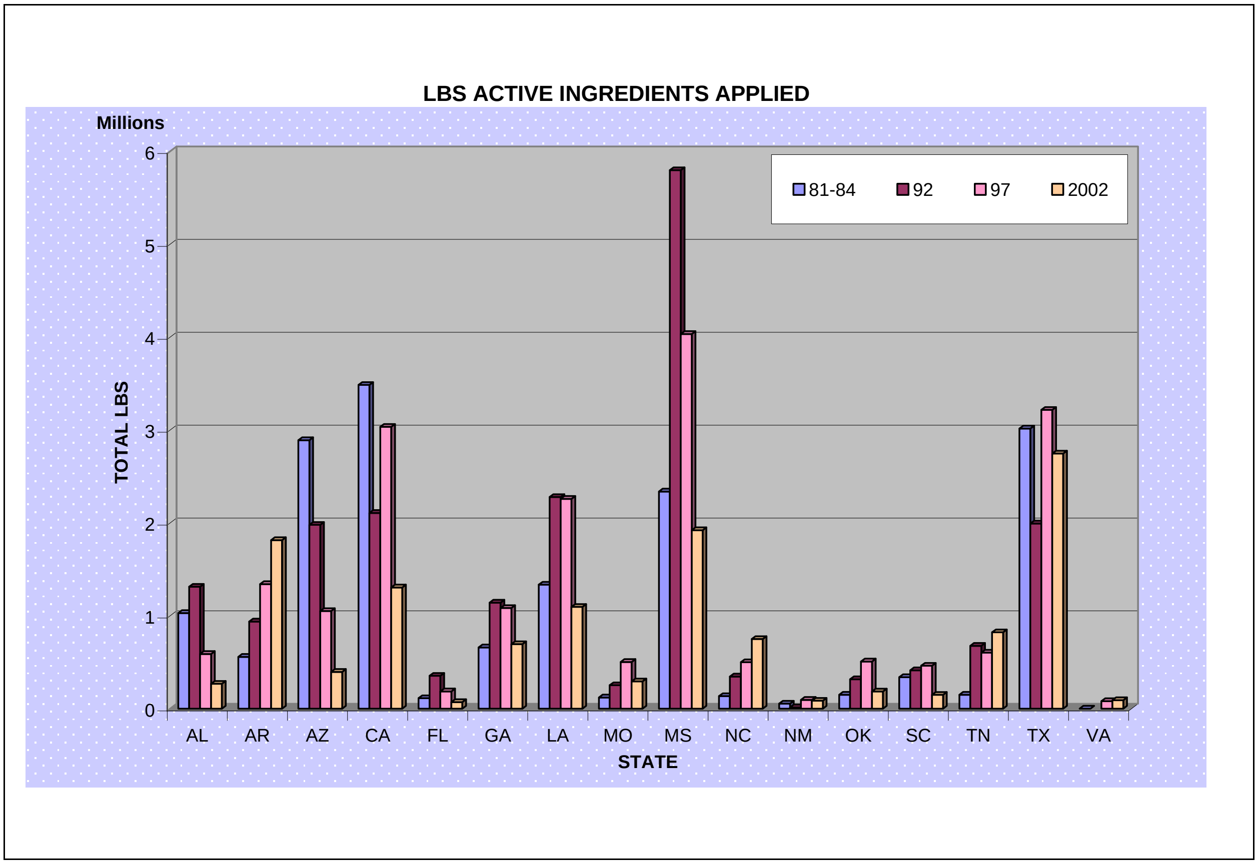
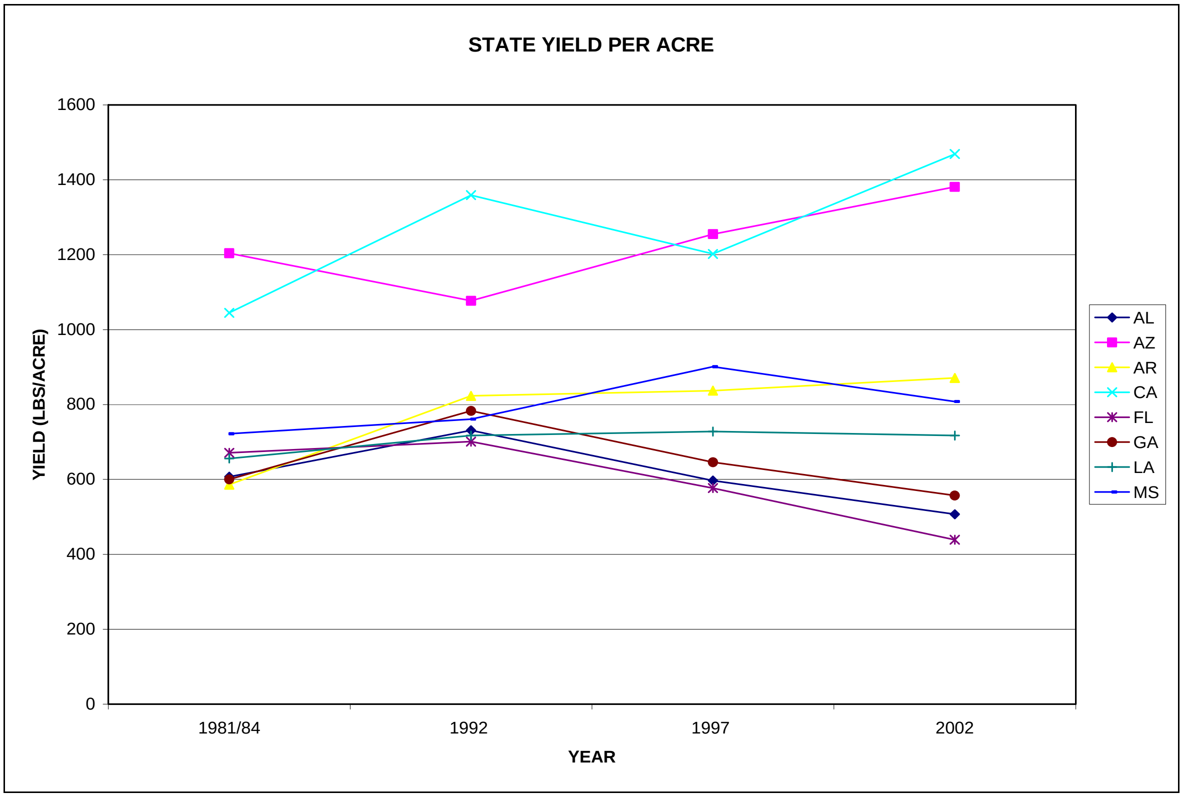


Figure 4.3: Cotton Pesticide Use by State (Total Pounds Applied)



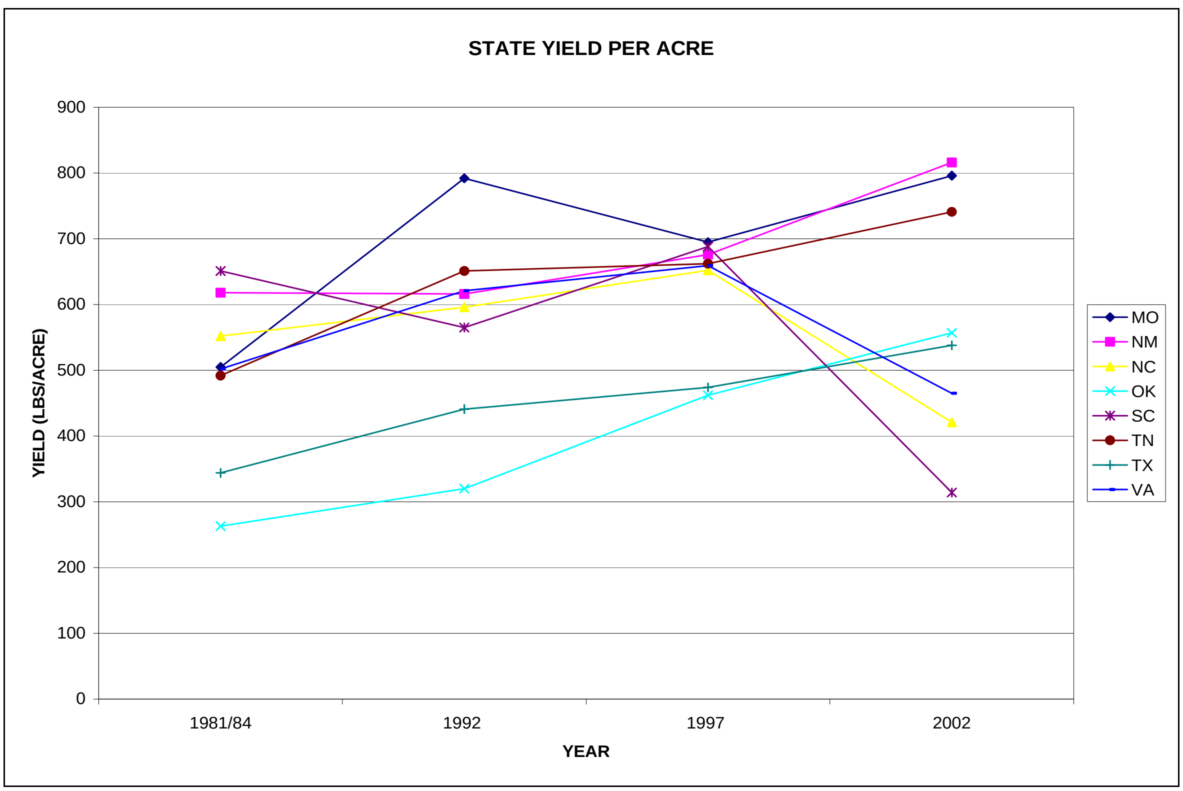
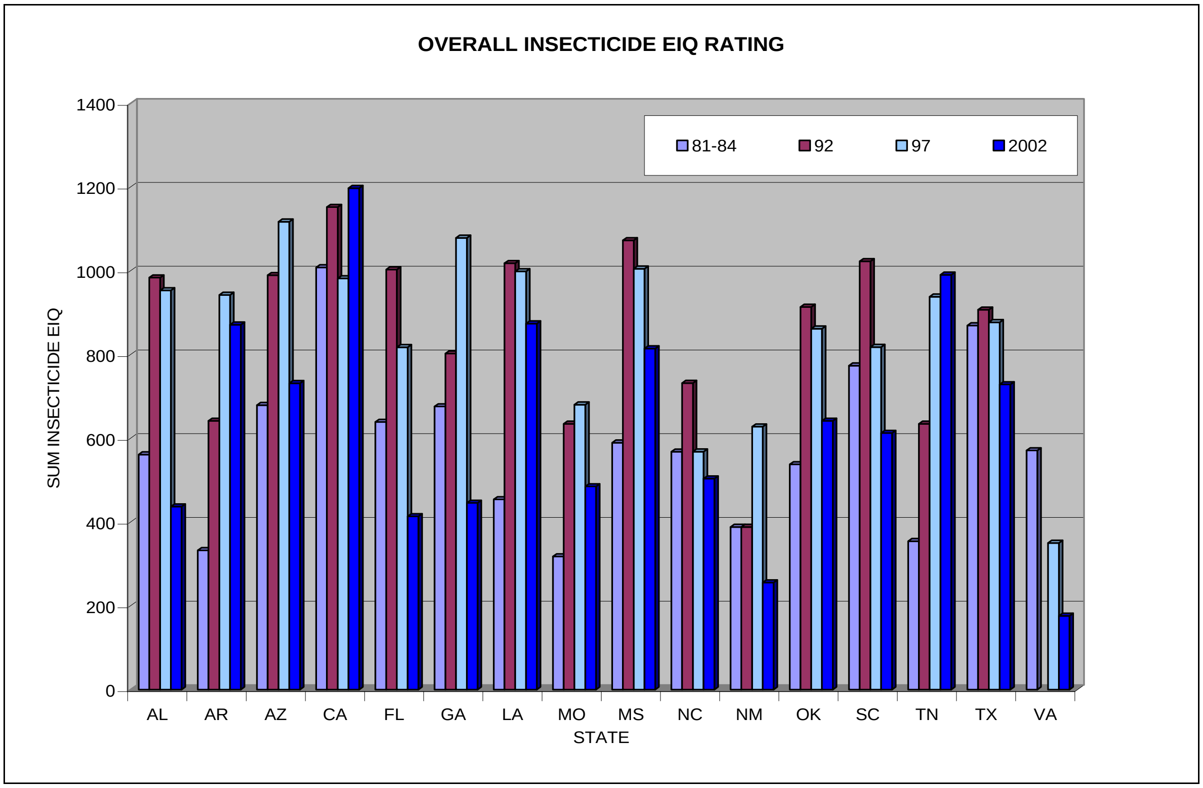


Figure 4.4: State Yield (pounds/acre)



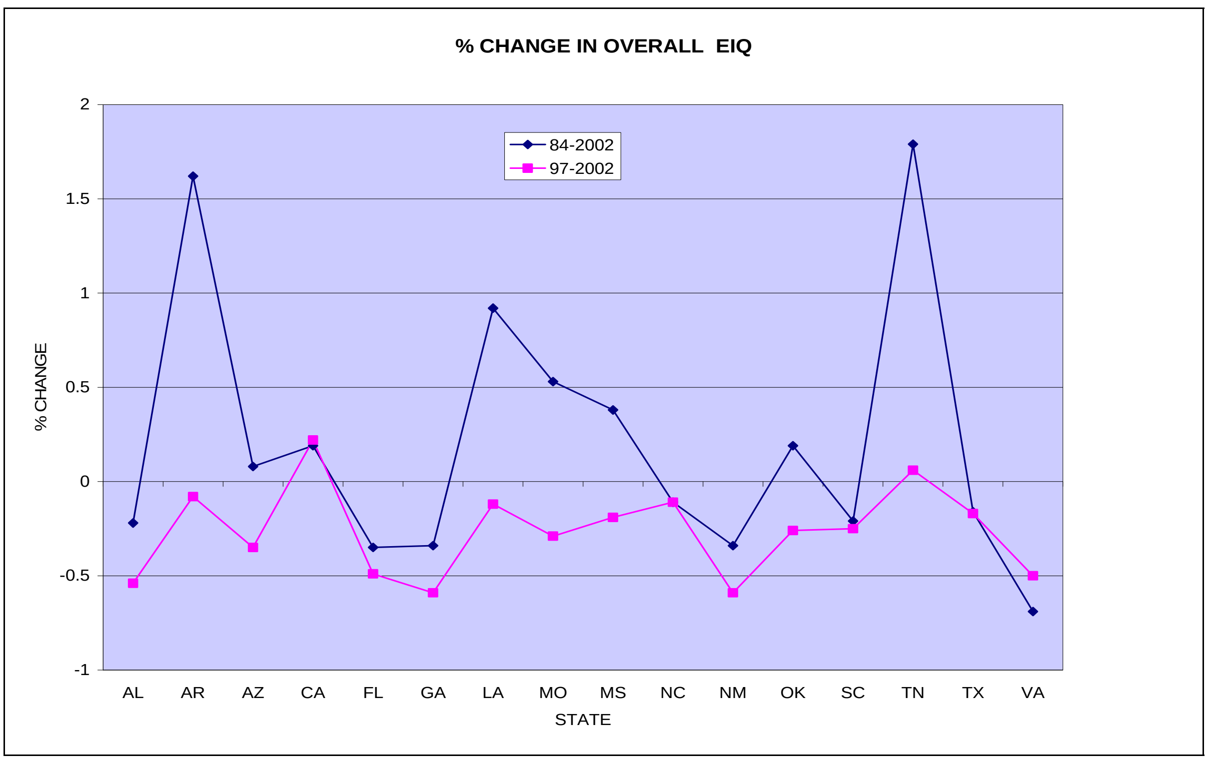
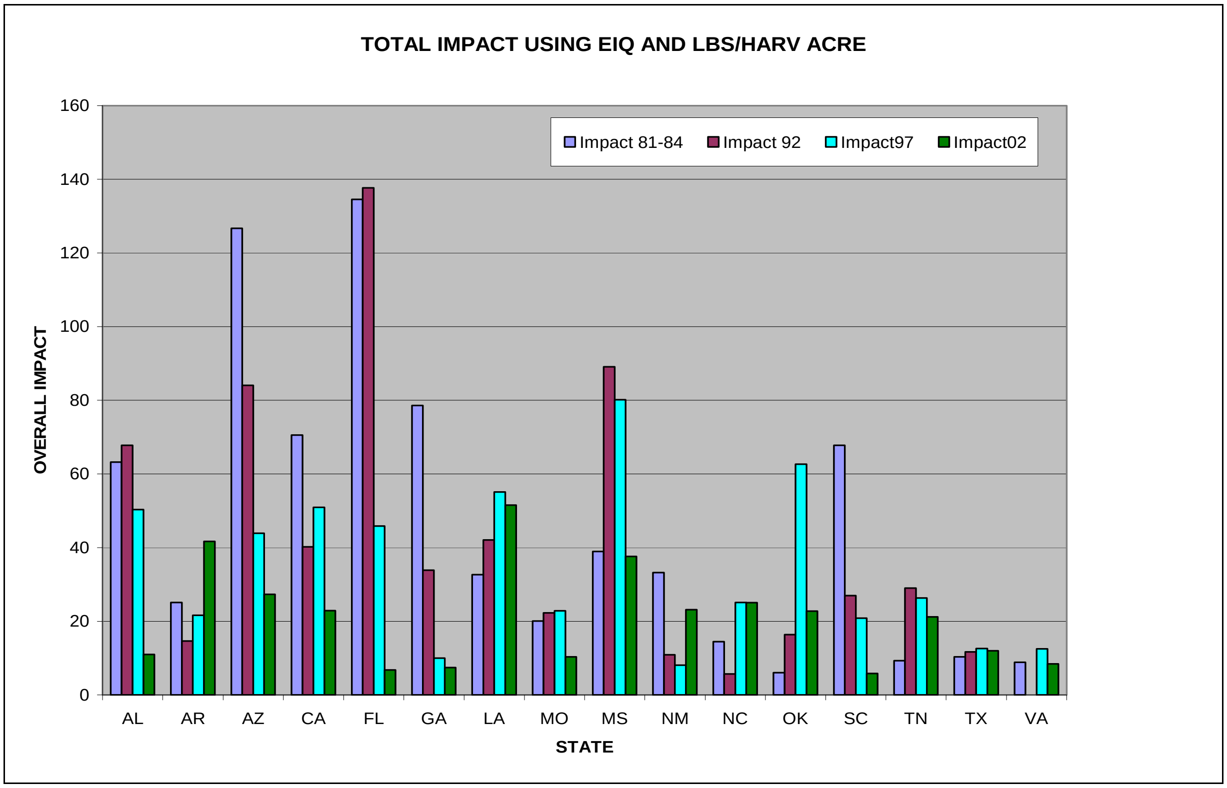


Figure 4.5: Environmental Impact Using EIQ Rating, and Percent Changes



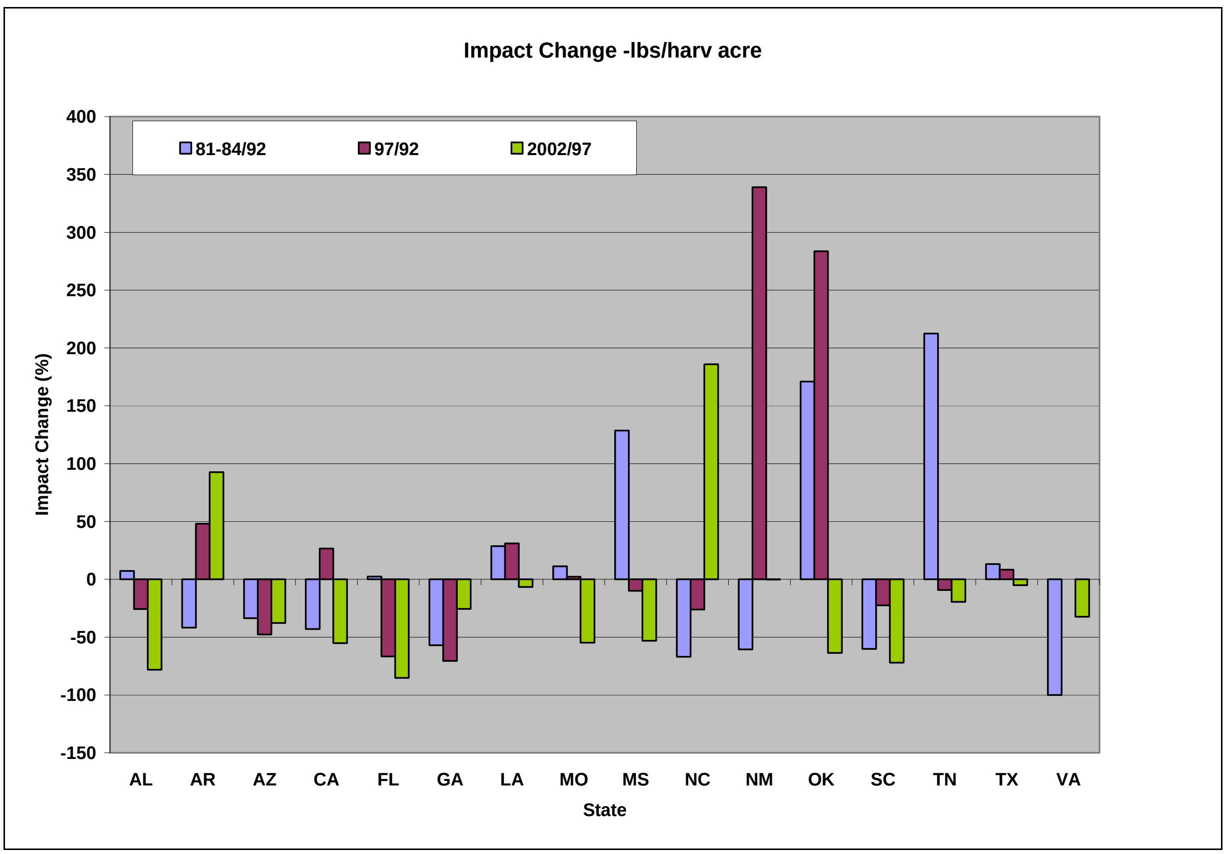
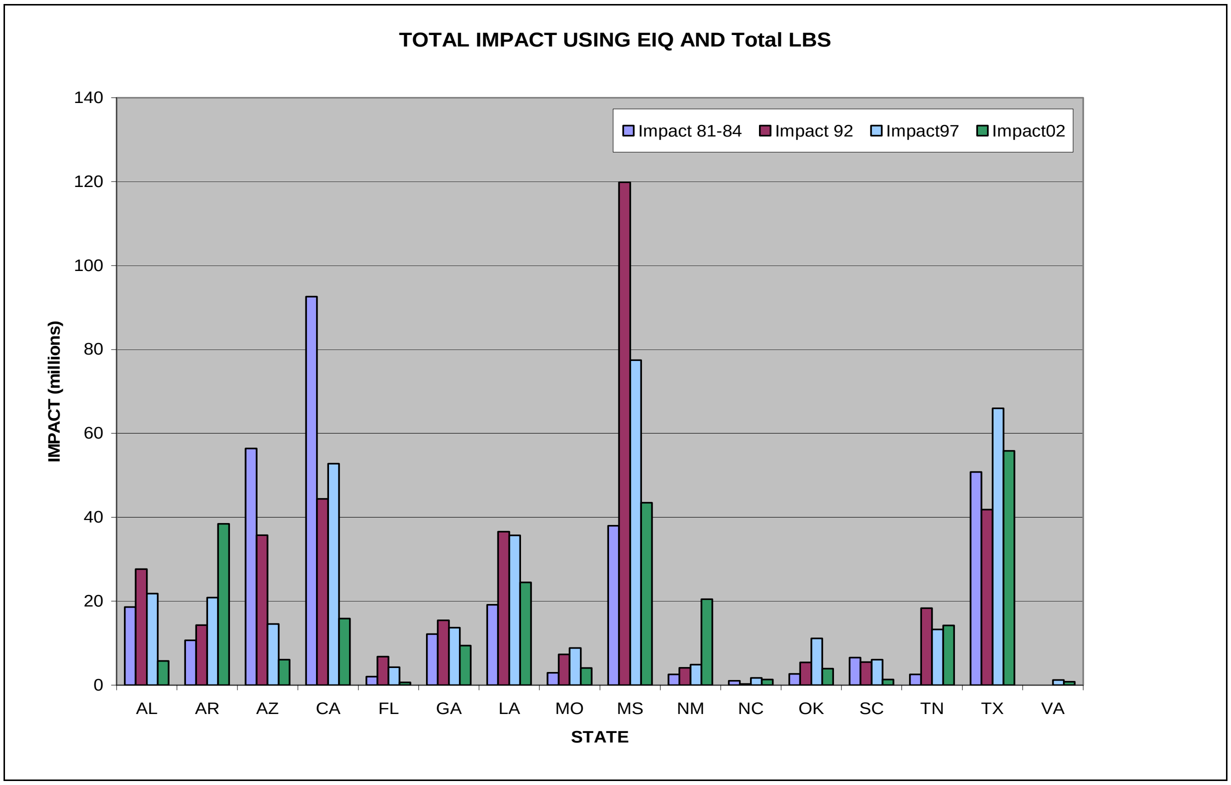


