MRI REPORT

A STUDY OF THE EFFICIENCY OF THE USE OF PESTICIDES IN AGRICULTURE

VOLUME I

Midwest Research Institute
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Kansas City, Missouri 64110

RvR Consultants
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FINAL REPORT
July 1975

Contract No. 68-01-2608
MRI Project No. 3949-C

For

Environmental Protection Agency
Strategic Studies Unit, OPP (HM568)
401 M Street, N.W.
Waterside Mall, Room 507
Washington, D. C. 20460

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A STUDY OF THE EFFICIENCY OF THE USE OF PESTICIDES IN AGRICULTURE

VOLUME I

By

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PREFACE TO VOLUME I

This report describes the results of a study conducted jointly by Midwest Research Institute (MRI) and RvR Consultants during the period 1 August 1974 to 14 February 1975. The study was performed for the Strategic Studies Unit, Office of Pesticide Programs, U.S. Environmental Protection Agency (EPA), under Contract No. 68-01-2608, entitled "A Study of Wasteful Pesticide Use Patterns." The EPA Project Officer was Mr. Allan Zipkin.

Work on this program (MRI Project No. 3949-C; RvR Project No. 67) was conducted with Dr. Rosmarie von Rümker as task leader. The program was under the general supervision of Dr. H. M. Hubbard, Director of MRI's Physical Sciences Division, and Dr. E. W. Lawless, Head, Technology Assessment Section. The MRI project members consisted of Mr. Gary Kelso, Group Leader; Miss Kathryn Lawrence; and Mr. Francis Bennett. Dr. Arthur Allen acted as consultant to the program. The RvR project members were Dr. Rosmarie von Rümker and Mrs. Freda Horay.

Approved for:

MIDWEST RESEARCH INSTITUTE

H. M. Hubbard, Director
Physical Sciences Division

2 July 1975

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ABSTRACT

A study was made of the efficiency of the use of pesticides to identify and quantify the wastes and losses which occur in the treatment of agricultural crops. The study was reported in two volumes. The first volume identified the management practices and decisions for three crops--corn, sorghum, and apples--that may lead to wasteful pesticide use, and quantified the pesticide wastes occurring on each crop as a result of these management practices. The second volume identified the physical factors that cause pesticide waste and losses both during and after crop treatment for agriculture in general, and estimated the application and postapplication pesticide losses and wastes that occurred in 1971 for each of the three above crops. The physical factors which were examined extensively in this study were pesticide overapplication and nonuniform distribution, pesticide drift, and pesticide losses from crops due to runoff and soil erosion.

SECTION I

INTRODUCTION

BACKGROUND

The use of pesticides in the agricultural sector of our society is often required for the effective production of food and fiber. Crops have to compete with weeds, insects, fungi, nematodes and other pests which would decrease yield quantity and/or quality if left uncontrolled. Pesticides are also employed against insects and other pests threatening human health or comfort, or destroying structures, stored products, etc.

Controlling the pests that attack food crops is a monumental and ever-increasing problem. Throughout the world there are 18,000 species of weeds, 1,800 of which cause annual economic losses. Each major crop is infested with between 10 and 50 different weeds, and most cultivated crops are subject to infestation from about 200 weed species. There are over 10,000 species of pest insects, 50,000 species of fungi causing 1,500 different diseases, and more than 1,500 species of nematodes that can damage and destroy crops. Despite the advanced pest control technology available today, these pests cause losses amounting to about one-third of the potential agricultural production each year.

Though pesticides have become necessary to assist man in meeting vital health and nutritional needs, they can be damaging as well as beneficial to both man and his environment. To minimize the cost and maximize the benefits of pesticides to society as well as to the individual user, pesticides must be used in the most efficient and effective way possible. Unfortunately, not all of the quantities of pesticides used in agriculture are employed in this manner. Unnecessary or otherwise nonbeneficial uses of pesticides and unwanted, avoidable discharges of pesticides into the environment are wasteful economically as well as ecologically.

The U.S. Environmental Protection Agency has been charged by the Congress to regulate pesticides in such a manner that the economic, social, and environmental costs of their use do not exceed benefits. In carrying out this mandate, the Agency is interested in promoting the most effective and efficient use of pesticides where they are needed, and in assisting farmers in protecting their crops from pests at minimum cost to themselves and to society. The objective of avoiding pesticide wastage and losses has assumed increased priority and urgency as a result of the energy crisis. Many pesticides are petroleum-based chemicals. The production, formulation, distribution and application of all pesticides consumes additional energy. On the other hand, control of pests by other conventional methods may require more labor, larger amounts of fuel for farm equipment, or other costs.

This study deals with the efficiency of the use of pesticides. Here, efficiency is used in the sense of being inversely related to wastage and losses of pesticides, and our study excluded energy considerations. The study focused on the identification and quantification of avoidable pesticide wastes and losses that cause unnecessary costs to users as well as to society, without offsetting benefits.