Figure 4.6: Seasonal Environmental Impacts using Pounds/Harvested Acre by State



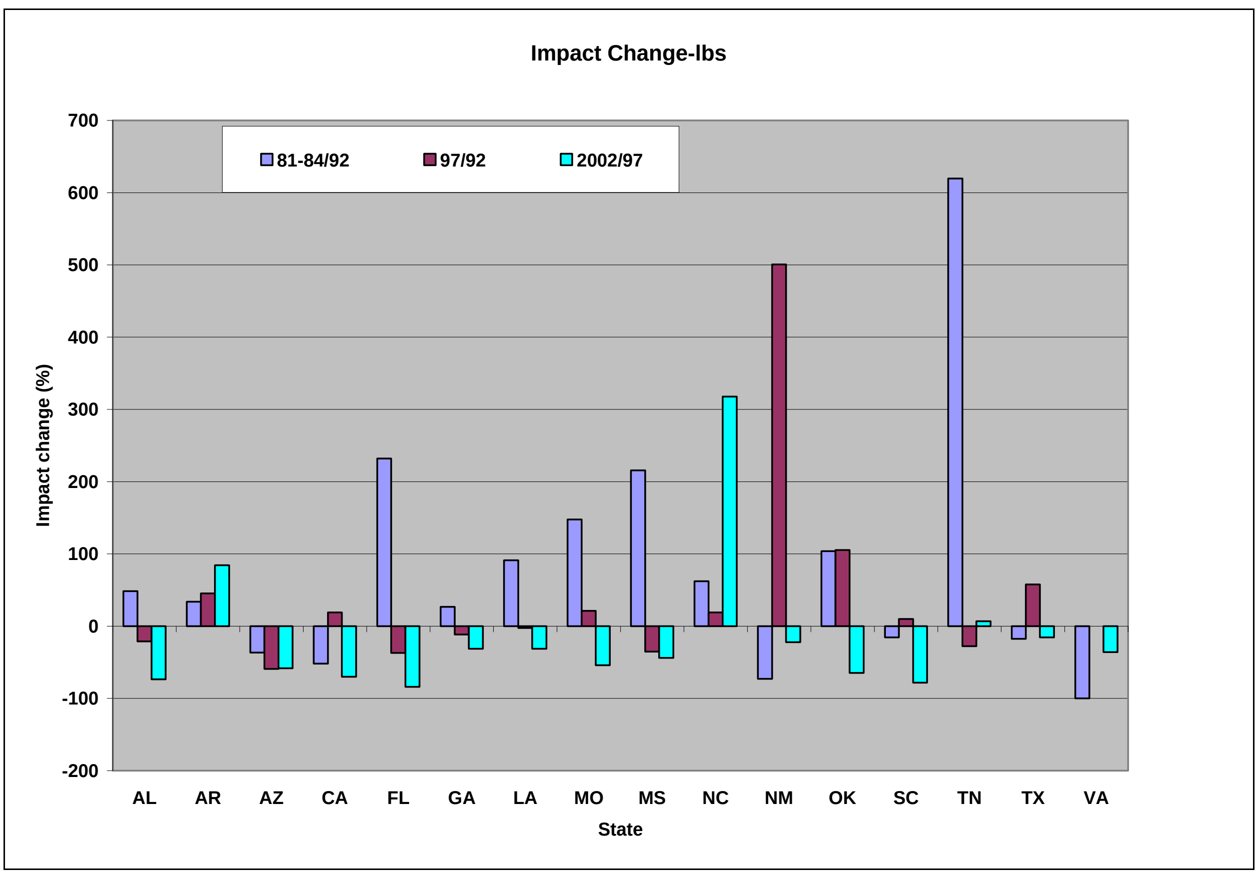
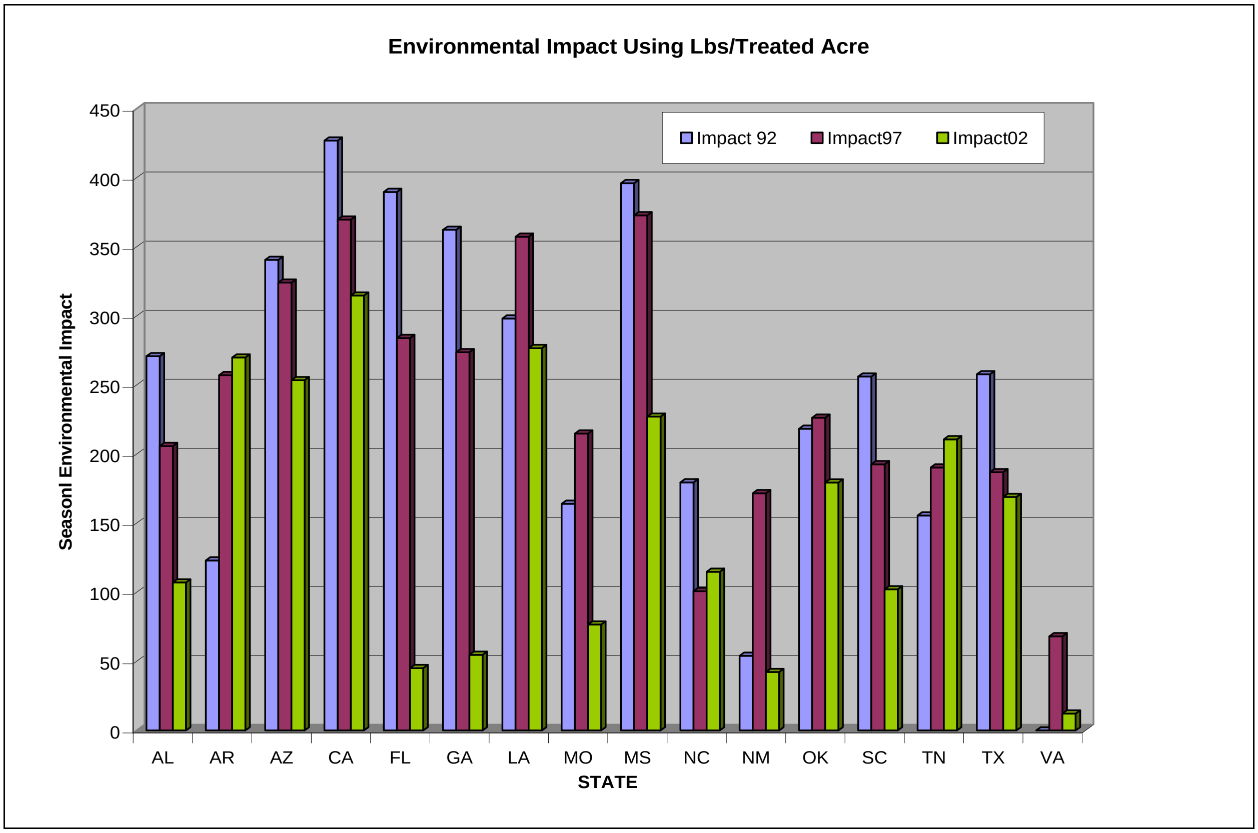


Figure 4.7: Seasonal Environmental Impacts using Total Pounds by State



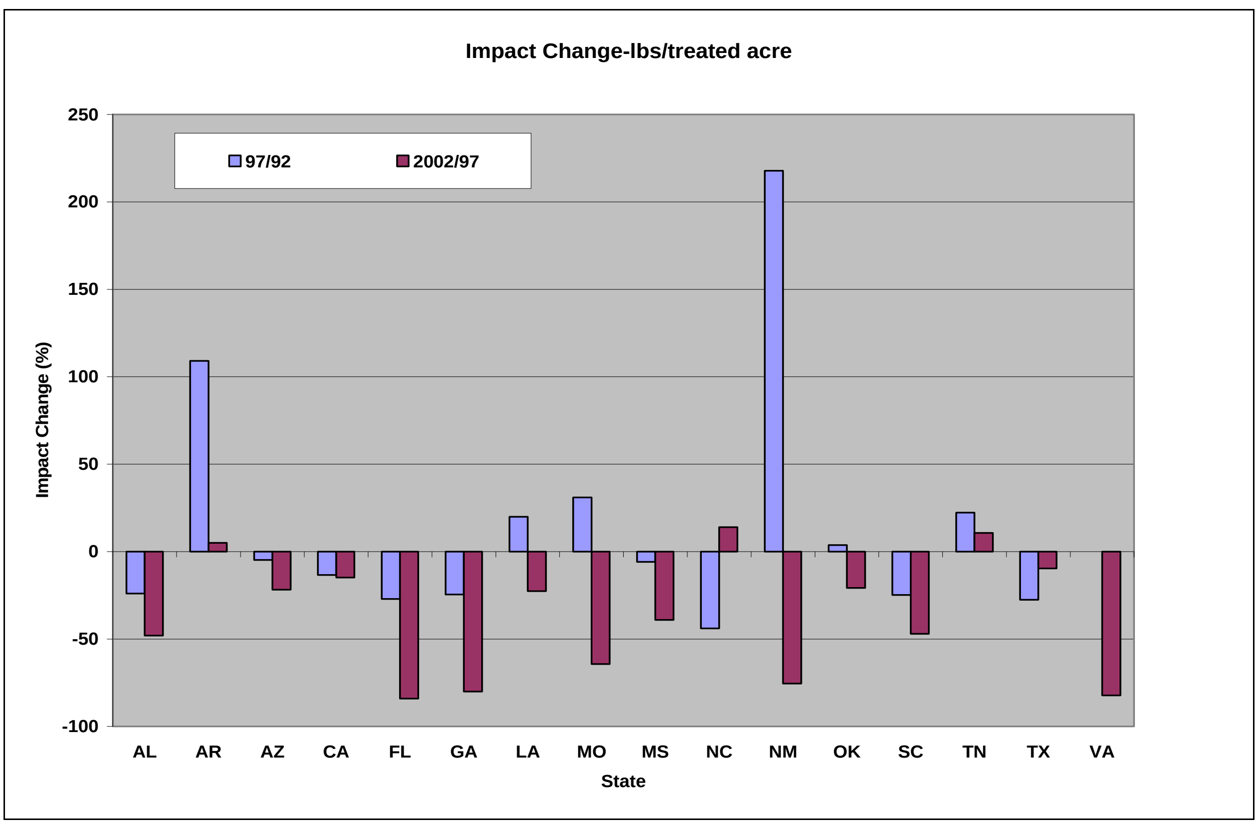


Figure 4.8: Seasonal Environmental Impacts using Pounds/ Treated Acre by State

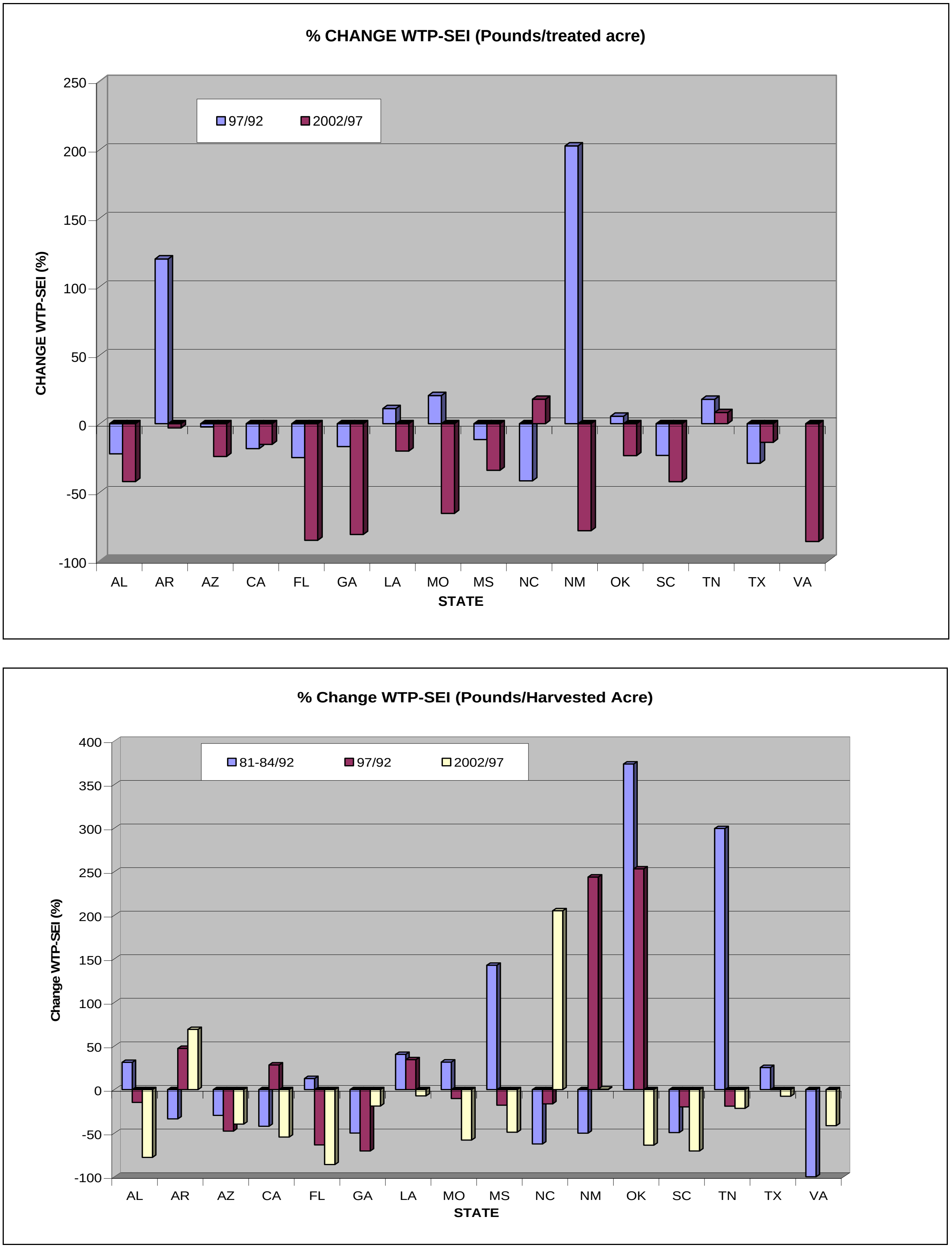


Figure 4.9: WTP weighted Seasonal Environmental Impacts

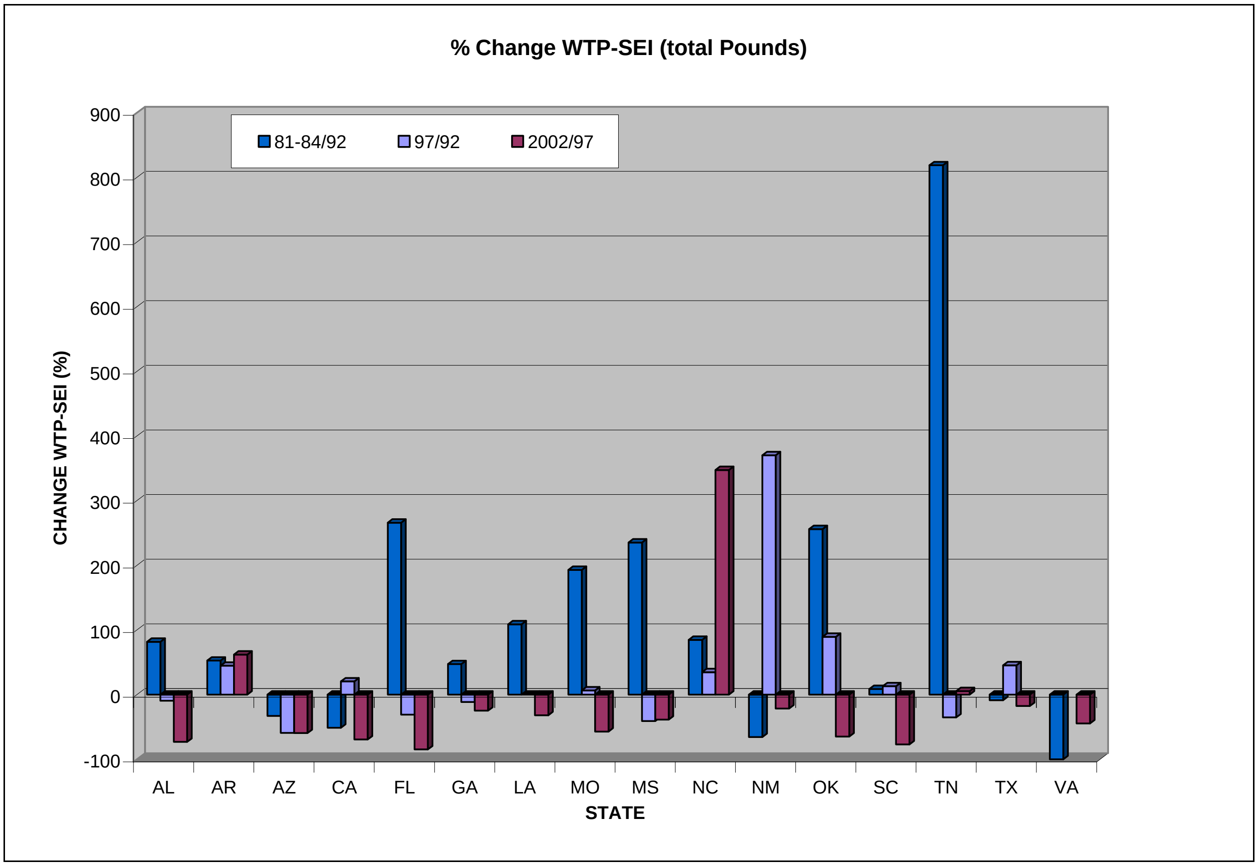
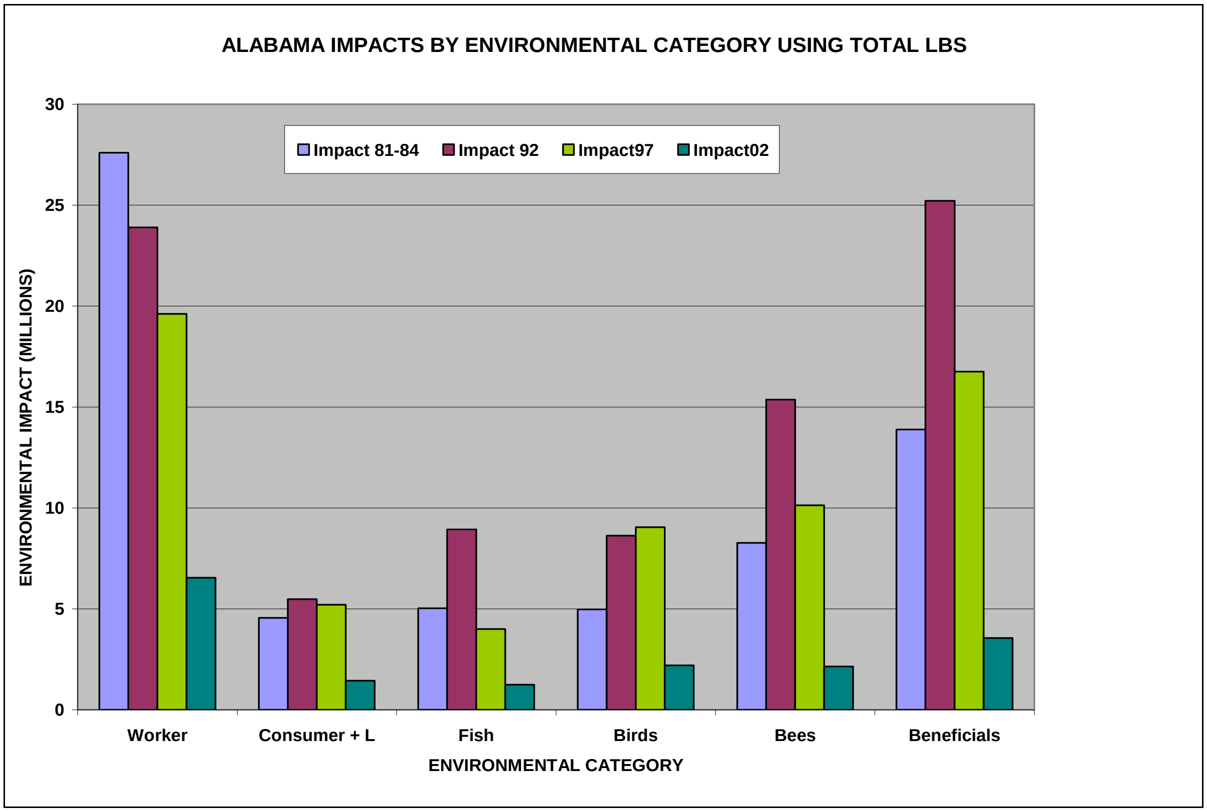


Figure 4.10: WTP weighted Seasonal Environmental Impacts on Total Pounds



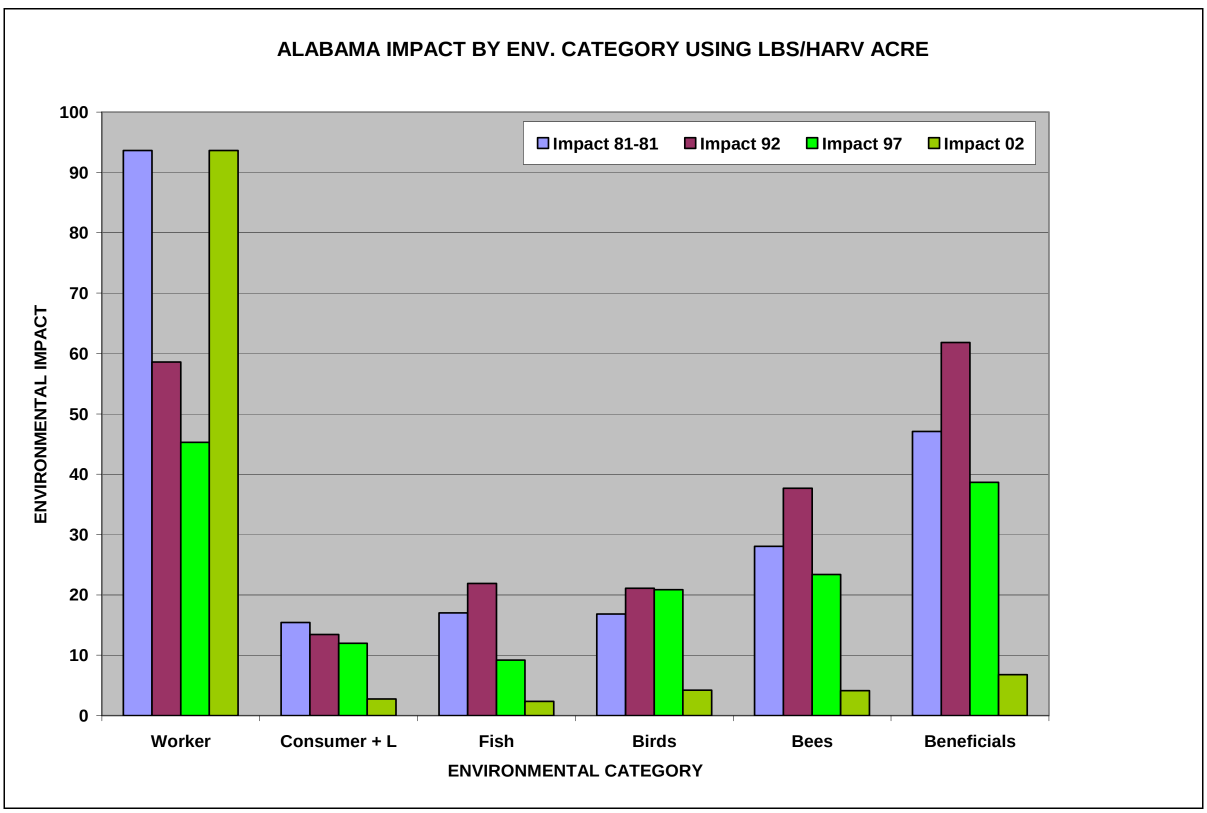
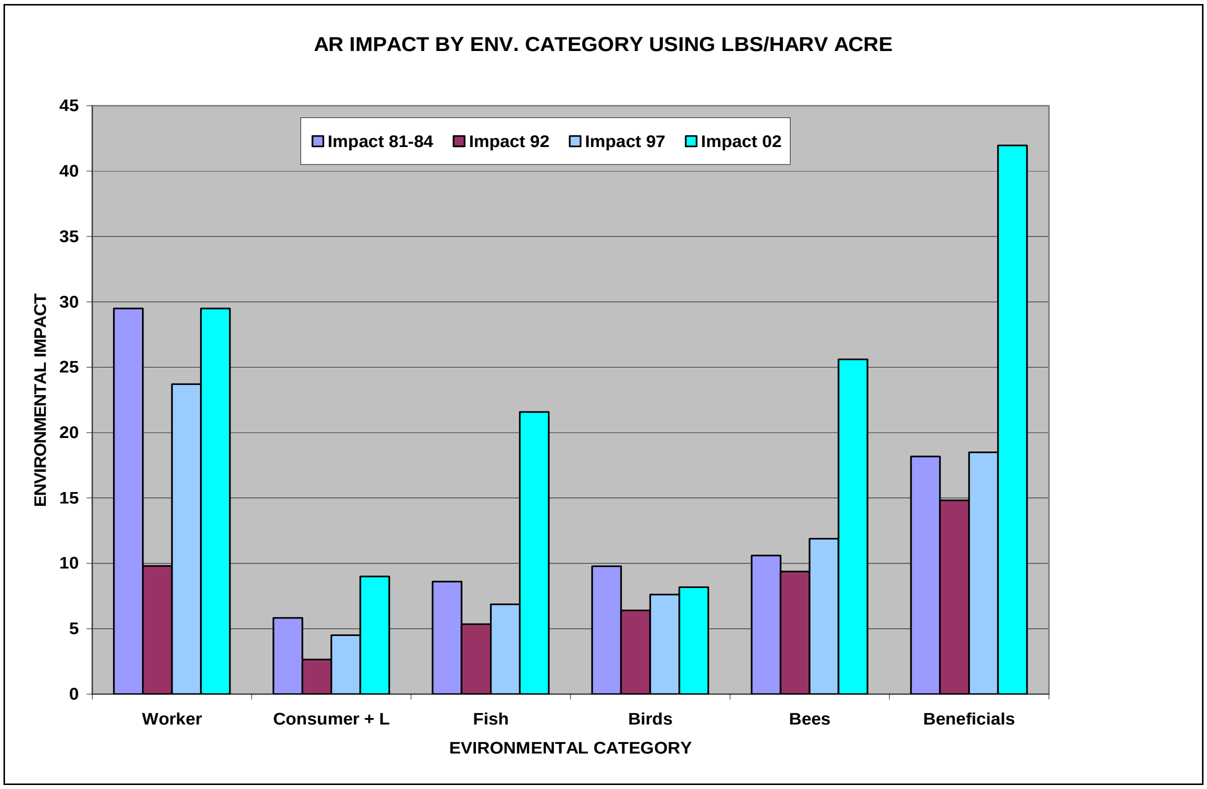


Figure 4.11: Alabama Impacts by Environmental Category



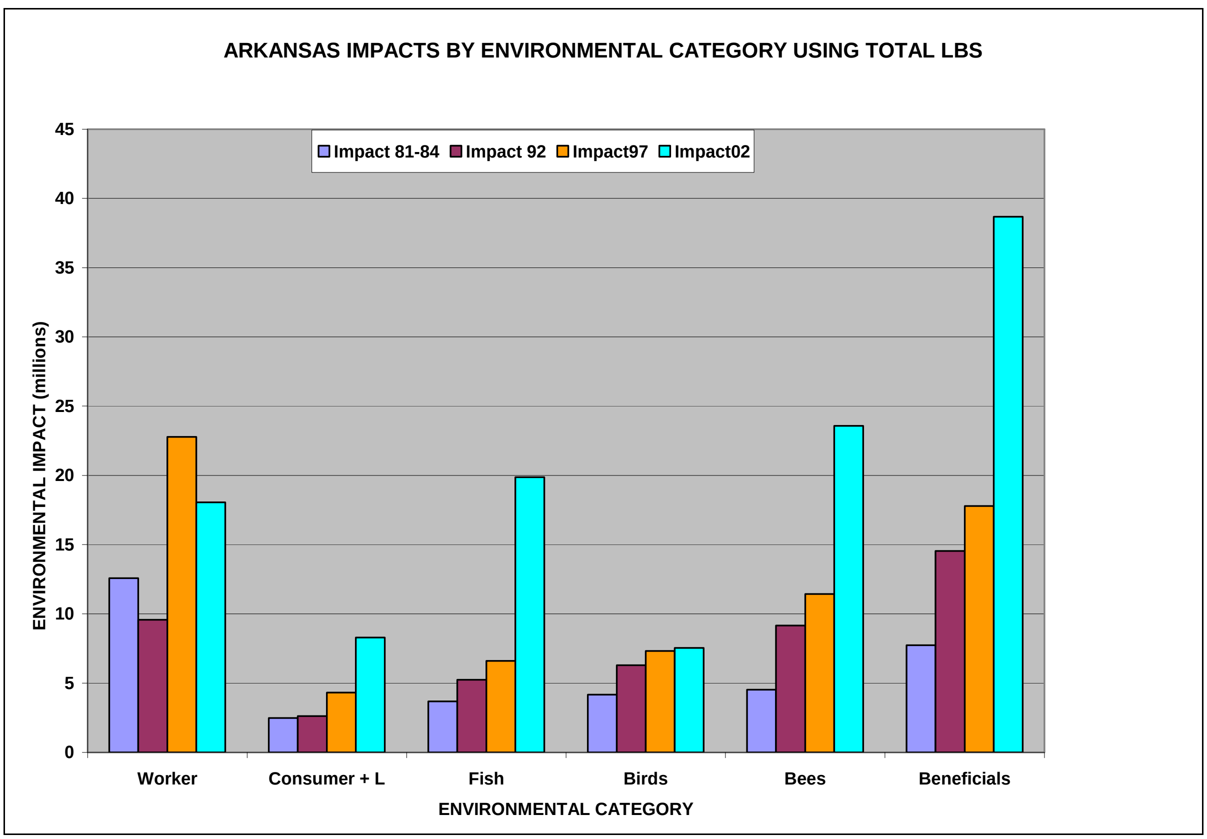
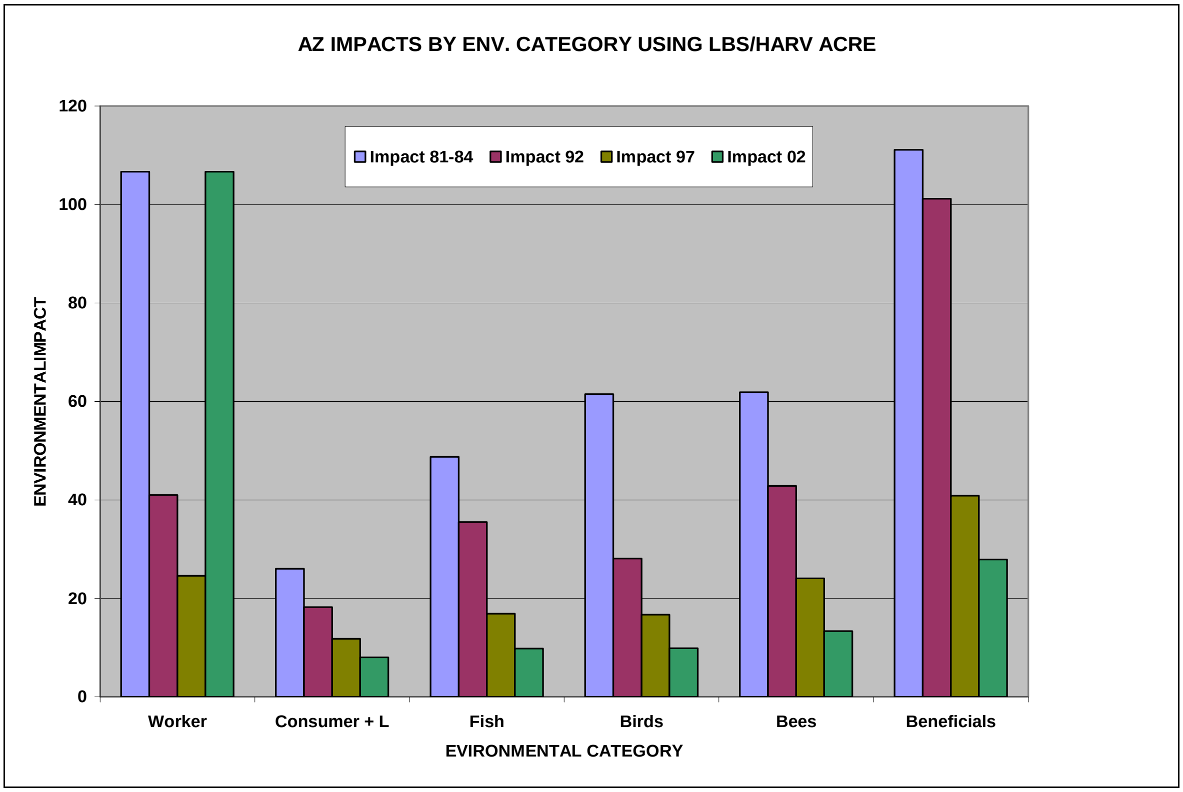


Figure 4.12: Arkansas Impacts by Environmental Category



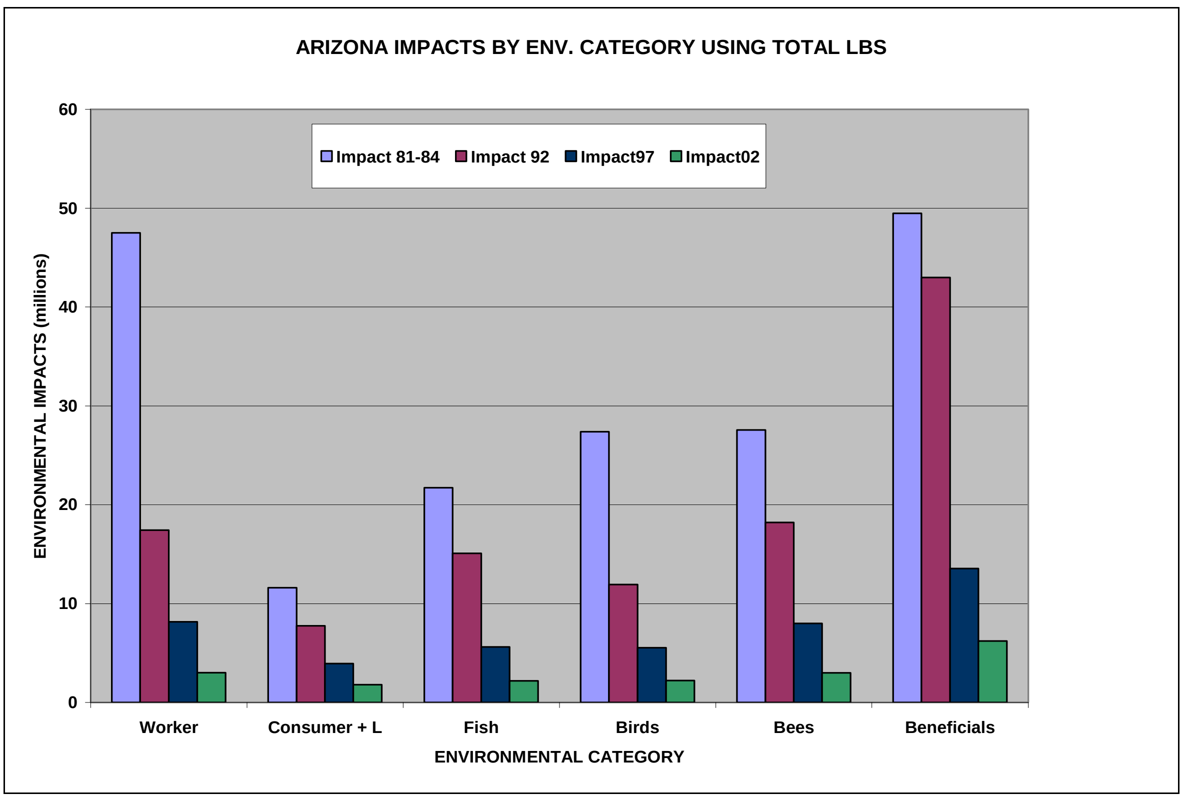
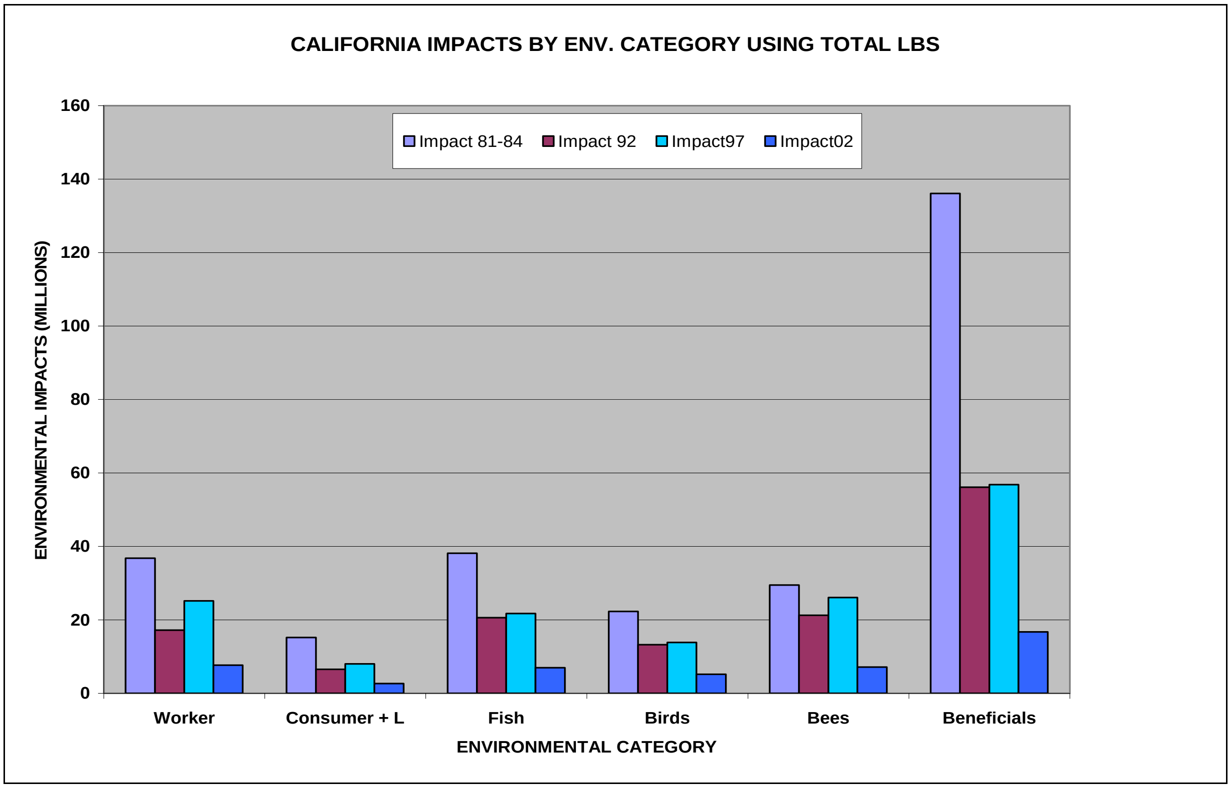


Figure 4.13: Arizona Impacts by Environmental Category



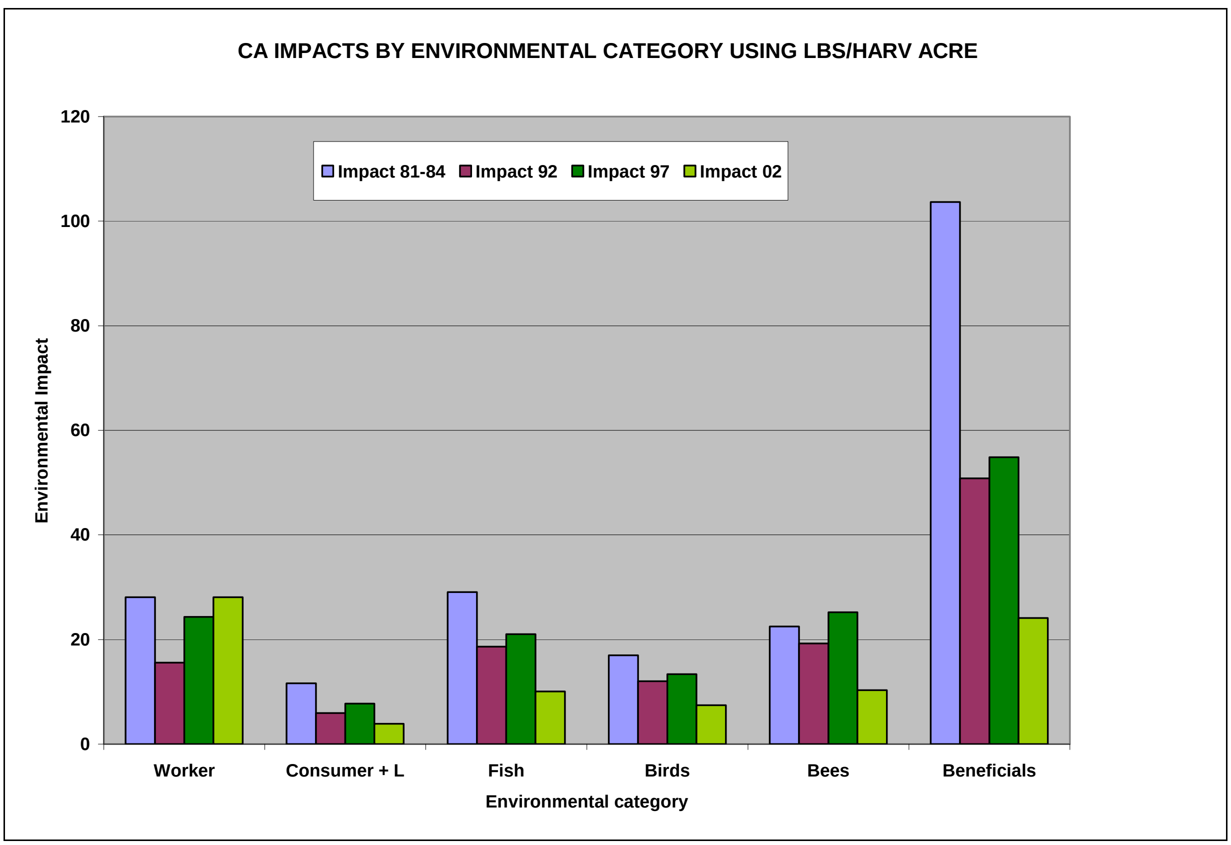
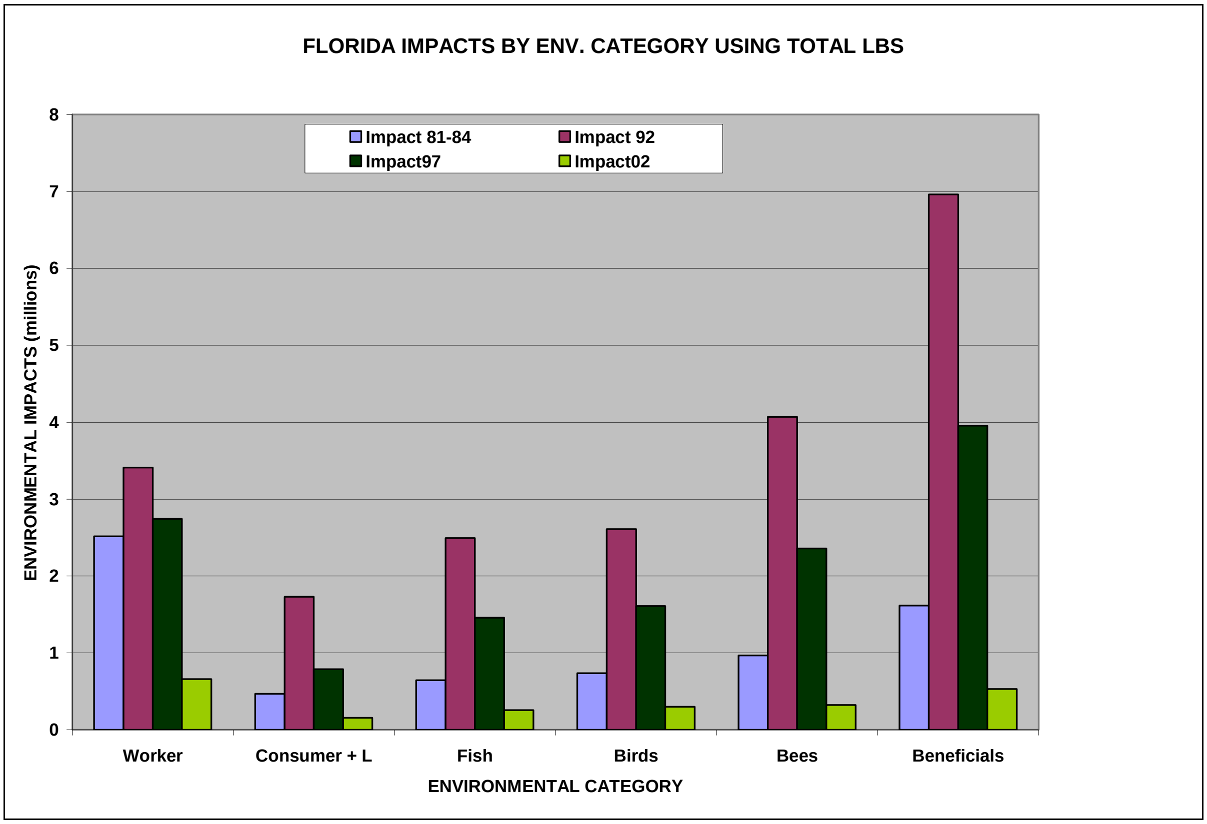


Figure 4.14: California Impacts by Environmental Category



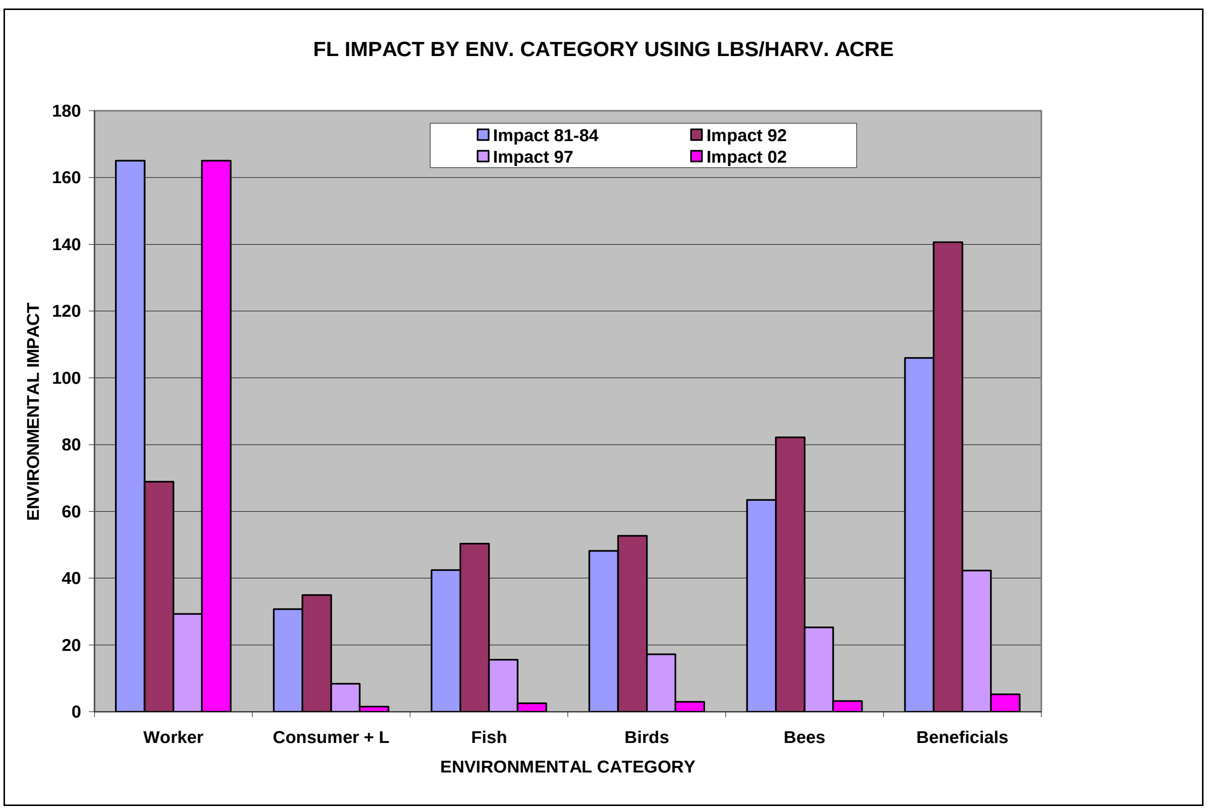
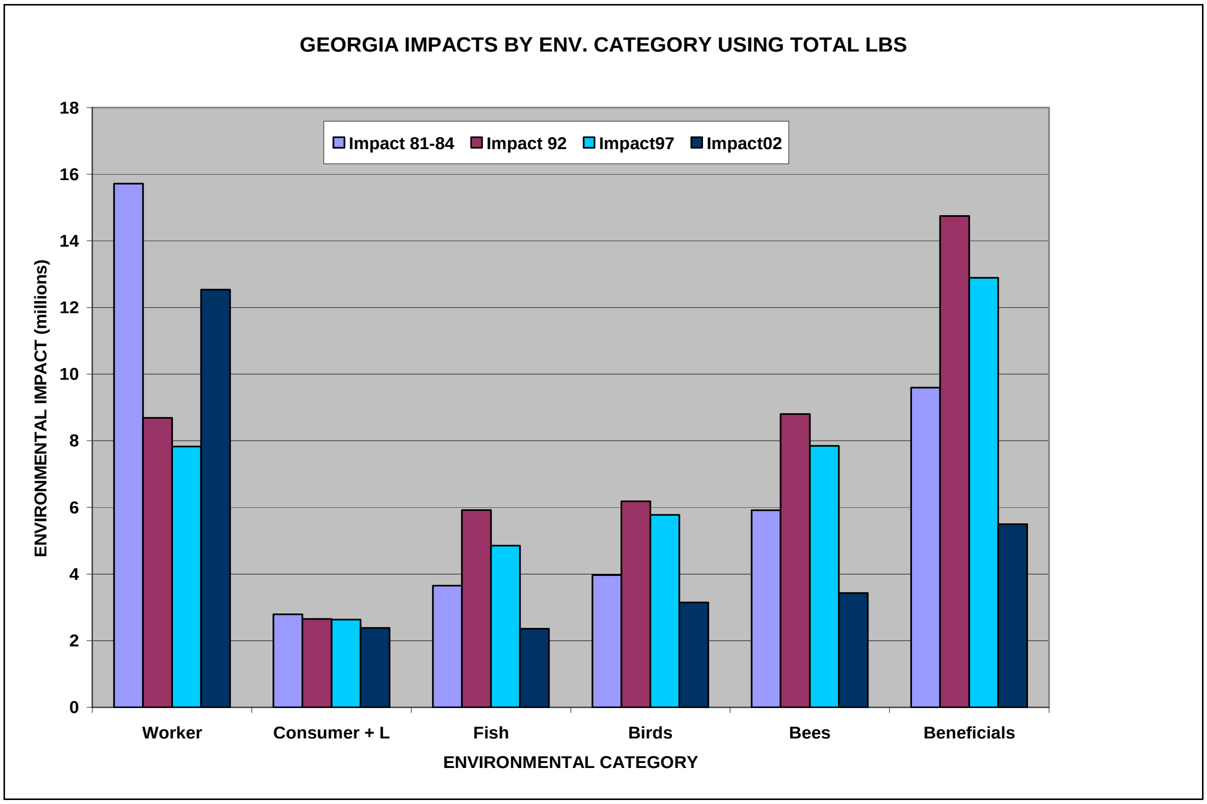