OBJECTIVES

The major objectives of this study were:

* To define and identify pesticide wastes and losses.

* To identify and evaluate wasteful pesticide use practices on selected agricultural crops.

* To identify and evaluate avoidable pesticide losses during and after application.

* To quantify avoidable pesticide wastes and losses in as much detail as possible.

STUDY APPROACH

To accomplish these objectives, this project was divided into the following four major tasks which were conducted under a joint effort by MRI and RvR Consultants.

Task 1 - Select Suitable Crop/Pest/Pesticide Systems for Detailed Study

Many of the parameters of pesticide use cannot be studied in a broadly general way, but only as they apply to specific crop/pest/pesticide systems. Several criteria were considered and evaluated in order to select three study crops; these included volume of pesticides used on the crop, crop acreage, crop farm value, and existence of integrated pest management programs on the crop. A numerical rating system was developed (see Appendix A, Table A-4), and the crops which rated highest were: (a) corn; (b) cotton; (c) the conglomorate category of vegetables; and (d) soybeans. Other crops that ranked high, but with some variation in order depending on the criteria used, were sorghum, apples, and wheat.

Cotton was dropped from further consideration because it is already the subject of several other studies. Sorghum was selected ahead of soybeans because of pesticide use patterns and the greater number of integrated pest management studies on sorghum. Apples were selected ahead of vegetables since no single vegetable species appeared to be as suitable as apples. Therefore, the crops selected for study were: (a) corn; (b) sorghum; and (c) apples.

The detailed data and considerations on which this choice of study crops were based were developed by RvR Consultants and are included in this report as Appendix A.

Task 2 - Define and Identify Pesticide Wastes and Losses

Our search of the literature failed to produce any publications in which pesticide wastage and losses have been defined, analyzed and categorized systematically. This was therefore an important requirement early in the project. An initial set of definitions was developed by the project team and then further improvements and refinements were made in consultation with the EPA project officer. The results of these efforts are presented below in the section on "Definitions and Identification of Pesticides Wastes and Losses."

The categorization of pesticide wastes and losses indicated several different principles by which the subsequent tasks might be organized. For several reasons, we have structured our studies along two general themes: (a) pesticide wastage due primarily to management decisions before application, and (b) pesticide losses due primarily to physical factors during and after application.

One of the major reasons for this structure is that wastage of pesticides due to management decisions before application differs greatly among different crops, pests, types of pesticides, and geographic regions, so that generalizations or extrapolations to or from other crops, pests, types of pesticides or regions cannot be made. By contrast, findings in the area of pesticide losses during or after application due to physical factors may apply to crops, pesticides or regions other than those studied if the physical and environmental conditions of the pesticide use are sufficiently similar. Thus, investigations on drift, runoff and other aspects of pesticide losses due primarily to physical factors were useful in Task 4 regardless of the crop involved, while in Task 3, our investigations had to focus on the three selected crop/pest/pesticide systems, and our findings apply only to them.

<u>Task 3 - Identify and Evaluate Wasteful Pesticide Use Practices on the Three Selected Study Crops</u>

This task was carried out primarily by RvR Consultants with MRI furnishing some of the statistical data for the crop pesticide usage and crop acreages. For each of the study crops, the use patterns of herbicides, insecticides, miticides, fungicides and other pesticides were studied in relation to the need for treatment. Management factors that might contribute to nonbeneficial uses of pesticides were investigated. Special attention was given to pesticide application rates and frequency of application as:

* Specified in the registered label of the product;

* Recommended by the Federal/State Cooperative Extension Service;

* Recommended by other crop protection advisors;

* Commonly used by growers;

* Required for economic pest control; and

* Used in integrated pest management programs (where applicable).

In line with the objective to quantify pesticide wastage and losses in as much detail as possible, quantitative aspects received prime attention throughout this phase of the study.

The data and information needed in this task were obtained from a variety of sources, including a thorough search of the literature and interviews with experts such as public and private crop protection advisors, growers, and other knowledgeable persons. Some of these interviews were conducted by telephone, others in person in the field and at several recent scientific meetings.

Furthermore, a limited mail survey was conducted of extension entomologists, weed scientists, and plant pathologists working in the leading corn, sorghum, and apple producing states. The results of this survey were also helpful to the project.

Task 4 - Identify and Evaluate Avoidable Pesticide Wastes and Losses Occurring During and After Application

This task was carried out by MRI. The study examined the problem of pesticide wastes and losses occurring during and after application. The approach taken to this aspect of the study is given in Section VIII.

SECTION II

DEFINITION AND IDENTIFICATION OF PESTICIDE WASTES AND LOSSES

EFFICIENT USE OF PESTICIDES

This study deals with the problem of efficiency in the use of pesticides. According to contemporary dictionaries, "efficient" is broadly defined as "producing the desired effect or result with a minimum of loss or waste."