Figure 4.15: Florida Impacts by Environmental Category



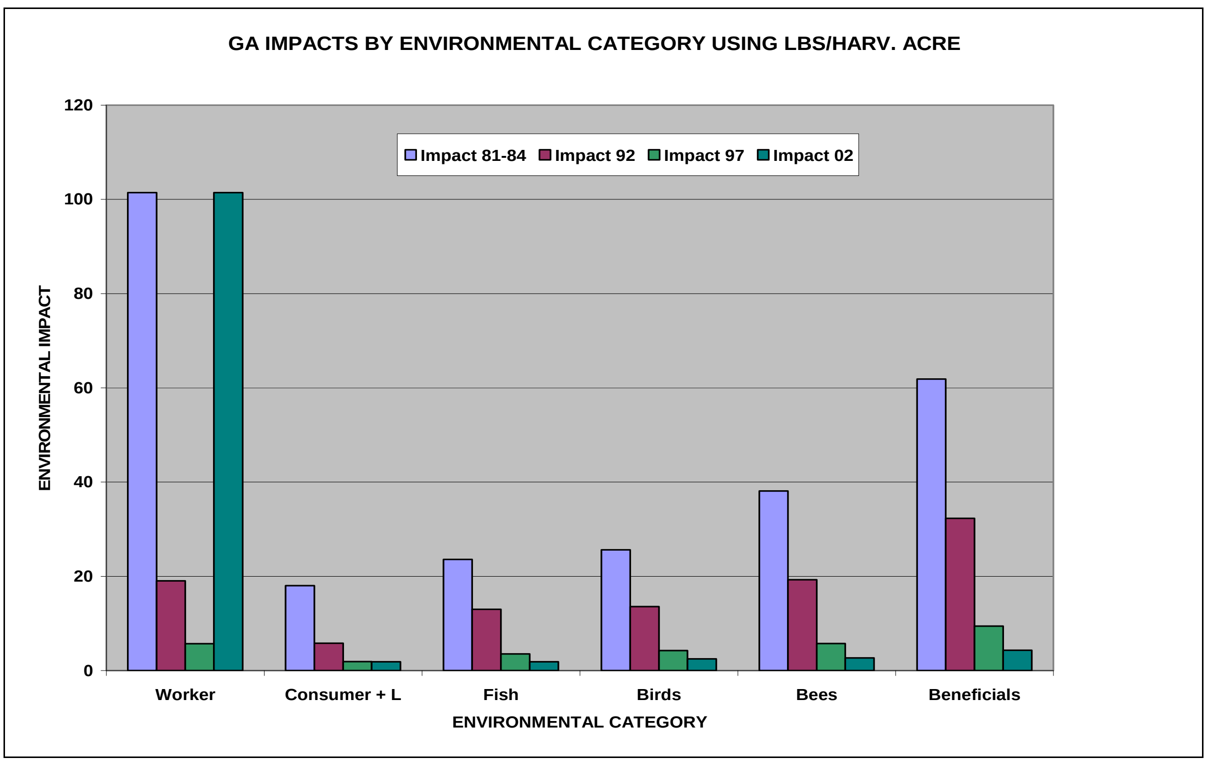
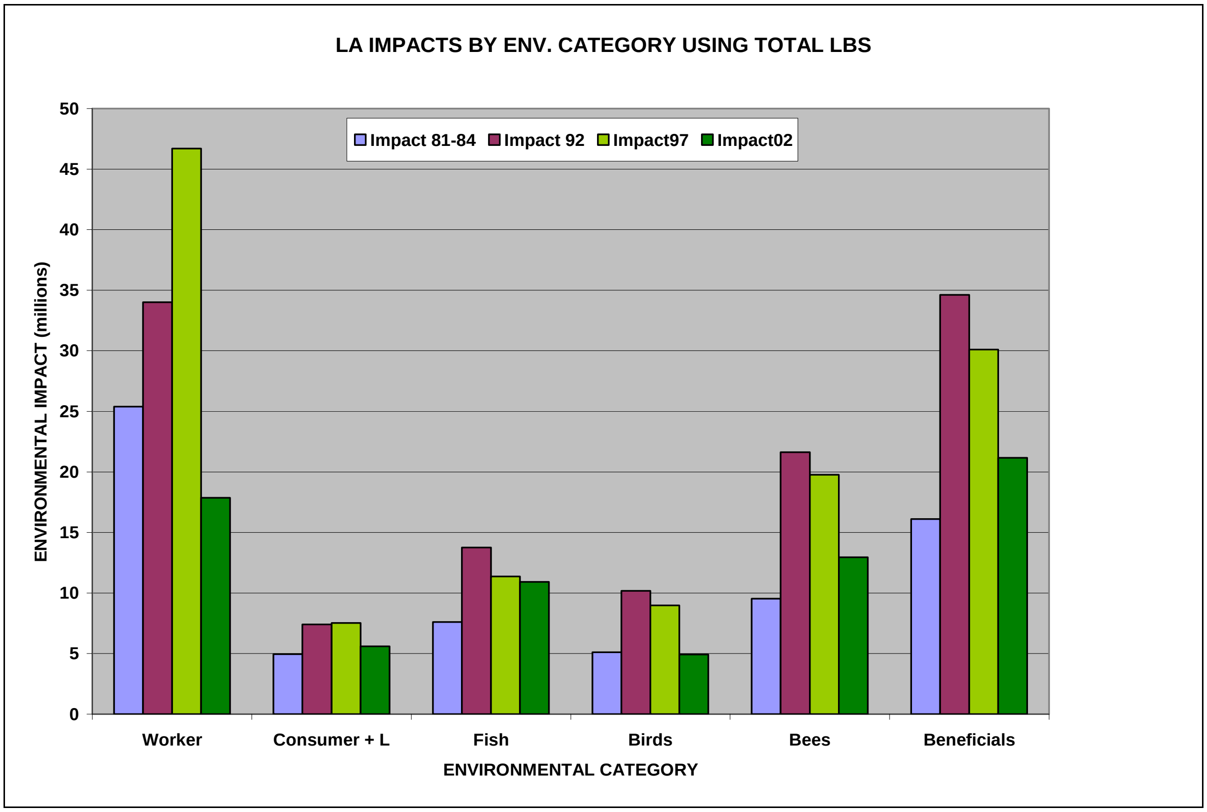


Figure 4.16: Georgia Impacts by Environmental Category



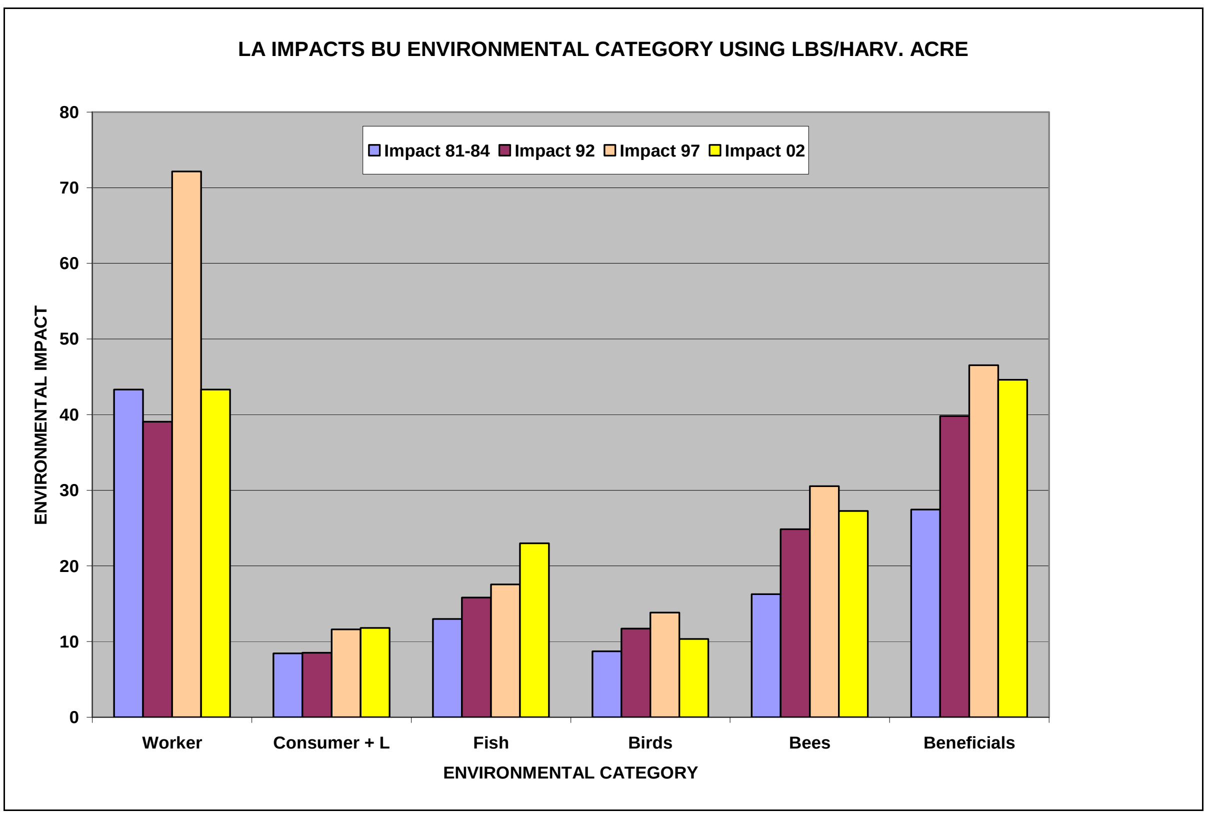
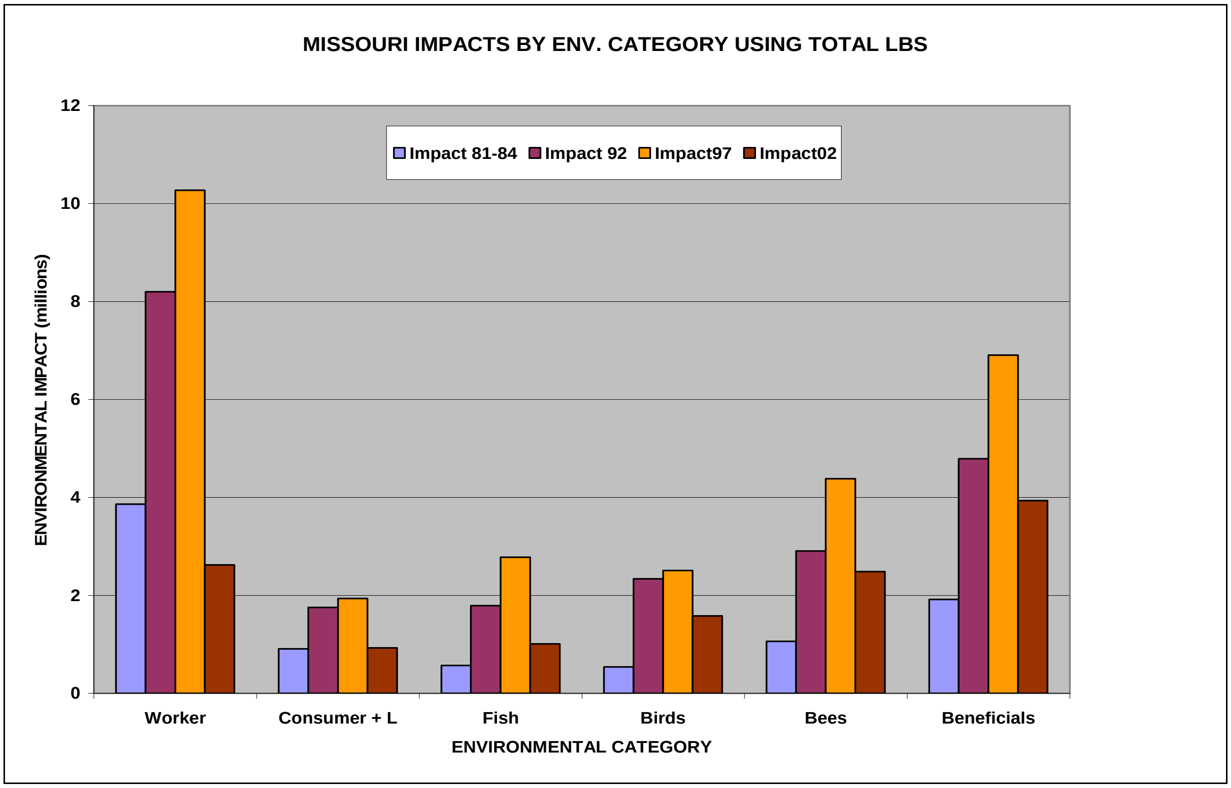


Figure 4.17: Louisiana Impacts by Environmental Category



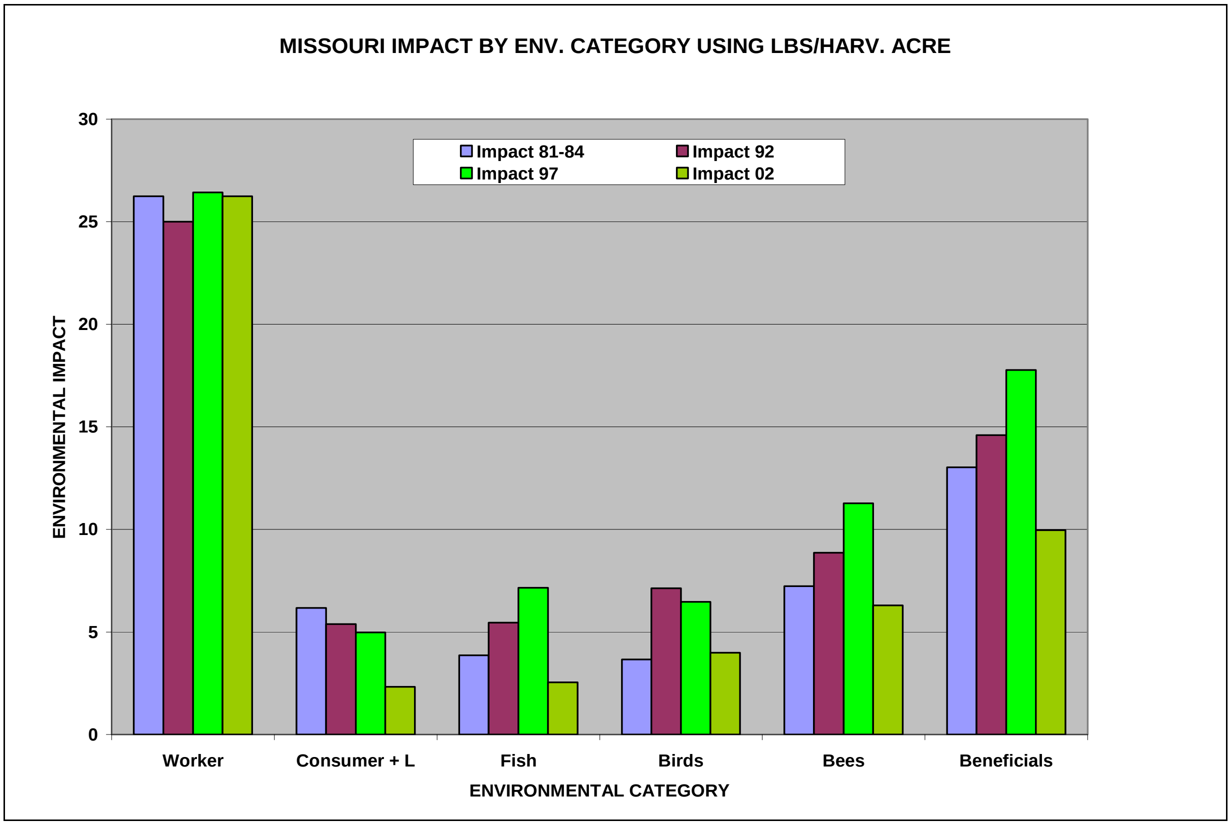
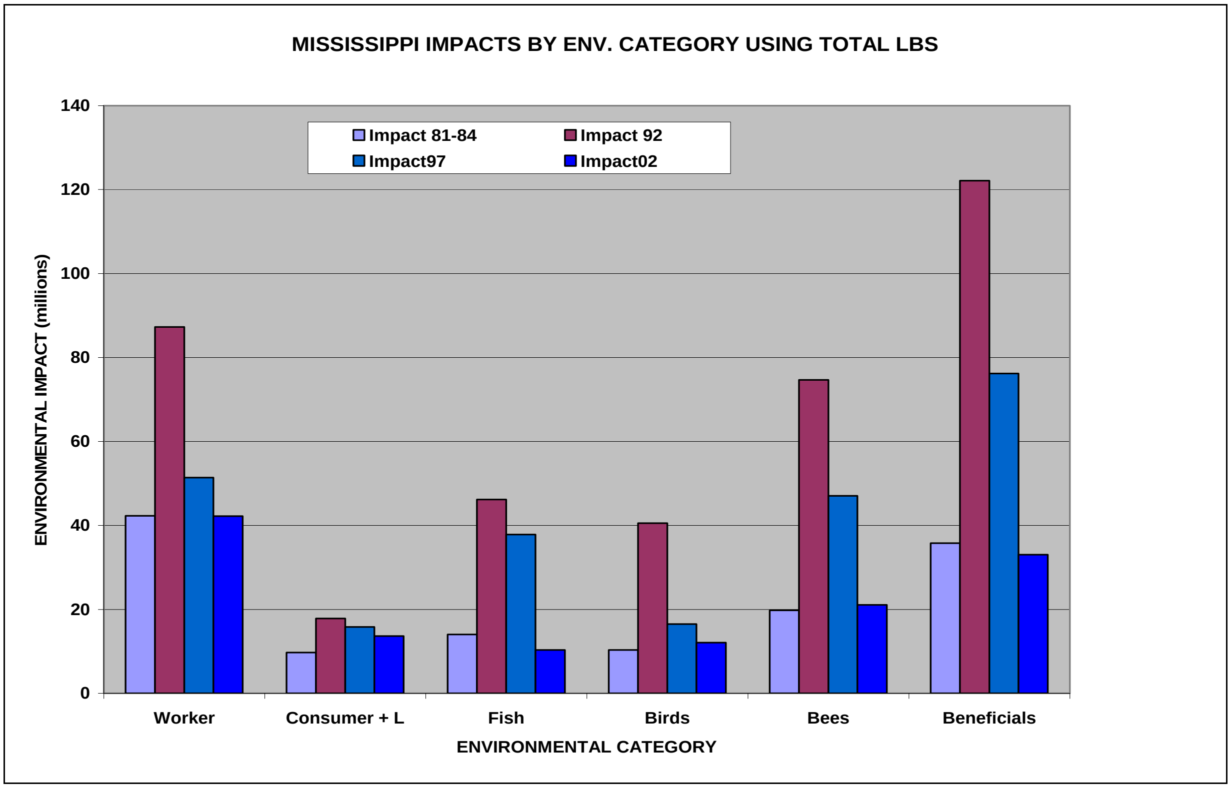


Figure 4.18: Missouri Impacts by Environmental Category



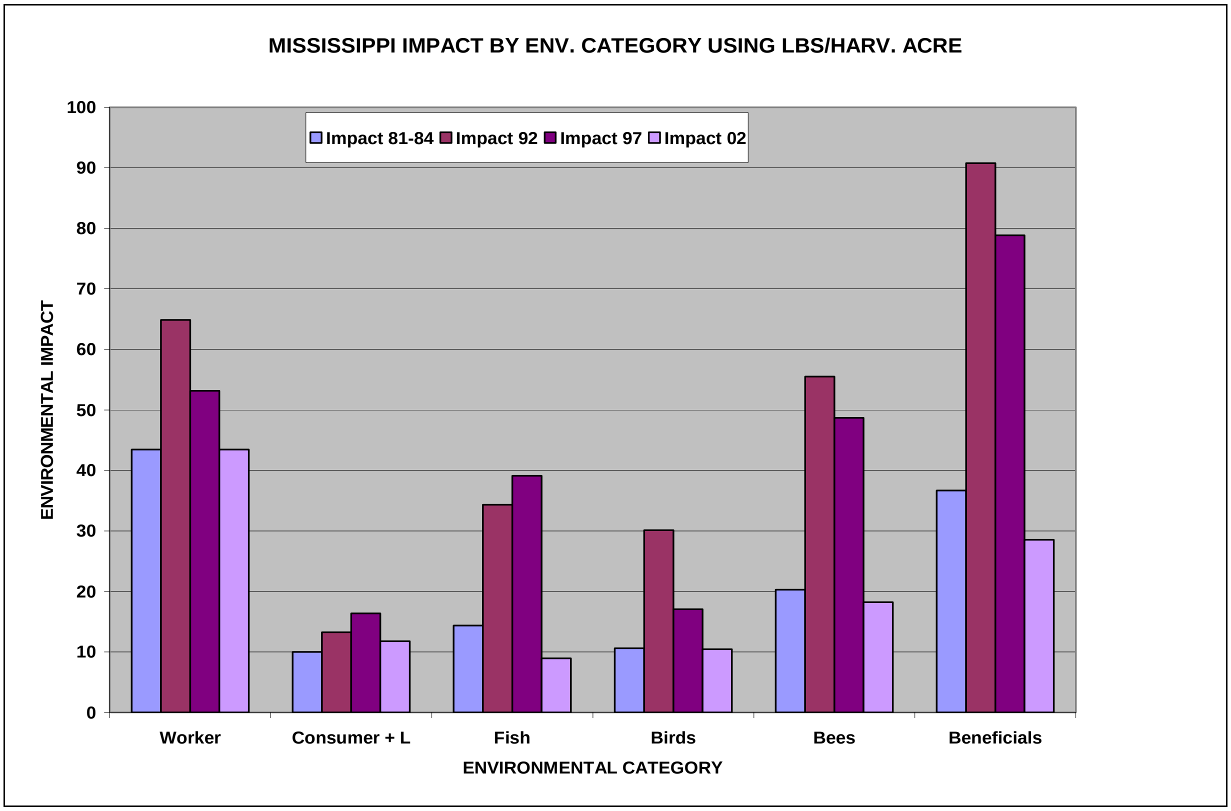
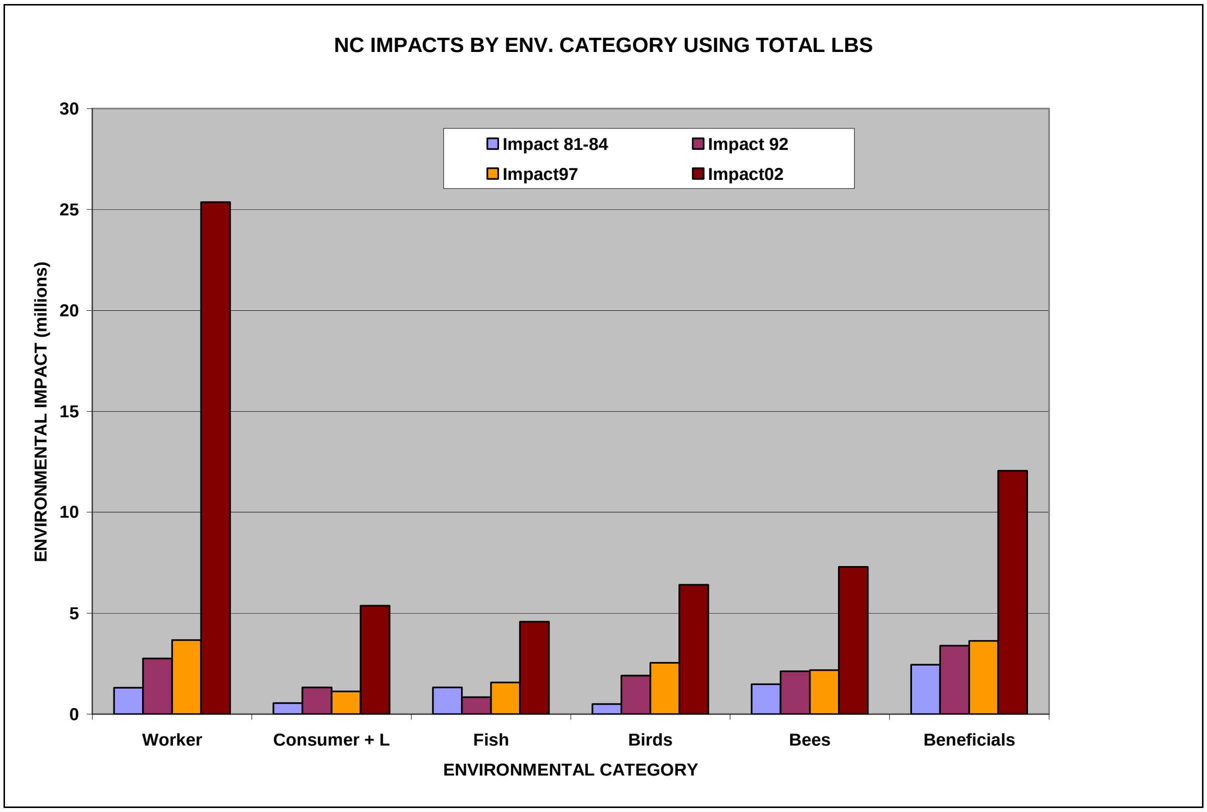


Figure 4.19: Mississippi Impacts by Environmental Category



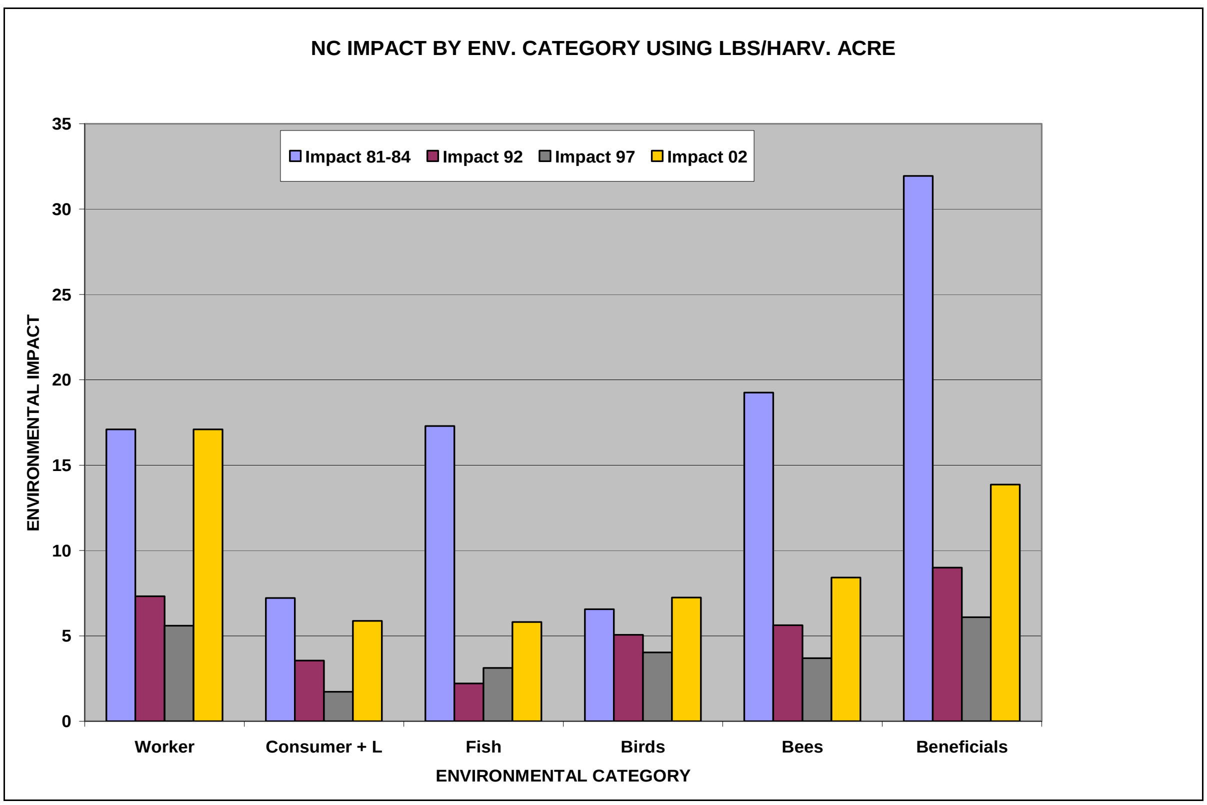
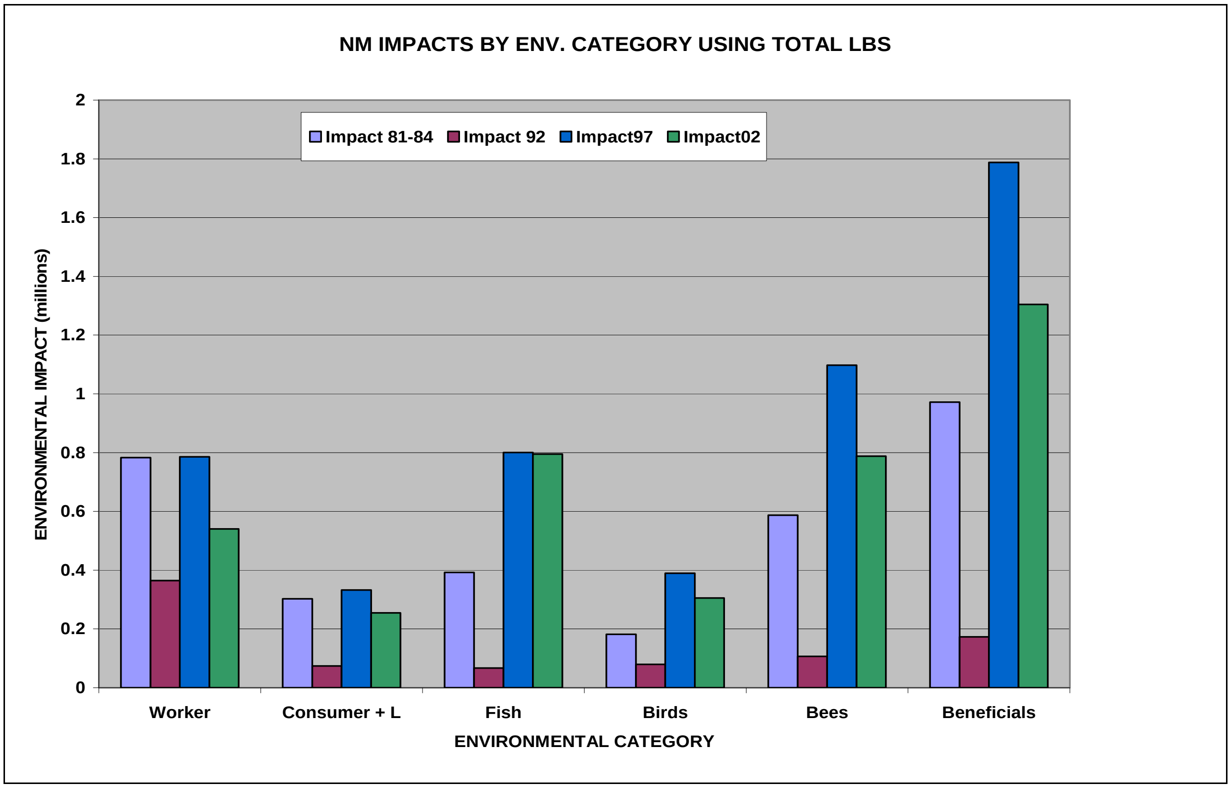


Figure 4.20: North Carolina Impacts by Environmental Category



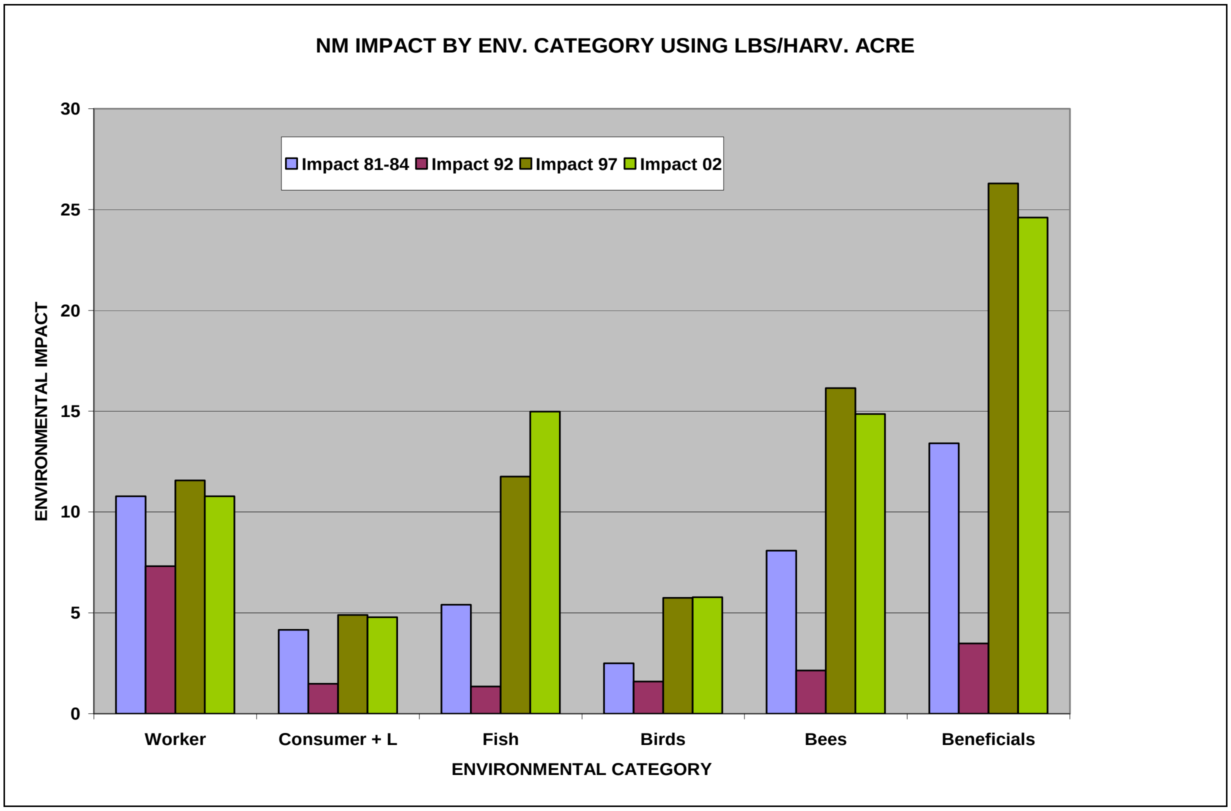
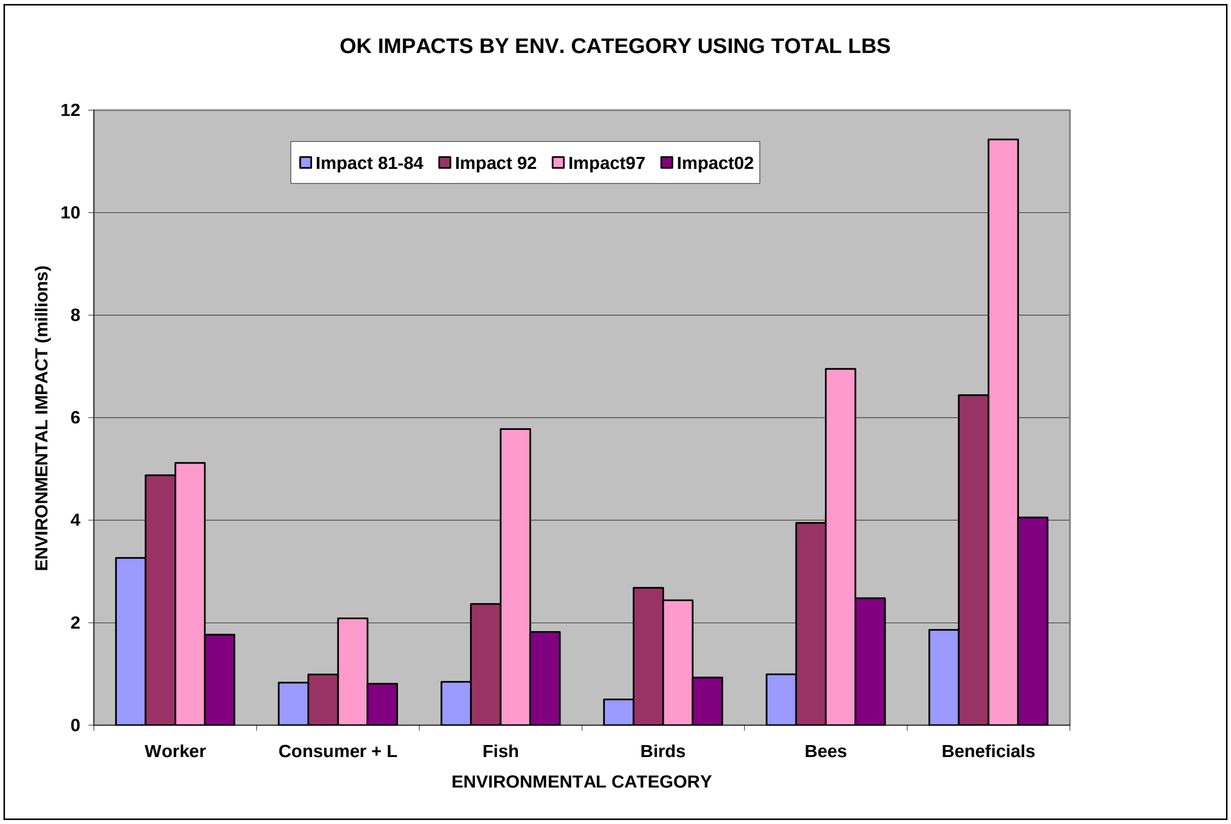


Figure 4.21: New Mexico Impacts by Environmental Category



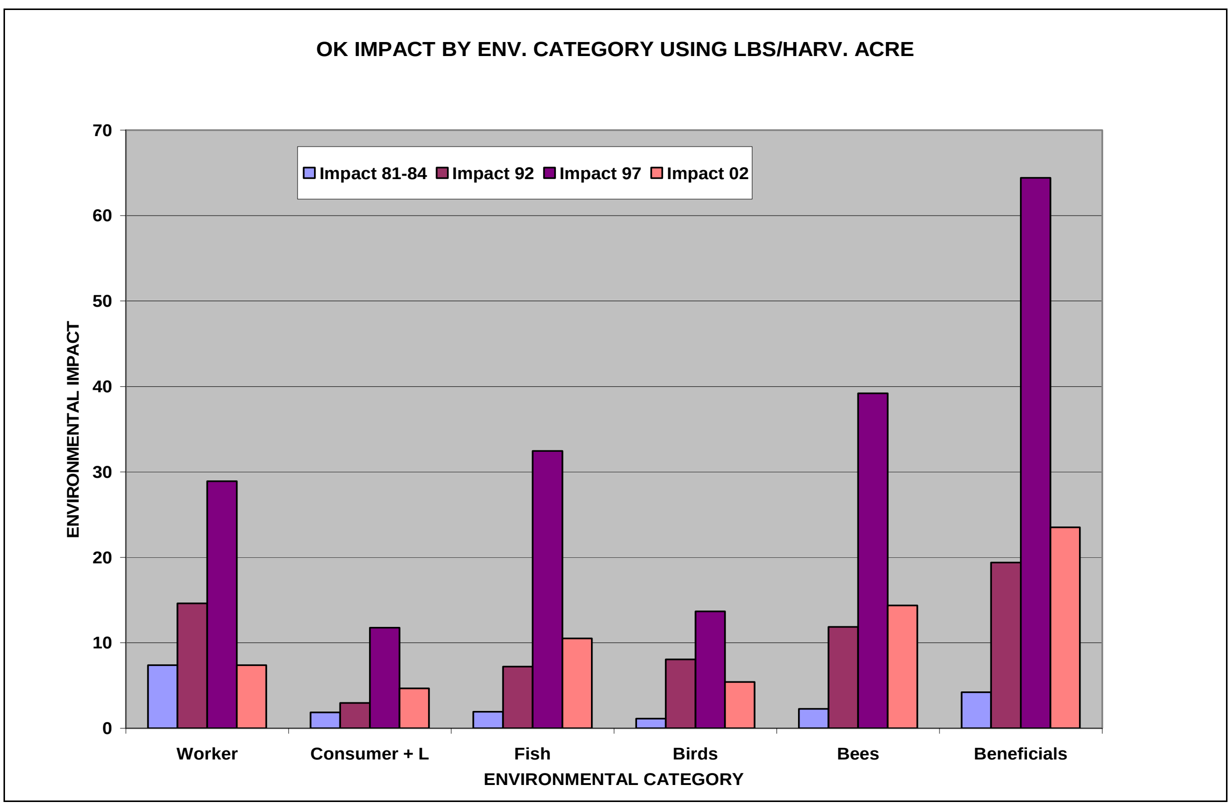
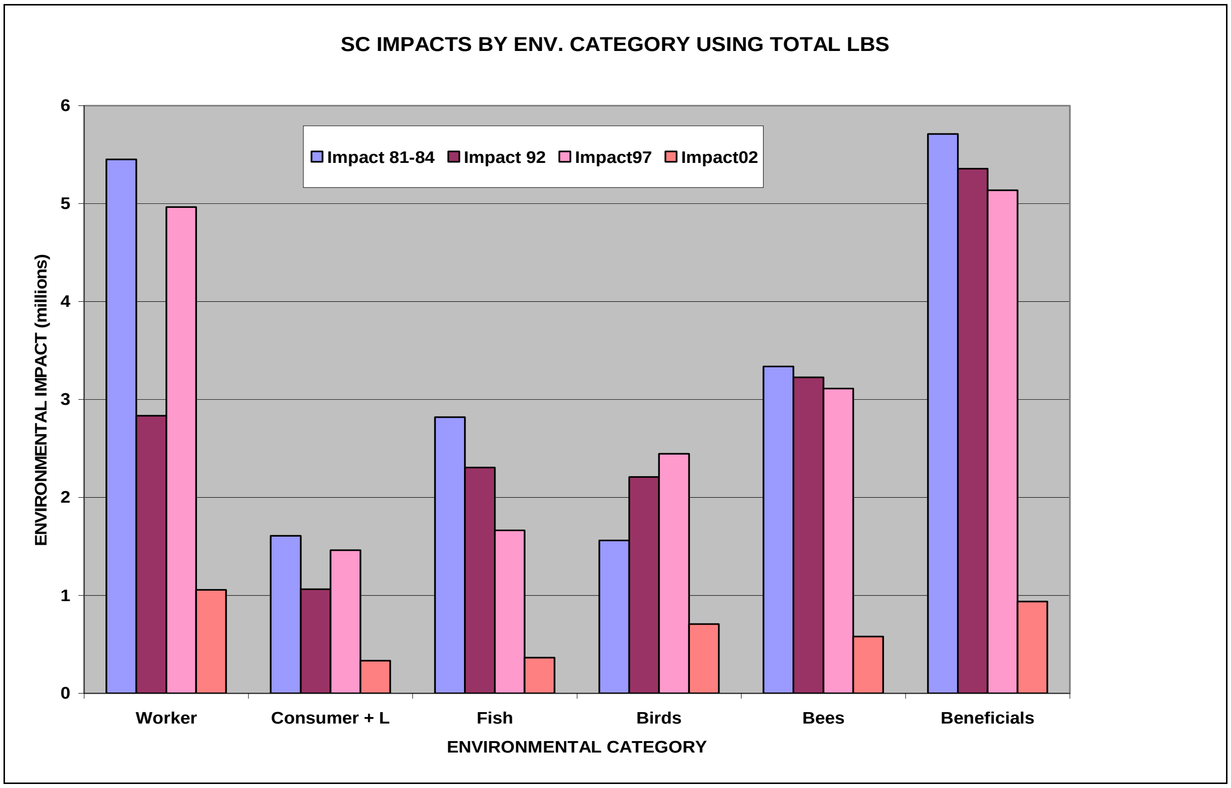


Figure 4.22: Oklahoma Impacts by Environmental Category



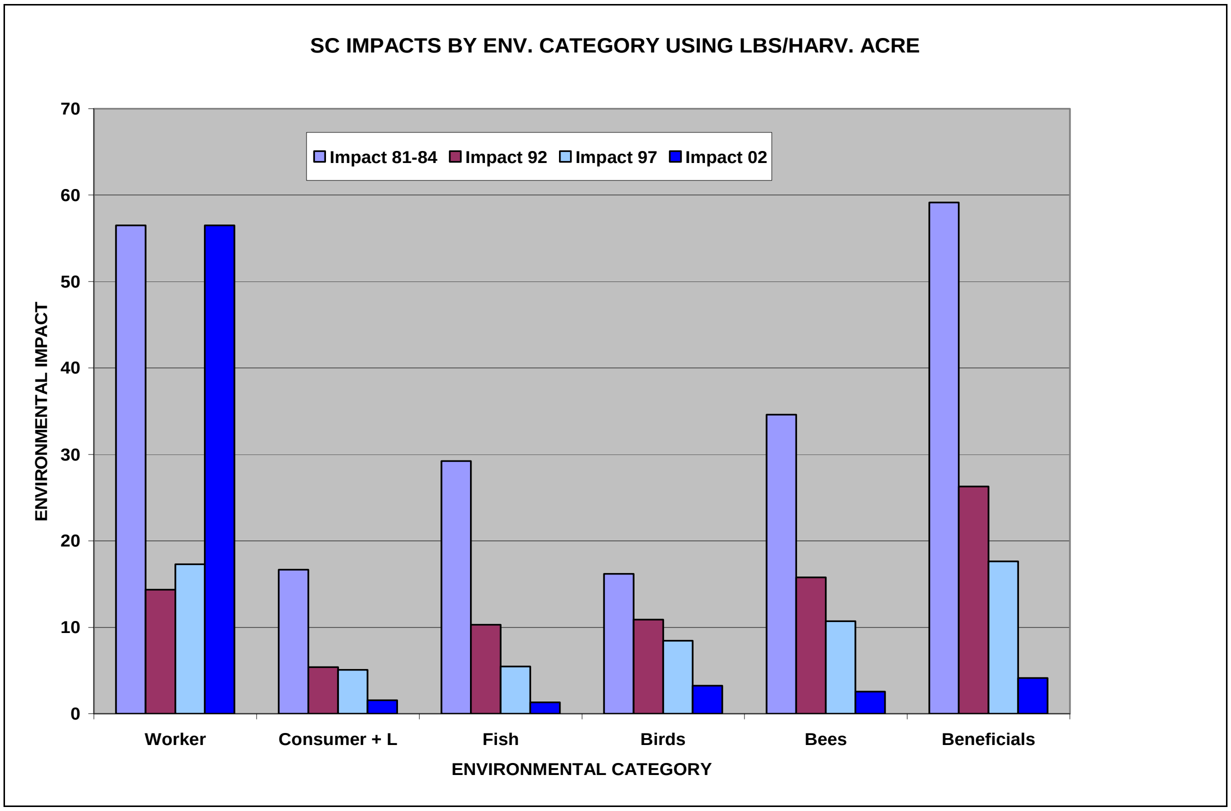
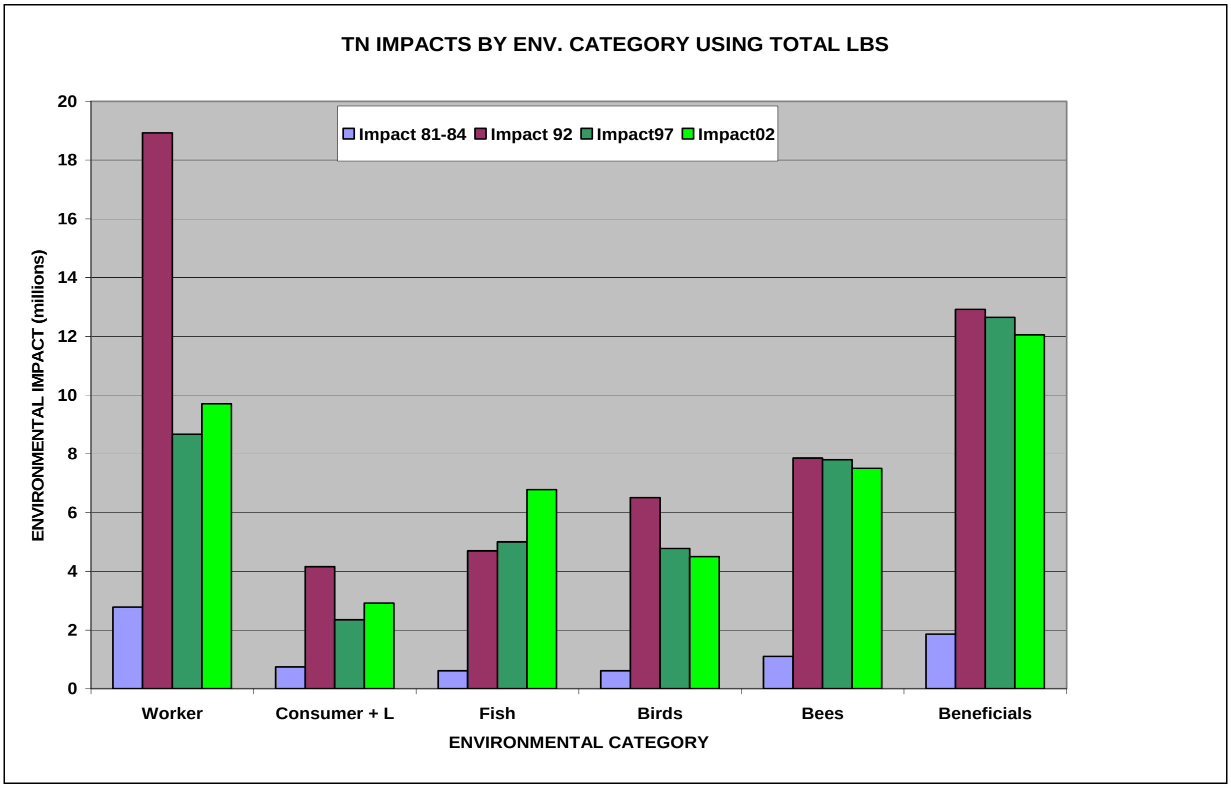