When pesticides are used in agriculture, the desired effect usually is to prevent a yield loss (quantity and/or quality) that pests would cause if left uncontrolled. Maximizing efficiency in the use of pesticides requires minimizing pesticide wastes and losses; wastes and losses are inversely related to efficiency.

PESTICIDE WASTES AND LOSSES

Pesticide wastes and losses may be categorized by a number of different criteria which are partly overlapping. These include:

* Avoidability (some wastes and losses are avoidable, some are not);

* Type of waste or loss (unnecessary use, overuse, misuse, etc.);

* Cause of waste or loss (management decisions, physical factors);

* Relationship to time of application (before, during, after); and

* Quantity of pesticide involved.

These different aspects of pesticide wastes and losses and their interrelationships require some further definition and discussion.

AVOIDABLE VERSUS UNAVOIDABLE PESTICIDE WASTES AND LOSSES

Pesticide Wastage

For purposes of this study, pesticide wastage, or wasteful use is defined as unnecessary use, overuse or misuse of pesticides. Every application of a pesticide is preceded by someone's decision to make that application. At that decision point, wasteful pesticide uses could be avoided by a decision not to make an unnecessary application, or not to apply the pesticide at an unnecessarily high rate. Therefore, most or all wasteful pesticide uses are avoidable in principle. (It is recognized, of course, that things are not that simple in practice because decision-makers often have no certain way of knowing whether a given pesticide use is necessary or not, or whether a given rate of application is too high, too low, or just right.)

Pesticide Losses

For purposes of this study, pesticide losses are defined as unwanted pesticide deposits, or pesticide quantities that do not reach the intended target and, therefore, do not contribute to accomplishing the purpose of the application. In most pesticide uses, very little of the pesticide applied actually reaches the site of action within the target pest. Thus, by this very broad definition, a large percentage of all pesticides is "lost."

A schematic description of the possible fate of a given quantity of insecticide sprayed topically on a crop for insect control is helpful in illustrating the situation (Figure 1, taken from a recent report by von Rümker et al., 1974*). The percentage loss figures (in terms of the quantity applied = 100%) do not represent one specific case, but were composited from several field studies. Typical losses due to drift were taken from the studies by Adair et al. (1971), Akesson and Yates (1964), and Brazzel et al. (1968). Losses due to surface runoff from the target area were composited from the studies by Caro et al. (1973), Ritter et al. (1974), and White et al. (1967). Information on the propensity of pesticides for volatilization and leaching has been reported by von Rümker and Horay (1972). Furthermore, it was assumed that the degree of ground cover of the target crop in the target area is 75%, and that not more than 10% of the insecticide quantity impacting on the target crop will impact near target insects. Of the quantity impacting near target insects (4% of the applied rate), only a small portion will actually be absorbed by the target insects through contact, inhalation, and/or ingestion. Thus, ultimately, only a very small fraction of the quantity applied (much less than 1%) will reach the site of toxic action inside the target insect.