Figure 4.23: South Carolina Impacts by Environmental Category



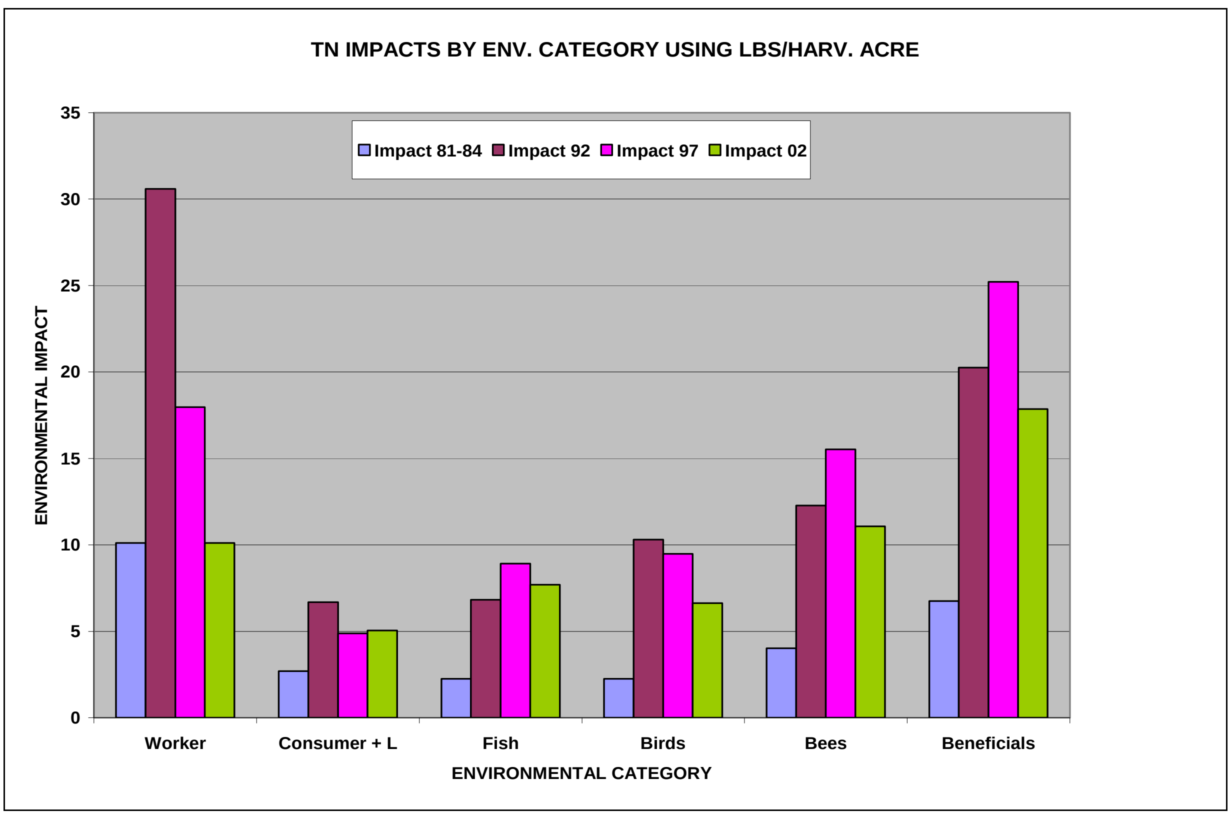
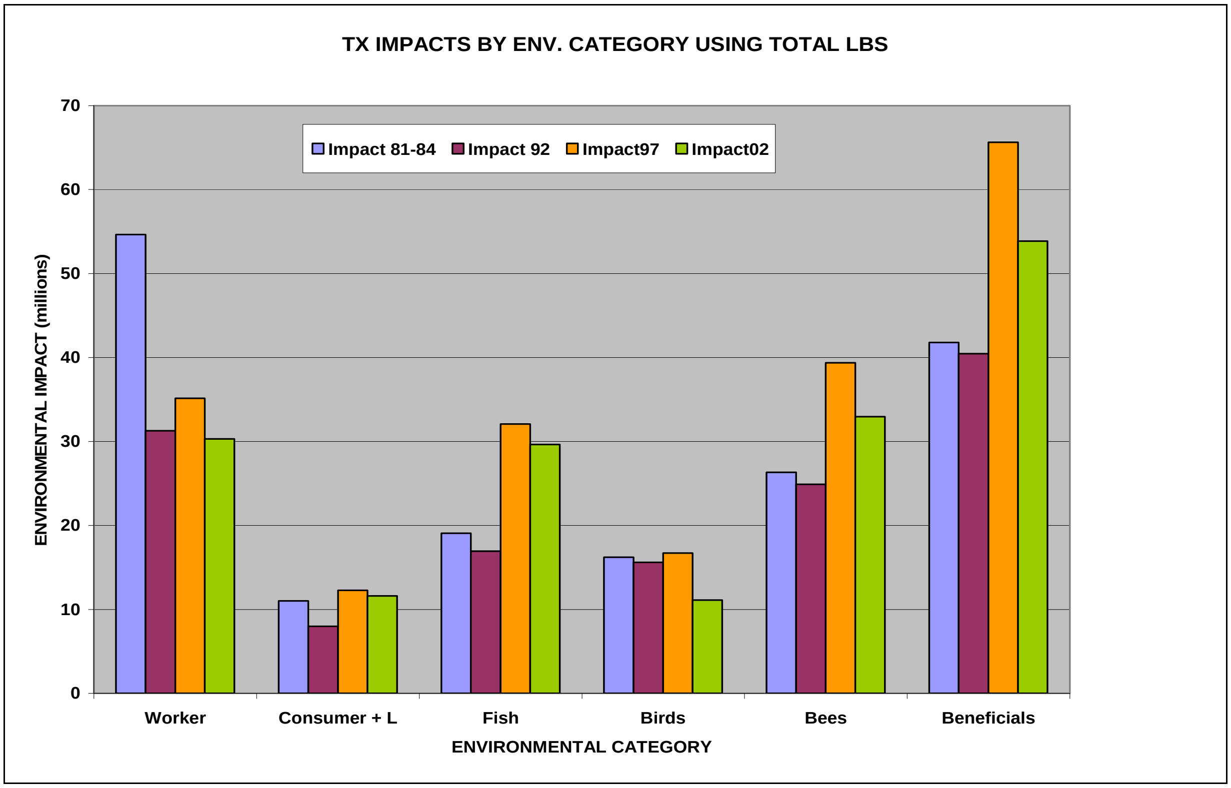


Figure 4.24: Tennessee Impacts by Environmental Category



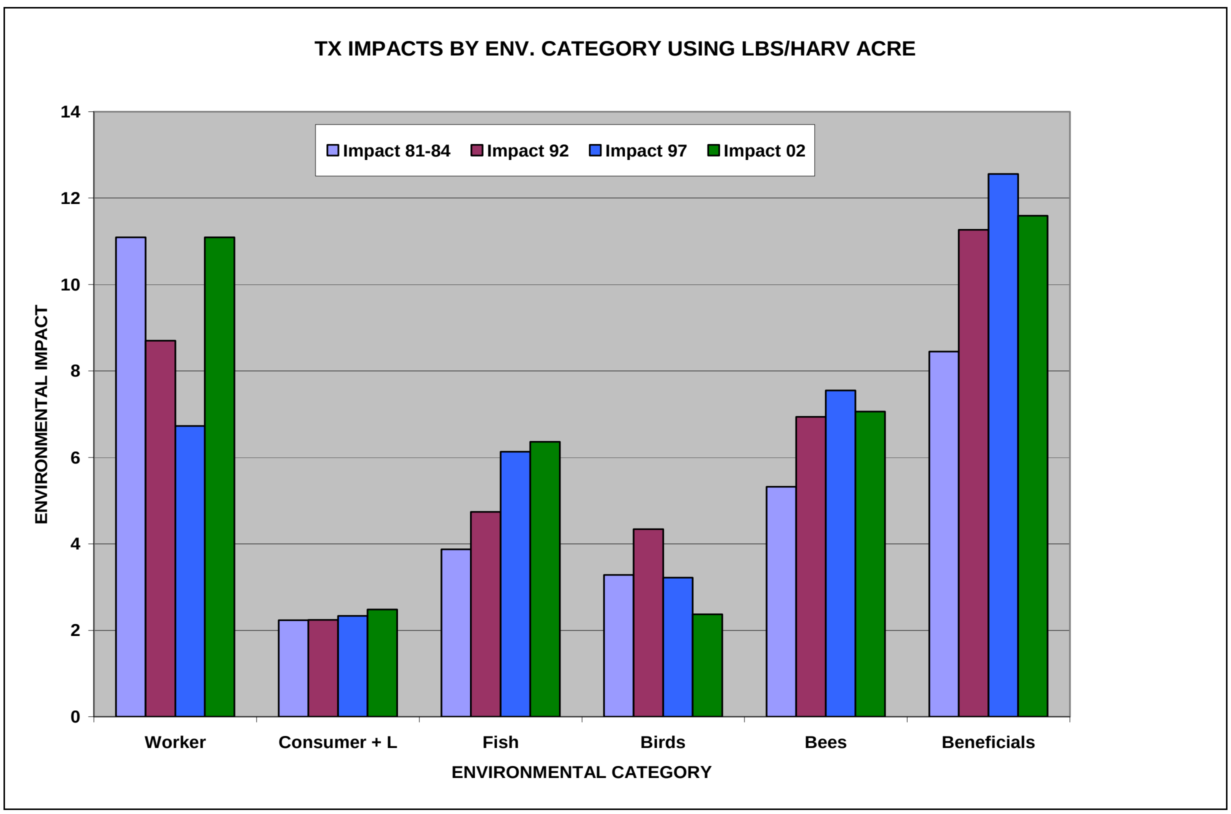
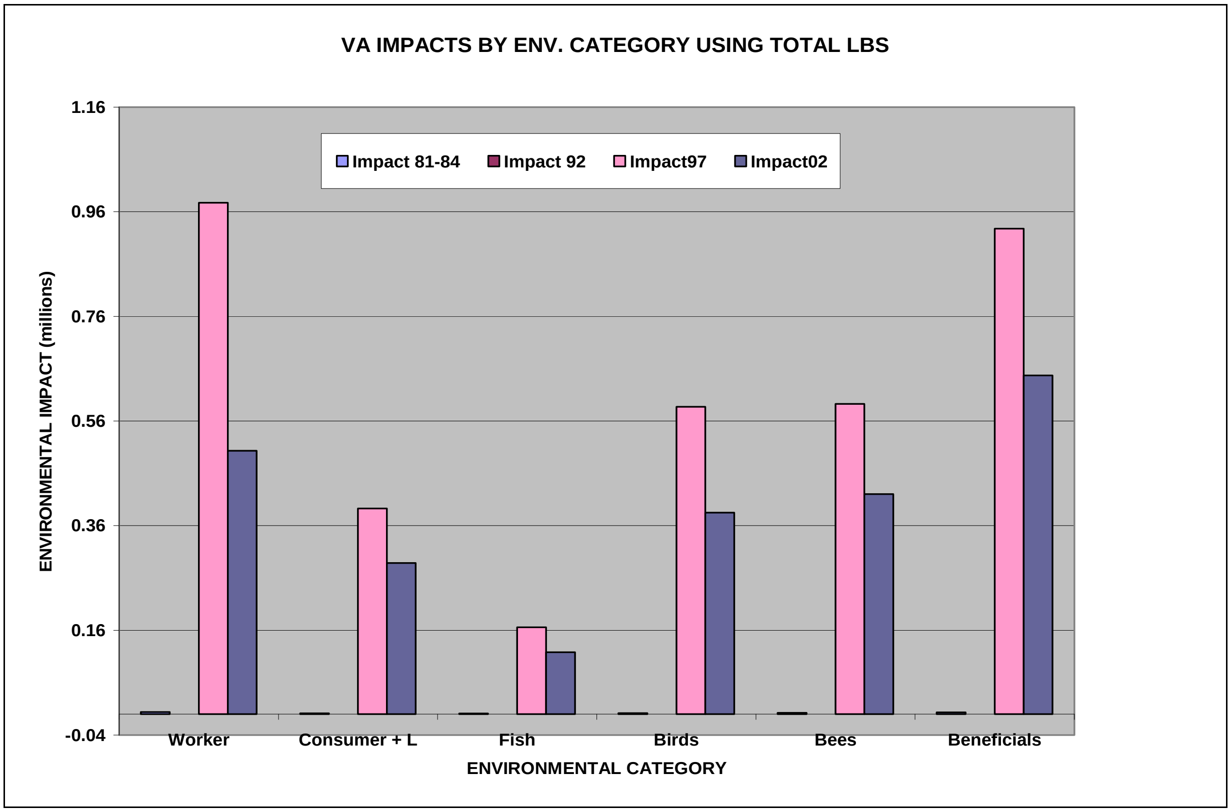


Figure 4.25: Texas Impacts by Environmental Category



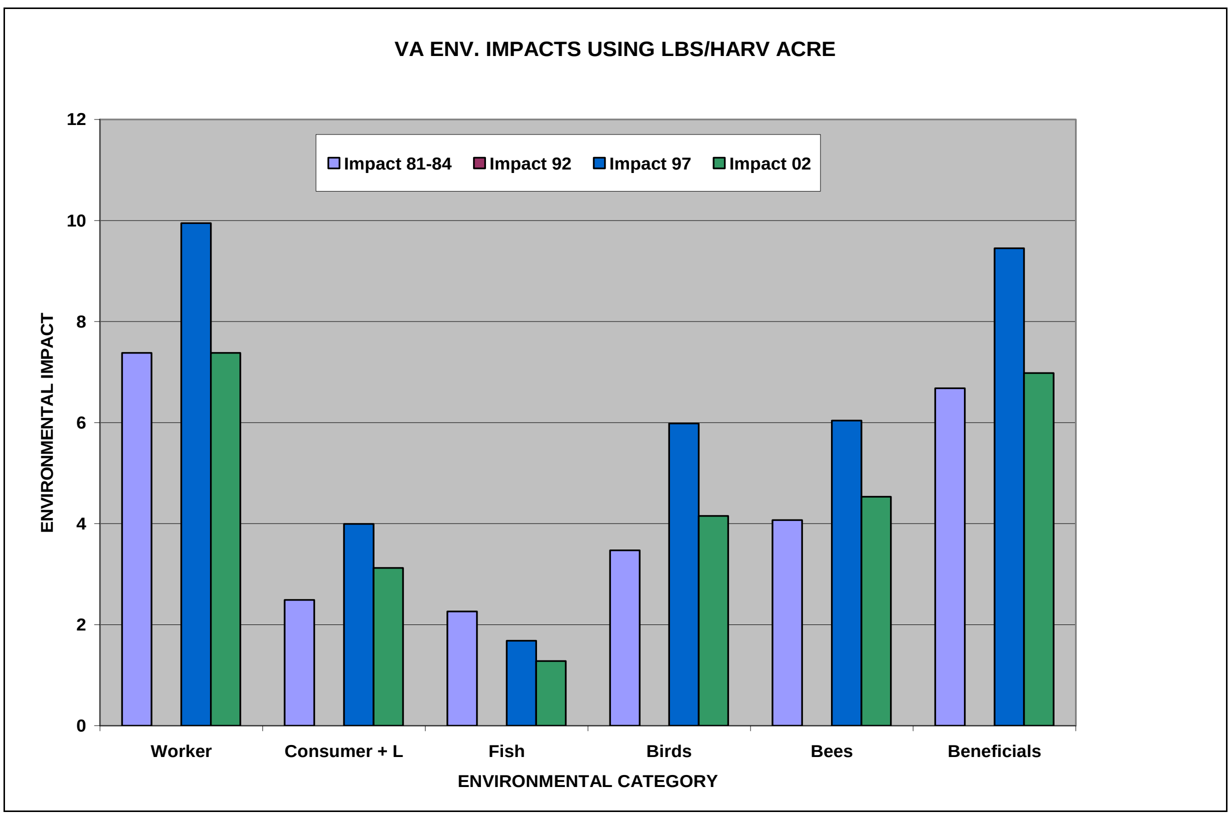


Figure 4.26: Virginia Impacts by Environmental Category

4.8 Conclusion

Cotton has always been a major contributor to the economies of the producing States. The arrival of the boll weevil and the subsequent control-related issues threatened this industry and the dependent local economies. Control of the boll weevil began with reliance on biological and cultural practices in the late 19th century. The discovery of Calcium arsenate in 1917 allowed cotton farmers to rely on chemical control. The discovery of synthetic organic insecticides after World War II offered an even more efficacious form of chemical control. The synthetic insecticides began with chlorinated hydrocarbons in 1945. Most cotton farmers of the late 1940s and early 1950s became accustomed to using insecticides on a season-long, fixed or calendar preventive treatment schedule irrespective of pest numbers or crop damage. Chemical control of the boll weevil brought with it the twin evils of environmental effects and destruction of natural enemies. Most notable were natural enemies of the bollworm/tobacco budworm complex (Heliothis sp.) and the cotton aphid, as evidenced by the frequent outbreaks of these pests during the calcium arsenate era (King et al. 1996).

U.S. crop production has relied in great part on pesticide use. Cotton production dependence on pesticides is even more pronounced, as evidenced by the fact that currently, cotton ranks second only to corn in pesticide use in the U.S (Gianessi and Reigner, 2006). Even though this reliance has been blamed in large part on the boll weevil, the cotton plant has historically been associated with a host of other pests. The principal ones include; cotton bollworm (*Heliothis zea*), tobacco budworm (*Heliothis virescens*), pink bollworm (*Pectinophera gossypiella*), cotton leafworm (*Alabama argillacea*), cotton aphid (*Aphis gossypii*), cotton fleahopper (*Psallus seriatus*), beet armyworm (*Euschistus conspersus*), Lygus (*Lygus hesperus*) and spider mites (*Tetranychus spp.*). For instance, the cotton leafworm caused major destruction in 1847 and continued to be a major pest of cotton for several years before the arrival of the boll weevil in the U.S. (Ridgway et al. 1983). Later on, the cotton bollworm was recognized as a major pest in Texas.

Some control against these two pests was achieved using Paris green (introduced in 1872 for control of the leaf worm), light traps, poisoned baits, sprays or dusts of arsenicals and trap crops (Ridgway et al. 1983). The boll weevil was however unresponsive to all these earlier forms of control. None of the other cotton pests achieved the notoriety of the boll weevil due to its rapid spread and difficulties in its control. The search for boll weevil control resulted in the "pesticide treadmill" situation due to (Ridgway et al. 1983) insecticide resistance. By the 1960's, problems of resistance to insecticides, secondary pest outbreaks (aphids, cotton bollworm) and environmental and health hazards emerged as a new wave of threat to the cotton industry. These problems served to steer the development of the boll weevil eradication program.

The problem of secondary pest outbreaks was first noticed during the Calcium arsenate era. This chemical killed predatory and parasitic insects that fed on cotton aphids and bollworms, resulting in the two insects becoming pests in their own right (Perkins, 1983). However, this was only a minor problem, solved by adding nicotine to the arsenical compound to kill the secondary pests. Secondary pests first became a serious problem after introduction of synthetic organic chemicals. On the other hand, environmental concerns about pesticide use did not become a prominent public issue until Rachel Carson wrote her book "Silent Spring" in 1962 (Perkins, 1982). In the book she addressed primarily the effects of pesticides on human and wildlife health. This helped change the public's view on the use of pesticides in agricultural production.

This study contributes to the existing literature by including a quantitative measure of the improvement in pesticide impacts. Previous literature has evaluated impacts from the boll weevil program in terms of reduced application rates, number of applications and total pounds applied. By using the EIQ to measure cotton pesticide impacts, we are able to show by how much the harmful impacts have declined. Additionally, we are able to show how each environmental component is affected by these pesticides.

CHAPTER 5: CASE STUDY II

ENVIRONMENTAL EFFECTS FROM METHYL BROMIDE BAN: AN APPLICATION TO FLORIDA TOMATO PRODUCTION

5.1. Introduction

The United States (U.S.) consumes the most methyl bromide annually, 42 million pounds (29.4 percent) of the worlds' 143 million (U.S. EPA, 1997). Of this share, 83 percent is used for pre-plant soil fumigation, 11 percent for post-harvest treatment of stored commodities, and 6 percent for fumigation of structures (Rosskopf et al., 2005). The National Center for Food and Agricultural Policy (NCFAP) estimated that about 35 million pounds (active ingredient) of methyl bromide are used annually for pre-plant soil fumigation in the U.S. The uses among different crops are shown in Figure B.1. Florida and California are the top methyl bromide users in the U.S. because the weather conditions in these two states favor higher pest populations. Florida accounted for 36 percent of the pre-plant methyl bromide use in 1997. Crops depending on methyl bromide for fumigation in Florida include tomato (50 percent), bell peppers (32 percent), strawberry (12 percent), others; cucumber, summer squash, water melon and muskmelon (Fig B.2). A methyl bromide phase-out program has received widespread attention because there is not yet a single chemical alternative that can completely replace methyl bromide (Anderson and Lee-Bapty, 1992; Duafala, 1996).

5.1.1. Tomatoes

Tomatoes are a member of the botanical family *Solanaceae*. Commercial tomato production did not begin until after 1860, when tomatoes were finally accepted by consumers (Orzolek et al., 2006). Tomatoes are generally a warm-season crop. The U.S. is one of the world's leading tomato producer, second only to China. Tomatoes (Lycopersicon esculentum) grown in the U.S. are mainly for the fresh and processing markets. Fresh-market tomatoes are grown in every State in the nation. Florida however, is the leading fresh-market tomato producing State in the U.S. ($\geq$ 40 percent), with California coming in second (about one third of U.S. production). Major Florida growing regions are partitioned into four districts, namely: district 1 (Dade County), district 2 (east coast), district 3 (southwest), and district 4 (Tampa Bay area) (Figure B.3). The East Coast comprises Broward, Palm Beach, Martin and St Lucie counties. The southwest includes Collier, Hendry and Lee counties. The Tampa Bay area includes Hillsborough, Manatee, Hardee and Sarasota counties. Another major tomato growing county is Gadsden in the north of Florida. California, on the other hand, is the leading processing-market tomato producer (accounting for 95 percent of all U.S. processing tomato output) not only in the U.S., but in the whole world as well.

In the past, tomato producers relied heavily on methyl bromide (MeBr) as a broad spectrum soil fumigant for the management of soil insects, pathogens, nematodes and weeds. Despite this widespread dependence on MeBr, this fumigant has been found to be associated with serious health effects and to cause stratospheric ozone layer depletion. Hence, its phase-out was mandated by the U.S. Environmental Protection Agency (EPA) to help mitigate these effects. In 2007, tomato production accounted for 25% of MeBr use in the U.S. Methyl bromide in combination with chloropicrin is applied to more than 80 percent of Florida's tomato acreage.

Methyl bromide is applied at least two weeks prior to planting transplants for management of soil insects, pathogens, nematodes and weeds (especially nutsedges).

5.1.2. Tomato problems

Tomato production in Florida poses several challenges in terms of weeds, pests, diseases, and, fruit disorders due to extreme soil moisture and weather conditions. Warm temperatures ($\geq 20^{o}C$) are the norm between March and November (Santos 2007). Some of the common diseases are; bacterial canker, bacterial speck, bacterial spot, leaf blights, viruses, early blight, late blight, anthracnose, and bacterial soft rot can cause huge crop losses. Main tomato pests include; Colorado potato beetles, aphids, corn ear worm, European corn borer, armyworm, thrips, whiteflies, spider mites, and fruit flies. Weed species regularly occurring in Florida vegetables include grasses and sedges. According to Santos (2007), the main grasses are crabgrass (*Digitaria*), bermudagrass (*Cynodon*), barnyardgrass (*Echinochloa*), goosegrass (*Eleusine*), and fall panicum (*Panicum*), and the broadleaves pigweed (*Amaranthus*), common purslane (*Portulaca*), common lambsquarters (*Chenopodium*), nightshade (*Solanum*), Florida pusley (*Richardia*) eclipta (*Eclipta*), sida (*Sida*), evening primrose (*Oenothera*), and beggarweed (*Desmodium*). These weeds usually grow in row-middles and through planting holes. The sedges are purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*C. esculentus*), which usually penetrate the polyethylene mulch, making them very difficult to control.

After emergence, weeds can be controlled using herbicides, plastic mulch, or a good crop-rotation system. Plant diseases and fruit disorders can be managed using fungicides and disease-resistant varieties, maintaining proper plant nutrition, rotating crops, and growing in soil with good air and water drainage. Pests can be controlled using insecticides, but monitoring using traps and scouting can help reduce insecticide use substantially (Orzolek et al., 2006). Methyl bromide enabled producers to achieve control of most of these problems before they emerged.

5.2. Major uses and Sources of Methyl Bromide

Methyl bromide, an odorless, colorless gas used as an agricultural pesticide, was introduced in the 1980s as an effective way to control weeds and increase fruit yields. Common or trade names include: Brom-o-Gas, Bromomethane, Celfume, Embafume, Haltox, MB, MeBr, Methogas, Profume, Terr-o-Gas and Zytox. Methyl bromide (MeBr) was historically used as an industrial fire extinguishing agent and was introduced in the U.S. from Europe in the 1920s. Current uses of Methyl bromide include fumigation inside dwellings/homes and other structures (office buildings, warehouses, silos, mills, vaults, ships and freight cars) to control termites, insects and rats. These quarantine uses are currently exempt from the ban.

Methyl bromide is also used to fumigate soil, usually under gas-proof sheeting to control pests in soil, mainly; nematodes, fungi, insects, and weeds, and orchards before planting, and fruits and vegetables after harvest. It has been used on more than 100 crops worldwide, the main ones being strawberry, bell pepper, and tomato. Soil fumigation consumes the bulk of methyl bromide production. For instance, methyl bromide usage on Florida tomatoes has previously ranged from 5,159,400 to 8,229,800 pounds of active ingredient annually (USDA-NASS, 1992-2004).

Methyl bromide is a highly effective broad-spectrum soil fumigant, applied generally before planting in combination with chloropicrin, to control soil-borne diseases, nematodes and weeds of economically important crops. Florida and California use MeBr on fruits and vegetables to fight microscopic parasitic roundworms known as root-knot nematodes, and major soil-borne diseases such as bacterial wilt, southern blight, Fusarium wilt (*Fusarium oxysporum f. sp. lycopersici*), and Fusarium crown and root rot (*Fusarium oxysporum f. sp. radicis-lycopersici*).

In 1991, however, Methyl bromide was listed by the Parties of the Montreal Protocol as an ozone-depleting substance (ODS). Due to its high ozone depletion potential (ODP) of 0.6, it was placed under the U.S. Clean Air Act of 1990. Under this Act, the importation and production of methyl bromide was to cease by the year 2001, with total phase-out from developed countries by 2005 (Osteen, 2003; U.S. Department of Agriculture (USDA), 2008a; U.S. Environmental Protection Agency, 2008).

Apart from ozone depletion, there are a number of other concerns that have led countries to impose restrictions on MeBr use. These concerns include residues in food, toxicity to humans and associated operator safety and public health, detrimental effects on soil biodiversity, and pollution of surface and ground water. As indicated by the U.S. Department of Agriculture, the phase-out of MeBr as a pre-plant soil fumigant may have substantial impact on the production levels of many agricultural crops due to adopting more expensive and less effective alternatives. This is mainly because so far there is no known single alternative fumigant, chemical, or other technology that can readily substitute for MeBr in efficacy, cost, ease of use, availability, worker and environmental safety (Osteen, 2003; U.S. Department of Agriculture (USDA), 2008a).

The Methyl Bromide Technical Options Committee (MBTOC) defined ‘alternatives’ as those non-chemical or chemical treatments and/or procedures that are technically feasible for controlling pests, diseases and weeds, thus avoiding or replacing the use of MeBr. The search for substitutes / alternatives has been hampered by findings that indicate the risks from such substitute chemicals may be as great as those from the pesticides being banned, so that there are no positive health benefits from such substitutions (Knutson, 1999). This search has also been challenging due to regional differences in soil types and weather conditions. The differences may lead to discrepancies in the efficacy of the alternatives (VanSickle 2000). Partial synthetic chemical and non-chemical options exist that can be used for the development of integrated pest management and integrated farming systems, which were never developed before due to the presence of broad-spectrum fumigants (Braun and Supkoff, 1994). According to Knutson (1999), fruits and vegetables are more adversely affected by a broad-based reduction in pesticides than are field crops. While research on MeBr alternatives continues, the U.S. Environmental Protection Agency (EPA) continually prioritizes the registration of MeBr alternatives for various sectors. Some primary alternatives available and under development for the tomato sector are listed in Table 5.1.

Table 5.1: Primary MeBr alternatives for the Florida Tomato Sector

Alternatives available	Alternatives under development
1,3-Dichloropropene	Dimethyl Disulfide
Chloropicrin	Furfural
Iodomethane	Pebulate
Metam Sodium	Propargyl Bromide
Glyphosate (H)	Sodium Azide
Paraquat (H)	
Halosulfuron-methyl (H)	
s-Metolachlor (H)	
Trifloxysulfuron-methyl (H)	
Rimsulfuron (H)	
Metam Sodium + Chloropicrin	
1,3-Dichloropropene + Metam Sodium	
1,3-Dichloropropene + Chloropicrin	
Fosthiazate	

Source: U.S. EPA- Methyl Bromide Alternatives

Various studies in Florida have demonstrated that there is no perfect one-to-one replacement for methyl bromide against nematodes, soil-borne diseases, and weeds. The best recommendation thus far is to combine the activity of various active ingredients and improve fumigant retention in the soil using mulches (Santos, 2007). The main challenges to finding alternatives to methyl bromide are in relation to efficacy (due to the broad spectrum activity), low cost, ease of use, wide availability, worker, and environmental safety. With regard to efficacy, most of the alternatives registered so far are effective either against nematodes, diseases, or both, with little to no weed management activity. It is therefore recommended to mix the fumigants with herbicides and insecticides, a measure that greatly increases their cost. The proposed herbicides include glyphosate, paraquat, halosufuron methyl, s-metachlor, rimsulfuron, and trifloxysulfuron methyl. Effectiveness of the soil fumigant alternatives is shown in Table 5.2.

Table 5.2: Florida Maximum Use Rates and Effectiveness of Soil Fumigant Alternatives

Fumigant Chemical	Max.Use Rate	Relative Pesticidal Activity		
		Nematode	Disease	Weed
Methyl bromide 67/33	350 lb	Excellent	Excellent	Good-Excellent
Chloropicrin	300 lb	None - Poor	Excellent	Poor
Methyl iodide	350 lb	Good-Excellent	Good-Excellent	Good-Excellent
Metam sodium	75 gal	Erratic	Erratic	Erratic
Telone II	18 gal	Good-Excellent	None - Poor	Poor
Telone C17	26 gal	Good-Excellent	Good	Poor
Telone C35	35 gal	Good-Excellent	Good-Excellent	Poor
Pic-Clor 60	250 lb	Good-Excellent	Good-Excellent	Poor
Metam Potassuim (Kpam)	60 gal	Erratic	Erratic	Erratic

Source: Noling et al 2007

5.3 Objective

The objective in this study is to evaluate the environmental impacts of each of the proposed methyl bromide alternatives, to determine the least toxic choice. Due to the multidimensionality of pesticide effects, we also estimated the impacts to workers, consumers, birds, bees, fish, and beneficial arthropods.

5.4. Literature Review

Several studies exist that have evaluated the economic aspects of the MeBr phase-out. Most of the studies have focused on yield losses from the ban. One of the first economic impact assessments of the ban was carried out by The USDA National Agricultural Pesticide Impact Assessment Program (NAPIAP). They concluded that the phase out of MeBr as a fumigant would result in a substantial impact on many commodities because available alternatives are either less effective or more expensive than MeBr (NAPIAP, 1993; Ferguson and Padula, 1994), and that the effect would be most felt in Florida and California. They estimated that the effects to fumigation would be $1.5 billion dollars in annual lost production in the United States alone. This estimate does not include post-harvest, non-quarantine uses and quarantine treatments of imports and other future economic aspects such as lost jobs, markets, etc. The report predicted that the major crop losses would occur with tomatoes ($350 M), ornamentals ($170M), tobacco ($130M), peppers ($130M), strawberries ($110M) and forest seedlings ($35M).

Another study by Carpenter et al. (2000) estimated a much lower annual economic loss to U.S. producers and consumers resulting from a pre-plant ban of agricultural uses of MeBr to be $479 million. Of these, they estimated that losses of $235 million may occur in annual crops (tomatoes, strawberries, peppers, etc.), $143 million in perennials (orchards and grapes), and

$101 million in nurseries and ornamentals. They attributed these losses to decreases in yield with use of alternative pest control strategies, increased production costs, changes in the marketing window in response to supply and demand among others.

5.5 Methodology

We employ the methodology outlined in Chapter 3. In estimating the environmental impacts from the methyl bromide ban, we use the Field Use EIQ rating criterion. Methyl bromide alternatives are essentially supposed to control the same pests as methyl bromide, hence the choice to use Field use EIQ rating. This criterion enables us to determine the toxicity / environmental impacts for each alternative compared to methyl bromide.

$$\text{Field Use EIQ } = EIQvalue * \%a.i./acre * Rate \qquad (5.1)$$

Most of these alternatives are combinations of two or more chemicals; hence their field use rating was estimated as a linear weighted average, with weights as the percent active ingredients of the component chemicals. Two of the main tested formulations for Florida tomatoes have been combinations of 1,3-Dichloropropene, and Iodomethane, plus Chloropicrin. The estimation also accounted for the contribution to the impact from the herbicides, since it is recommended to add the herbicides to the alternatives due to their poor weed management activity. We also accounted for an addition of metam sodium or metam potassium as recommemnded by Noling et al. (2007). They recommended the addition for maximum weed control. To obtain the EIQ field use rating, we then account for the EIQ value and percentage of each component in the formulation. Using an example of *Midas @98:2* (98% Iodomethane and 2% Chloropicrin), its EIQ field use rating was obtained using the formula below.

Midas EIQ field use rating

$$= (IodomethaneEIQ * \%Iodomethane) + (ChloropicrinEIQ * \%Chloropicrin) * Midasrate \qquad (5.2)$$

Table 5.3: Methyl Bromide and Alternatives' Risk levels

Active Ingredient	Ground water	Surface water	Aquatic species	Acute human	Chronic human	Birds	Mammal	Beneficial arthropods
MeBr	1	1	3	5	5	3	3	1
1,3-D	3	1	3	3	3	3	3	3
Chloropicrin	1	1	1	5	1	1	1	1
Iodomethane	1	1	1	1	3	3	1	3
Metam sodium	3	5	5	5	5	1	3	1
Herbicides								
Glyphosate	1	5	3	5	1	1	1	3
Paraquat	1	5	3	5	5	3	5	1
Halosulfuron-methyl								
S_Metachlor	3	3	3	1	3	1	1	1
Trifloxysulfuron-Methyl	3	5	1	1	0	1	1	1
Rimsulfuron								

Source: Alternatives obtained from U.S. EPA. Risk levels from EXTOXNET, Mullen (1995) etc.

5.6 Choice of Study Area

Not only is Florida ranked the largest tomato producer, it also consumes the largest amount of MeBr in the U.S. Florida accounts for 35 percent (11 million pounds annually) of pre-plant methyl bromide use (USDA-ERS # 756), using it on 98 percent of tomato harvested acres. Additionally, most of the research on methyl bromide alternatives has been carried out in Florida and California.

5.7 Data

Alternatives to methyl bromide for use on Florida tomatoes were obtained from the U.S. Environmental Protection Agency (U.S. EPA). This gives the available alternatives, and those under development for various use categories including tomatoes. The alternatives for tomatoes are included in Table 5.1. In order to calculate the environmental impact quotient field use rating for each of the alternatives, we needed data on EIQ, percent active ingredient, application rate. Some of the EIQ values were obtained from Kovach et al. (1992). This site also gives the environmental impact by environmental category. EIQ values for the rest of the alternatives were obtained using the formula developed by Kovach et al., with values of the EIQ components obtained from various sources, including IUPAC, EXTOXNET, Crop Data Management System (CDMS) that gives labels and msds for various pesticides. The CDMS also gives information on the percent active ingredient and recommended rates for some of the alternatives. Information on the maximum application rate for some of the alternatives was obtained from Noling et al. (2007). The application rate for trifloxysulfuron methyl was obtained from Jenning (2010).

5.8 Results and Discussion

We estimated the EIQ field use ratings, a measure of pesticide risk, for the various formulations of the recommended alternatives and for methyl bromide. The most commonly used formulation of methyl bromide in Florida is the 67/33, which has 67 percent methyl bromide and 33 percent chloropicrin. The most tested alternatives are different formulations of Iodomethane (methyl iodide), and 1,3-dichloropropene (*Telone*). We evaluated the EIQ field ratings for six different formulations of Iodomethane, and four formulations of 1,3-dichloropropene, each used in combination with Chloropicrin (Pic). We also evaluated the ratings for metam sodium (*Vapam*) (Table 5.4).

Iodomethane (*Midas)* formulations vary by percent compositions of Iodomethane and Chloropicrin, and 1,3-dichloropropene formulations (*Telone)* vary by 1,3-dichloropropene and chloropicrin compositions. *Midas* products have broad spectrum activity, and hence, they were evaluated without a Chloropicrin follow-up application. Telone products, on the other hand, have little disease activity and no weed activity. They were thus evaluated with a sequential application of Chloropicrin and herbicides.

Table 5.4: Fumigant and Herbicide Characteristics

Product	Formulation	Application rate (lb/acre)	EIQ	EIQ Field use rating
Methyl bromide	67/33	200	53.6	17465
Midas 98:2	97.8/1.99	137.5	16.2	2223
Midas EC Bronze	49.9/44.78	275	26.8	7273
Midas 50:50	49.9/49.75	275	29.0	7951
Midas EC Gold	32.93/61.69	415	31.3	12996
Midas 33:67	32.93/66.67	415	33.6	13873
Midas 25:75	24.95/74.63	550	35.7	19554
Telone II (1,3-D)	97.5/0	121.2	27.8	3285
Telone C17	81.2/16.5	147.9	29.6	4372
Telone C35	63.4/34.7	187.6	32.3	6067
Pic Clor 60	39/59.6	242	36.1	8739
Chloropicrin	96	150	42.4	6106
Vapam	42	320	26.6	3575
Herbicides				
Glyphosate	41	2	15.33	12.57
Napropamide	24.1	2	12.57	6.06
s-metolachlor	83.7	0.95	22	17.49
Paraquat (post-)	30.1	0.54	92	14.95
Halosulfuron methyl	75	0.024	20.2	0.36
Rimsulfuron	25	0.125	15.84	0.5
Trifloxysulfuron methyl	75	0.006	12.67	0.06

The main herbicides recommended are a mixture of napropamide and s-metolachlor as pre-emergent herbicides, followed by one or two applications of halosulfuran. For comparison purposes, we evaluated glyphosate (pre-emergent) and three other post-emergent herbicides: paraquat, trifloxysufuron methyl, and rimsulfuron. Table 5.4 gives characteristics, EIQ, and Field use ratings for the various fumigants. The EIQ can also be used to measure pesticide impacts. From Table 5.4, methyl bromide has the highest EIQ value of all the fumigants. The EIQ values for the Midas and Telone products differ by a minimal amount, and the values of both formulations increase with the Chloropicrin component. Among the herbicides, paraquat is the most toxic, with an EIQ value of 92, compared to values between 12 and 22 for the rest of the herbicides.

Results showing the EIQ field use ratings for Midas, Telone + Pic, and Telone + Vapam, with and without herbicides are shown in Table 5.5, and graphically in Figure 5.1. From the results, the EIQ field use ratings for the herbicides are quite low. With the exception of paraquat, the post-emergent herbicides have the lowest values, less than one, and barely impact the pesticide risks of the alternative fumigants. This is evidenced from the fact that the charts for each fumigant are almost of equal height when comparing the EIQ field ratings with and without the herbicides. The implication from this is that choice of herbicide to use with the fumigants should be based on cost and efficacy on the target weeds, and not on the environmental impact of the herbicides, which is minimal.

A comparison of the three classes of alternative fumigants reveals that the field use impacts increase with percentage of Chloropicrin in the formulation. The same holds true for Telone + Pic, and Telone + Vapam. Of the *Midas* products, Midas 98:2 has the least pesticide risk, and Midas 25:75 has the highest risk. Among the Telone products, Telone + Vapam has lower risks than Telone + Pic, an indication that Chloropicrin is more toxic than metam sodium (Vapam). The problem, however, is that Vapam is considered to have semi-broad spectrum pesticidal activity, and it is not as consistent in achieving pest control. Chloropicrin, on the other hand, has been found to broaden other fumigants' spectra of activity and improve their levels of pest control beyond what either fumigant would achieve if applied alone. Therefore, Telone + Chloropicrin products would be more preferred to Telone +Vapam in terms of efficacy, even though the latter have lower field use pesticidal risks.

In comparison to methyl bromide, seven formulations have lower, and another seven have higher, risks than methyl bromide. With regard to pesticide risks, the seven less toxic fumigants in ascending order are; Midas 98:2, Telone II +Vapam, Midas EC Bronze, Telone C17 + Vapam, Midas 50:50, Telone II + Chloropicrin, and Telone C35 + Vapam. Considering both pesticide risk and efficacy, the ranking is altered in favor of Midas products thus; Midas 98:2, Midas EC Bronze, Midas 50:50, Telone II +Vapam, Telone C17 + Vapam, Telone II + Chloropicrin, and Telone C35 + Vapam. Overall, Midas 98:2 has the least impact, broad spectrum activity, and hence will be the best choice fumigant among the alternatives considered in this study.

Table 5.5: EIQ Field Use Ratings of Fumigants with and without Herbicides (100s)

		with pre-emergent herbicides		with nap+met and post-emergent herbicides				with glyphosate and post-emergent herbicides			
Product	w/o herbicides	glyp	nap+met	paraq	halos	trif	rim	paraq	halos	glyp+trif	glyp+rim
Midas@ 98:2	22.2	22.4	22.5	22.6	22.5	22.5	22.5	22.5	22.4	22.2	22.4
Midas@ EC Bronze	73.7	73.8	74	74.1	74	74	74	74	73.8	73.7	73.8
Midas@ 50:50	79.5	79.6	79.7	79.9	79.7	79.7	79.8	79.8	79.6	79.5	79.6
Midas@ Gold	130	130.1	130.2	130.3	130.2	130.2	130.2	130.2	130.1	130	130.1
Midas@ 33:67	138.7	138.9	139	139.1	139	139	139	139	138.9	138.7	138.9
Midas@ 25:75	195.5	195.7	195.8	195.9	195.8	195.8	195.8	195.8	195.7	195.5	195.7
Telone II +Pic	93.9	94	94.1	94.3	94.1	94.1	94.2	94.2	94	93.9	94
Telone C17 +Pic	104.8	104.9	105	105.2	105	105	105	105.1	104.9	104.8	104.9
Telone C35 +Pic	121.7	121.9	122	122.1	122	122	122	122	121.9	121.7	121.9
Pic Clor 60 +Pic	148.5	148.6	148.7	148.8	148.7	148.7	148.7	148.7	148.6	148.5	148.6
Telone II +Vapam	68.6	68.7	68.8	69	68.8	68.8	68.8	68.9	68.7	68.6	68.7
Telone C17 Vapam	79.5	79.6	79.7	79.9	79.7	79.7	79.7	79.7	79.6	79.5	79.6
Telone C35 +Vapam	96.4	96.5	96.7	96.8	96.7	96.7	96.7	96.7	96.5	96.4	96.5
Pic Clor 60+ Vapam	123.1	123.3	123.4	123.5	123.4	123.4	123.4	123.4	123.3	123.1	123.3
MeBr	99.8	99.9	100	100.2	100	100	100.1	100.1	99.9	99.8	99.9

glyp = glyphosate, halos = halosulfuron methyl, met = s-metolachlor, nap = napropamide, paraq = paraquat, rim = rimsulfuron, trif = trifloxysulfuron methyl

5.8.1 Impacts by Environmental Category

Results showing Field use rating by environmental category are shown in Table 5.6 and in Figure 5.2. They reveal variations among the various fumigants to different categories. With the exception of Midas@25:75, all alternative fumigants have the highest impact on workers, followed by beneficial arthropods. This ordering is reversed for Midas@25:75. Methyl bromide, too, has the highest effects on workers but the second highest effects on birds. Fish, on the other hand, are the least impacted by all fumigants, including methyl bromide, followed by consumers, with two exceptions where fish are the second least affected. The exceptions in this case are Midas@98:2, which has the least impacts on bees, and Telone II + Vapam, to which birds have the least effects. Overall, we find the highest impacts among workers followed by beneficial arthropods. On the other hand, fish have the least harmful effects followed by consumers. Impacts of the fumigants on water are minimal, resulting in lowered effect on fish. These results are in accordance with the fumigant nature of these products. The highest impacts are expected among categories that come into contact with the air, hence the workers and beneficial arthropods.

Aside from the fact that adding chloropicrin (Pic) to Telone products results into higher environmental risks than using metam sodium (Vapam), the ordering of the impacts is also altered for some environmental categories. This is due to the fact that chloropicrin and Vapam have different effects on each of the environmental categories, and the ordering of these effects varies for some of the categories. Among all the alternatives, however, Midas@98:2 has the least impacts on all the environmental categories, while Midas@25:75 has the highest. This result together with the discussion above on total impacts, suggests Midas@98:2 to be a better alternative to methyl bromide.

Table 5.6: EIQ Field Use Ratings by Environmental.Category (100s)

Fumigant	Worker	Consumer+L	Fish	Birds	Bee	Beneficials
Midas@ 98:2	25.2	5.6	1.5	12.8	0.5	21.2
Midas@ EC	67.2	14.7	7.5	44	23.2	64.7
Midas@ 50:50	71.9	15.7	8.2	47.6	25.7	69.6
Midas@ EC Gold	112.9	24.5	14.2	78.2	48.2	112.2
Midas@ 33:67	120.1	26.1	15.2	83.5	52	119.6
Midas@ 25:75	166.3	36.1	21.9	118	77.2	167.6
Telone II + Pic	98.6	20.1	10.8	42.2	47.3	62.8
Telone C17 + Pic	107.8	22	12	48.6	52.2	71.7
Telone C35 + Pic	121.4	25	14	59	59.7	86.2
Pic Clor 60 + Pic	138.5	28.9	17.2	78.3	70.4	112.2
Telone II + Vapam	81.4	20.2	15.7	11	27.9	49.5
Telone C17	90.6	22.2	16.9	17.4	32.8	58.5
Telone C35	104.2	25.1	18.9	27.8	40.2	72.9
Pic Clor 60	121.3	29.1	22.1	47.1	50.9	98.9
MeBr	121.9	18.9	4.6	71.3	22.1	60.6

5.9 Conclusion

Health and environmental concerns from chemical use have motivated preventive measures in almost all agricultural sectors. Concerns on the ozone depletion potential of methyl bromide led to declaration of its phase-out by 2005 following the Montreal Protocol of 1991. In response, the U.S. chemical manufacturing companies, together with the Environmental Protection Agency, have actively been seeking alternative fumigants to methyl bromide. Methyl bromide, a major fumigant for major crops around the world, is one of the pesticides causing environmental and human health concerns. Seeking alternative fumigants to methyl bromide is therefore of utmost importance, especially in the tomato industry.

Our concern in this paper was to determine the least toxic choice of the current alternatives based on their environmental impacts in comparison to methyl bromide. We find that workers and beneficial arthropods are the most affected by all fumigants. The results also indicate that while Chloropicrin is needed as a warning agent to all the alternatives, increasing the Chloropicrin component in the fumigant formulation greatly increases its hazard. The least hazardous alternatives then are products with low Chloropicrin. The best choice fumigant among the alternatives we considered is Iodomethane@98:2 (or *Midas*@98:2). Studies carried out so far on the methyl bromide substitutes focus of yield effects. While yield is of utmost importance, it is imperative to come up with alternatives that are safe to health and the environment. This case study therefore achieved this objective of determining the environmental safety of the proposed fumigants.

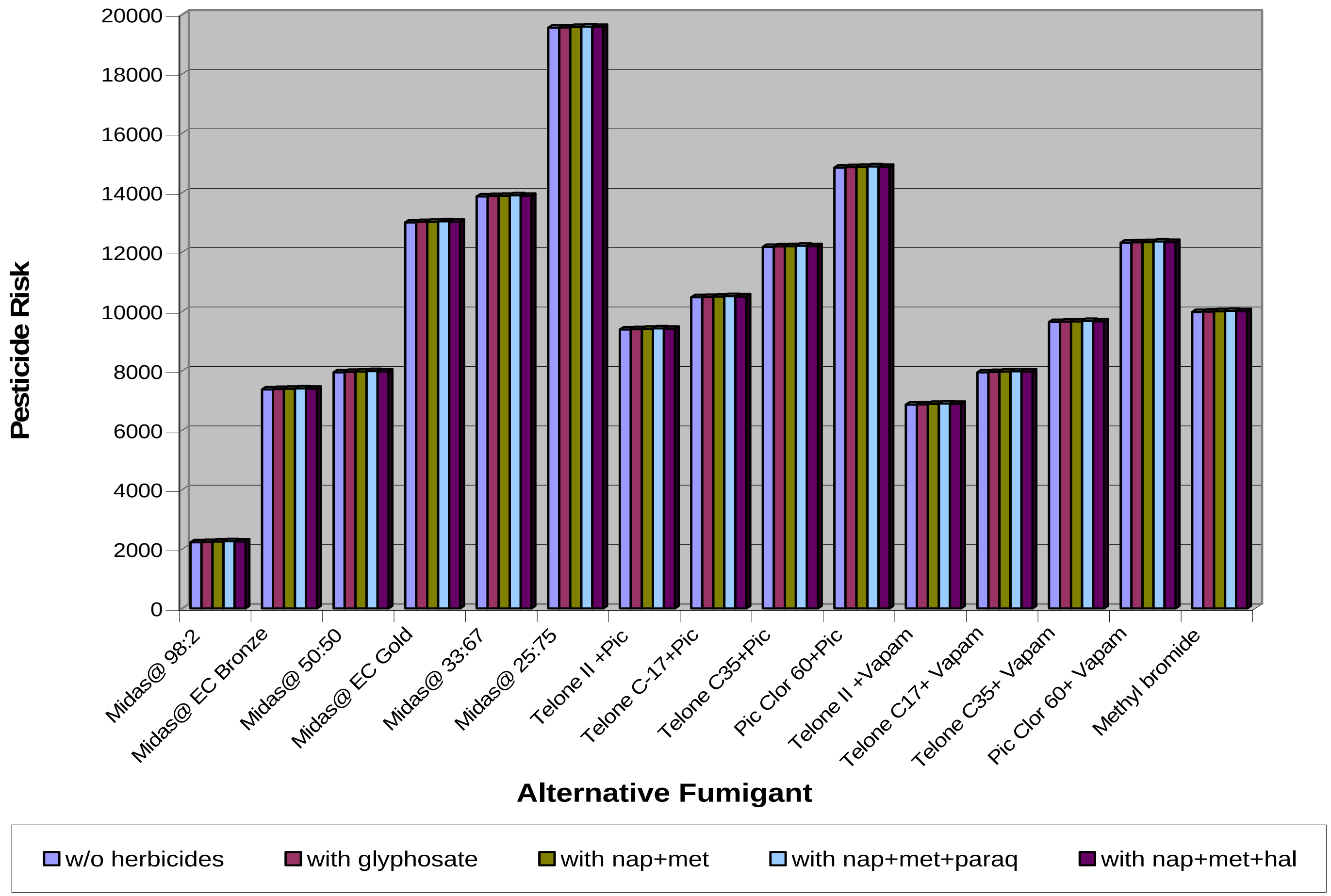


Figure 5.1: Fumigant Field Use Rating with and without Herbicides

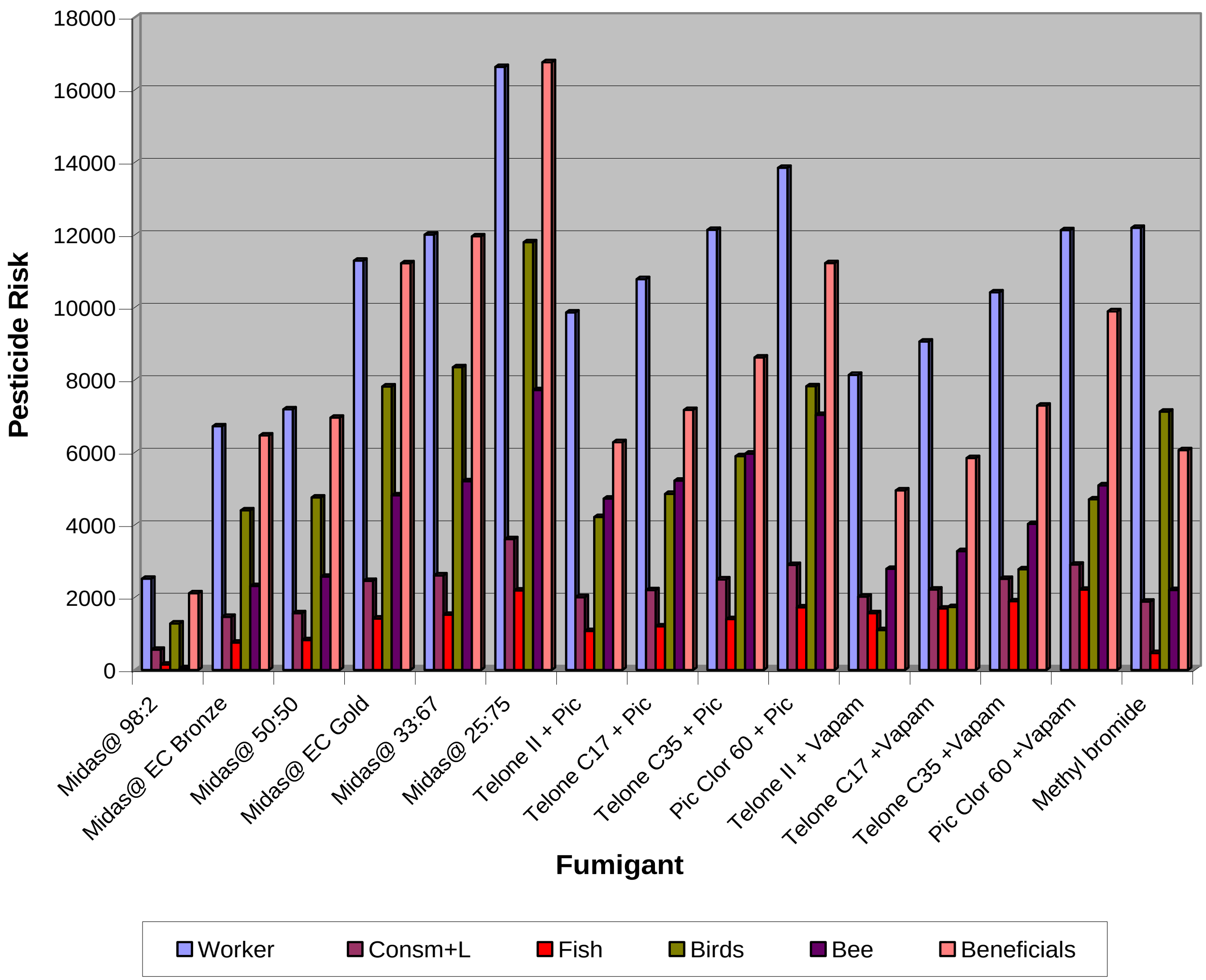


Figure 5.2: Fumigant Field Use Rating by Environmental Category

CHAPTER 6

SUMMARY, CONCLUSION, AND IMPLICATIONS

6.1 Study Summary

This study focused on the harmful environmental effects from pesticide use in U.S. cotton and tomato production. Cotton and tomato cropping systems were chosen as case studies, because they each are associated with high pesticide use in their respective crop categories. According to the 2002 National Pesticide use ranking by crop (pounds of active ingredient per year), cotton ranked second only to citrus in insecticide use, in 1997 and 2002. With regard to other pesticides, it ranks second to potatoes. Tomatoes rank second only to potatoes in other pesticide use, where methyl bromide is classified (Gianessi and Reigner, 2006).

We concentrated on change in pesticide use following inception of the boll weevil eradication program in cotton, and to alternatives to methyl bromide in Florida tomato production. Boll weevil infestations led to heavy pesticide dependence because of the importance of the cotton industry to the U.S. gross domestic product (GDP). Eradication was a way to curb this heavy dependence, reduce production costs and associated environmental effects. Since then, some of the very toxic pesticides have been phased out while formulations and application rates of the ones still in use have been reduced to help lower the environmental pesticide load. These actions have been carried out in response to (1) increased insect resistance; (2) development of more effective alternative pesticides; (3) growing public concern over adverse environmental side effects, and (4) government restrictions on pesticide use. Comparison was made between pesticides used before and after the boll weevil eradication program.

Methyl bromide, on the other hand, was approved for phase-out following the Montreal Protocol as one of the substances causing depletion of the ozone layer. Methyl bromide is used extensively as a broad spectrum fumigant in tomato production, and hence alternatives are needed before the phase-out. So far, it has been challenging to find broad spectrum alternatives, so that several pesticides are combined to achieve such action. The study addressed whether these alternatives have a lesser impact than methyl bromide on other environmental components; groundwater, surface water, acute and chronic human health, aquatic species, mammals, birds and beneficial insects. The comparison in the pesticide environmental impact was achieved using the Environmental Impact Quotient (EIQ) developed by Kovach et al. (1992).

While food security and ensuring low consumer prices are still at the core of agricultural production, emphasis is also placed on secondary issues arising from agricultural production. Such issues include the environmental and health issues arising from pesticide use. Our findings indicate a reduction in pesticide use both in quantity and type of pesticides used. The reductions in quantity have been largely achieved through a decrease in the number of applications. This in itself helps to reduce the environmental pesticide load. Additionally, there is been a shift away from pesticides considered more harsh on the environment toward less toxic alternatives; this translates to lower adverse environmental impacts.

The most common way in which change in pesticide use has been presented is in terms of the volume (quantity) of pesticides applied. This is an imperfect measure because differences in the rate of pesticides used, and in the environmental characteristics (mobility, persistence, etc.), are masked in comparisons using total pesticide volume. Analyses based on the volume of pesticides applied or number of pesticide applications are inadequate measures of pesticide impacts, because they ignore the crucial information on pesticide toxicity (Frisvold and Marra, 2004; Levitan, 2000; OECD, 2001; Nelson and Miranowski, 1996). Even though quantity and number of pesticide applications affect production costs, and are hence an economic problem, the issue to be addressed when analyzing environmental impacts is pesticide toxicity. By using an impact index, the environmental impact quotient (EIQ), this enabled us to account for pesticide toxicity.

6.2 Conclusion and Implications

Increased awareness on environmental and health effects from pesticide use have prompted policy measures aimed at reducing these effects. One such measure is Integrated Pest Management (IPM), and several versions of it, aimed at reducing pesticide dependence. These policy measures have in turn resulted in studies to evaluate the effectiveness of the preventive strategies in reducing the environmental impacts. In this study, we focused on determining the effectiveness of the Boll Weevil Eradication Program (BWEP) in reducing the environmental impacts from changes in insecticides used in U.S. cotton production in our first case study, and on impacts associated with methyl bromide alternative fumigants in Florida tomatoes in the second case.

General results from the cotton case study suggest that there has been a decline in pounds of active ingredients applied for most States, and more so between 1997 and 2002. The results also indicate declines in impacts evaluated using both the Environmental Impact Quotient (EIQ) and the Seasonal Environmental Impact (SEI). Overall, there are fewer declines between 1981/84 and 1992, slightly more between 1992 and 1997, and even more between 1997 and 2002. The

SEI results are uniform irrespective of the insecticide application rate measurement used. The main differences among them are in magnitude. The results show great variability among States, as expected, due to differences in climatic conditions and hence pest pressure.

Results from the tomato study revealed that Iodomethane (*Midas*) products have lower environmental impacts than Telone products. Following this, therefore, *Midas*@98:2 was found to have the least harmful environmental impacts and hence the best choice of fumigant. Additionally, the higher the concentration of Chloropicrin in the formulation, the greater the impacts. Hence, it is important to strictly limit Chloropicrin use to amounts necessary for efficacy. In line with this, we found that Telone products followed with an application of metam sodium (*Vapam*) had lower impacts than using Chloropicrin. In comparison to methyl bromide, we found seven products had less hrmful environmental impacts, namely: *Midas*@98:2, *Midas*@ EC Bronze, *Midas*@50:50, Telone II+Pic, Telone II + Vapam, Telone C17 + Vapam, and Telone C35 + Vapam. Of all the products evaluated, *Midas*@25:75 had the highest impacts. All these products are known to have poor weed control abilities, and therefore it is recommended to add herbicides. Our results found that the recommended herbicides had minimal environmental impacts and hence did not affect the overall impacts from the fumigants.

Impacts evaluated by environmental category revealed that workers and beneficial arthropods were the most impacted by both cotton insecticides and tomato fumigants. On the other hand, fish and consumers were the least affected by the tomato fumigants. Lowest impacts from cotton insecticides varied between consumers, fish and birds, among the various States.

The study contributes to the literature on environmental and health impacts of pesticide use, a course championed in all aspects of agricultural production. Studies are increasingly emerging that evaluate the environmental impacts of pesticide use intervention strategies in various crops, including apples, fruits and vegetables, onions etc. Economic analyses carried out previously have focused on the effects of the BWEP on production costs and the physical measures (number of applications and application rates) of reduced pesticide use. Studies on methyl bromide alternatives have also focused on yield and cost effects. This study uses the EIQ to determine how much the BWEP has contributed to the quest to lower the externality impacts from cotton pesticides. The study also contributes to the literature on environmental concerns in methyl bromide phase-out. Methyl bromide phase-out was due to its ozone depleting potential, so while care is taken to ensure alternatives sought are not ozone depleting substances, it is essential to determine their impact on other environmental components. This helps policy makers in choosing not only effective alternatives, but those that are less harmful.

6.3 Limitations and Further Research

There are three major limitations in our study. First is the fact that we could not obtain a monetary value of the environmental impacts in both case studies. This was due to the inability to obtain willingness-to-pay values. A second limitation in the cotton case study was in relation to the data. The USDA only started collecting pesticide use data from 1990, and even these, don't include all cotton growing states on an annual basis. This therefore limited us to other sources with more comprehensive data for all the cotton states, but this covered only 1981/84, 1992, 1997 and 2002. Hence, we were unable to obtain pesticide use data for all states in the earlier years before the boll weevil eradication program. This made it difficult to evaluate the difference in pesticide risks before and after the BWEP. We were only able to evaluate the impacts during the course of the program. Additionally, we could not obtain data for 2007 when most states were in the post-eradication phase. These data are yet to be published. This will have enabled us to assess how impacts have changed since 2002. These limitations affected our ability to perform an economic analysis to assess how the impacts have affected the supply.

Another limitation is related to the index used in our analysis. The EIQ index assigns pesticide risks as 1, 3 or 5, which limits the range of possible risk scores. According to the index, neutral effects are rated as 1 rather than 0. This affects the pesticide hazard/impact, obtained as the product of toxicity and exposure, for pesticides with minimal hazard. A pesticide with low toxicity of 1, and an exposure rating of 5, has the same estimated hazard as one with a high toxicity of 5 and a low exposure of 1. This therefore distorts the impact estimates obtained. Also related to the index is the issue of separability between groundwater and surface water. In places with a high water table, the Flint River basin in Georgia, surface water quickly mixes with groundwater, so that both waters have the same effects from a given pesticide application. For pesticides applied in such locations, and where the index assigns different risk levels to groundwater and surface water, the resulting estimated impact will be incorrect. The correct impact will be the one with both waters assigned the same risk level.

Further research can focus on the main limitation in our study, monetarizing the impacts obtained. Obtaining monetary values for cotton impacts might entail carrying out the study on a smaller scale, say for one region or state. This will make it feasible to obtain willingness-to-pay values, which are needed to get monetary values of the impacts. Additionally, there is also need to re-evaluate the weights used in the EIQ index to ensure they are more representative of the weight of each environmental component to overall effects from pesticides.

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APPENDIX A

COTTON INSECTICIDES, RISK LEVELS AND BOLL WEEVIL ERADICATION DATES

Table A.1: Cotton Pesticides and Risk levels

Pesticide	Risk Score: 1 = low 3 = moderate 5 = high							
Active ingredient	Ground water	Surface water	Aquatic species	Acute human	Chronic human	Bird	Mammal	beneficial
Abamectin	1	1	3	5	1	1	5	5
Acephate	1	1	1	1	1	3	3	5
Acetamiprid	1	3	1	1	1	1	1	3
Aldicarb	5	5	3	5	1	5	5	1
Amitraz	1	3	3	1	1	1	1	1
Azinphos methyl	1	5	5	5	3	3	5	5
Bifenthrin	1	5	5	3	3	3	3	5
Bt	1	1	1	1	3	1	1	3
Buprofezin	1	3	1	1	1	1	1	1
Carbaryl	1	3	3	3	1	3	1	5
Carbofuran	5	1	3	5	1	5	5	5
Carbophenothion	1	1	5	5	1	5	5	5
Chlordimeform		5	3				3	1
Chlorpyrifos	1	5	5	3	3	3	5	5
Cyfluthrin	1	3	5	3	1	3	3	5
Cypermethrin	1	3	5	5	3	1	3	5
Deltamethrin	1	1	5	3	1	1	5	5
Demeton	1	3	3	5	3	5	5	3
Diazinon	3	3	5	3	5	5	3	5
Dicofol	1	5	5	3	1	1	3	1
Dicrotophos	3	5	3	5	3	5	5	5
Diflubenzuron	1	1	1	1	1	1	1	1
Dimethoate	3	1	1	3	3	5	5	5
Disulfoton	1	3	5	5	5	5	5	5
Emamectin	1	3	5	1	1	5	1	5
Endosulfan	1	5	5	5	3	3	5	1
EPN	1	3	3	5	1	3	3	3
Esfenvalerate	1	5	5	3	1	1	3	5
Parathion	1	3	5	5	3	5	5	3
Fenamiphos	5	5	5	5	1	5	5	1

Table A.1 continued …

Fenpropathrin	1	3	5	3	1	1	3	5
Fenvalerate			4				2	3
Flucythrinate	1	3	5	5	1	1	3	5
Imidacloprid	3	3	3	1	1	3	1	5
Indoxocarb	3	1	5	1	1	3	1	5
L-cyhalothrin	1	3	5	3	1	1	1	5
Lindane	5	5	5	3	1	3	3	5
Malathion	1	1	1	3	5	3	1	5
Methamidophos	3	1	3	5	1	5	3	5
Methidathion	1	3	5	5	3	5	5	5
Methomyl	5	3	5	5	1	3	3	3
Methoxyfenozide								1
m- parathion	1	1	3	5	3	1	3	5
Monocrotophos	1	3	3	5	1	5	5	3
Naled	1	1	5	3	1	3	3	5
Oil	1	1	1	1	3	1	1	5
Oxamyl	1	1	3	5	1	5	5	5
Oxydemeton-M	1	3	3	3	1	5	5	5
Permethrin	1	5	5	3	3	1	3	5
Phorate	1	5	5	5	1	5	5	3
Phosphamidon	5	1	3	5	3	5	5	5
Profenofos	1	1	3	5	1	5	3	5
Propargite	1	5	5	5	3	1	3	1
Pyriproxyfen	1	1	5	1	1	1	1	1
Spinosad	1	3	5	1	1	3	3	3
Sulprofos	1	3	5	3	1	3	3	3
Tebufenozide	5	3	3	1	1	1	1	1
Thiamethoxam	5	3	5	1	1	1	1	5
Thiodicarb	1	3	5	3	1	1	3	3
Toxaphene	1	3	5	5	3	1	3	4
Tralomethrin	1	3	5	3	1	1	3	5
Trichlorfon	5	1	1	5	5	5	3	5
z-cypermethrin	1	3	5	3	1	1	1	5

Table A.2: The Boll Weevil Eradication Dates by State

State	Start Date-Fall	Year Eradicated	Acreage Eradicated
VA	1978	1984	100,000
NC	1983	1987	925,000
SC	1987	1990	286,000
GA	1987	1992	1,400,000
FL	1987	1993	121,000
AL	1987	2000	589,000
Central TN	1994	2000	23,000
KS		2002	53,000
AZ	1985(W),88(central)	1991	360,000
CA	1983	1991	850,000
MS	1997		
W TN	1998	2009	
MO	2001	2009	
AR	1997		
LA	1997	2009	
OK	1998		
NM	1998		
TX	1994 or 1999	R.Plains(2000)	

Table A.3: Cotton Insect and Mite Chemicals

Active Ingredient	1976 amount (lbs)/acre	1979 amount (lbs)
Acephate		0.03
Aldicarb	.043	.038
Azinphosmethyl	.021	.029
Carbaryl	.035	.001
Carbophenothion		.002
Chlordimeform	.407	.074
Chlorpyrifos		.005
Demeton		.001
Diazinon	.003	.002
Dicofol		.038
Dicrotophos	.023	.021
Dimethoate	.008	.018
Disulfoton	.167	.018
Endosulfan	.062	.001
Endrin	.028	
EPN	.563	.207
Fenvalerate		.033
Malathion	.004	.003
Methamidophos		.01
Methidathion		.012
Methomyl	.054	.031
Methyl parathion	1.823	.371
Monocrotophos	.136	.033
Naled		.002
Parathion	.062	.03
Permethrin		.052
Phorate	.015	.009
Propargite		.052
Sulprofos		.015
Toxaphene	2.409	.09
Trichlorfon		.004

From Suguiyama and Osteen, 1988

APPENDIX B

METHYL BROMIDE USE AND FLORIDA TOMATO REGIONS

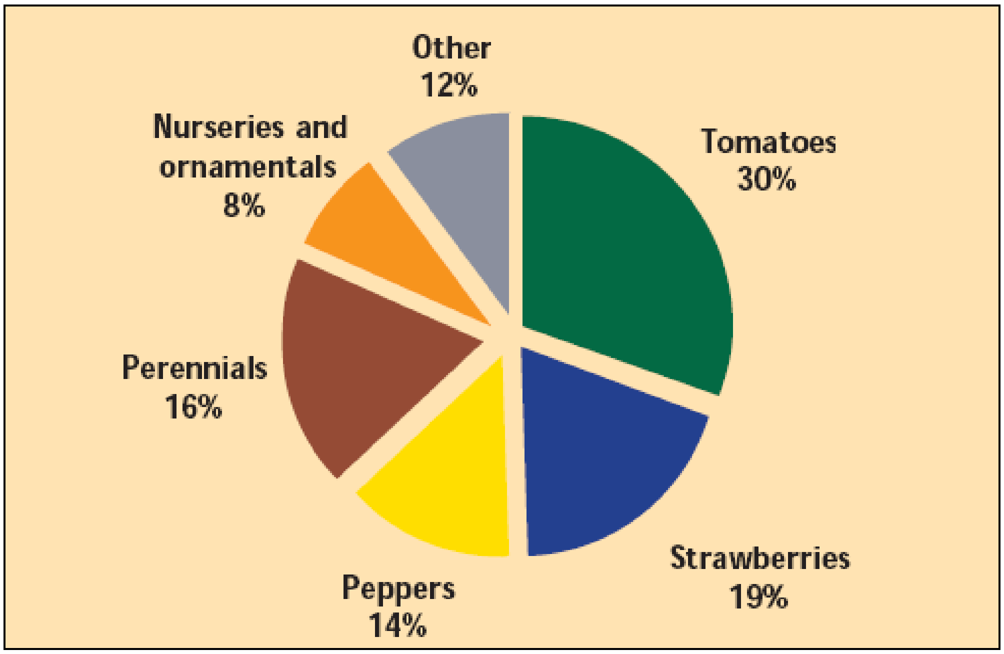

Figure B.1: U.S. Preplant Methyl Bromide Use
Source: National Center for Food and Agricultural Policy (NCFAP)

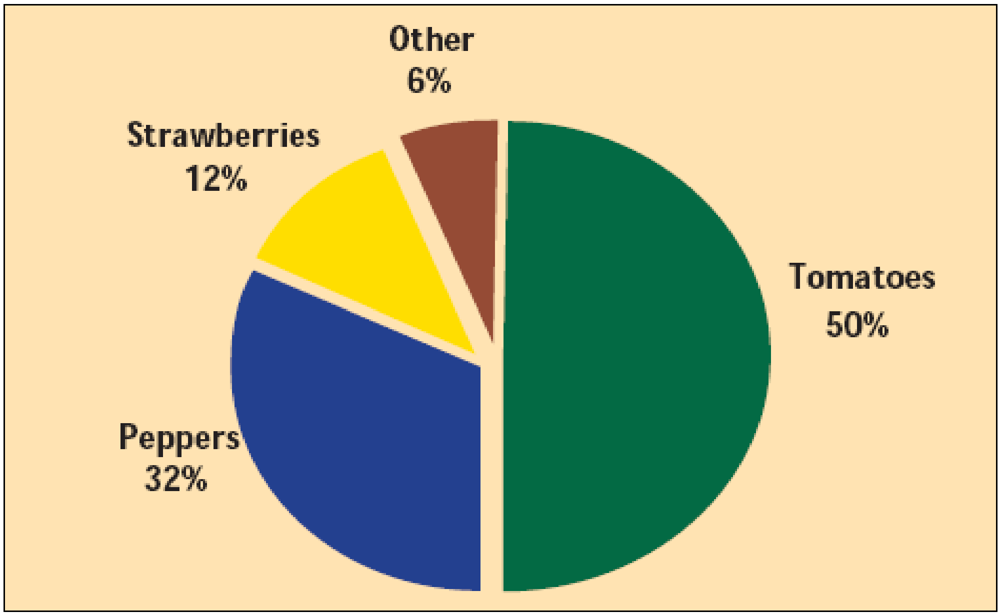

Figure B.2: Florida Pre-plant Methyl Bromide Use
Source: National Center for Food and Agricultural Policy (NCFAP)

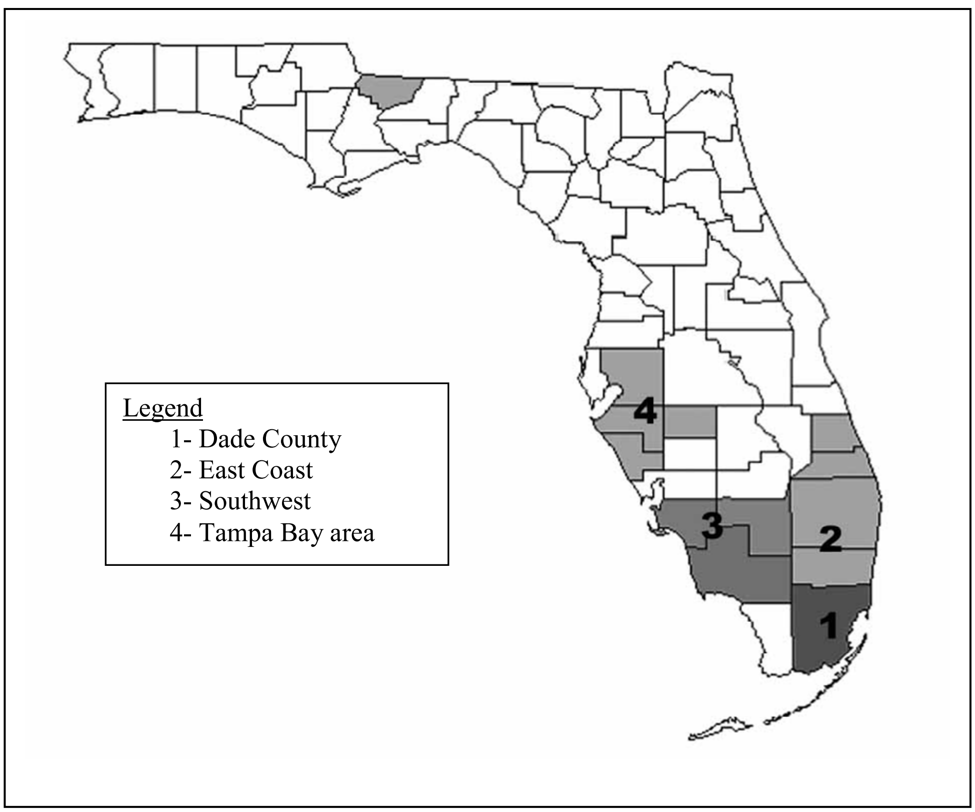

Figure B.3: Major Tomato Production Regions of Florida