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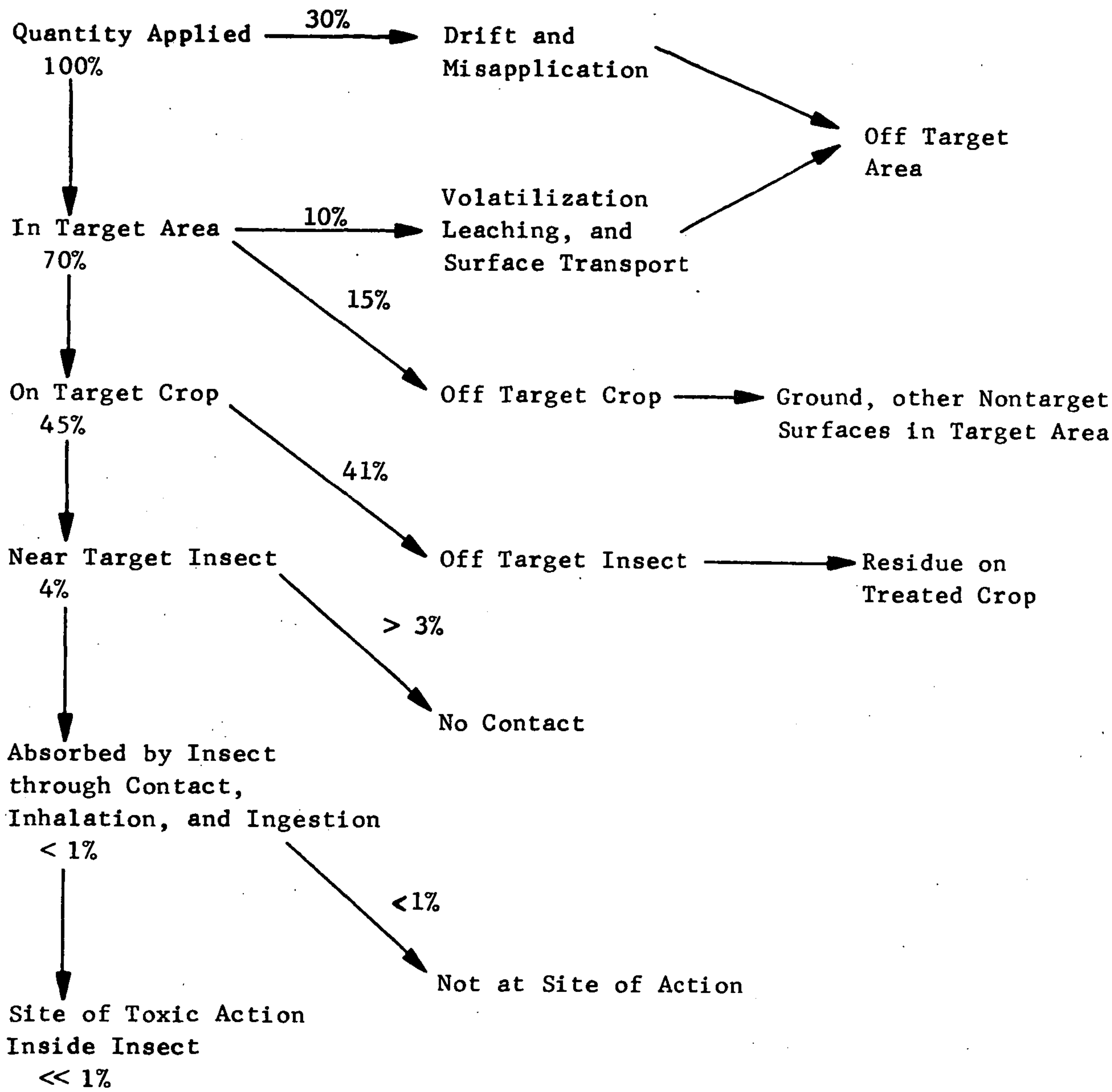
* References are given at the end of each section of this report.



Percentage distribution figures do not represent one specific case, but are composited from several different field studies and assumptions on the degree of ground cover and the density of target insects on the target crop.
Source: Report published by von Rümker, Lawless, and Meiners (1974), p. 108.

Figure 1. Aerial foliar insecticide application: typical losses between spray nozzle and site of toxic action.

Under field conditions, the rates of pesticide losses at each step may vary greatly, depending upon all elements in the system and their interrelationships, including the physical factors discussed in greater detail in other sections of this report. Regardless of how these factors interact, however, frequently only a very small fraction of the insecticide applied becomes effective for the intended purpose, i.e., controlling the target pest. Shaw and Jansen (1972) presented a similar mass balance for herbicide use. Mass balances for other types of pesticide uses, such as fungicides or soil insecticides, may be somewhat different, but they may also be quite inefficient if evaluated in this manner.

Thus, large quantities of chemical pesticides could be saved, and unwanted residues on treated crops and in the environment could be reduced, without sacrificing benefits, if the pesticide's route from the application equipment to the site of action inside the target pest could be made more efficient and less wasteful. Unfortunately, however, at the present state of pest control technology, a large percentage of the pesticide losses depicted in Figure 1 are unavoidable and cannot, therefore, be considered to be wasteful in a practical, operational or economic sense. These facts suggest the need for research aimed at improving the efficiency of pesticide application systems, and at the development of technologies for more efficient, less wasteful delivery of pesticides to their targets.

Our investigations in this project deal primarily with avoidable pesticide wastes and losses. Among the loss mechanisms depicted in Figure 1, drift, misapplication, and surface transport (runoff) are at least in part avoidable. These loss mechanisms were studied and are reported in Volume II of this report.

TYPES, CAUSES AND OTHER CHARACTERISTICS OF AVOIDABLE PESTICIDE WASTES AND LOSSES

For purposes of this study, avoidable pesticide wastes and losses are considered to include four major routes of waste. These categories, their definitions, underlying causative factors, relationship to time of application, and the quantities of pesticides likely to be involved are as follows.

Unnecessary Use

No treatment required, i.e., use of a pesticide in the absence of an established need to control or suppress the target pest(s).

Examples:

* Use of pesticides in preprogrammed application schedules based on the calendar instead of actual need.

* "Insurance"-type applications made regardless of need.

Unnecessary pesticide uses result from management decisions. Every application of a pesticide is preceded by a decision to make that application. Unnecessary applications are avoidable by a decision not to apply. Unnecessary pesticide uses may involve substantial quantities of pesticides. Therefore, the question if and to what extent pesticides are used unnecessarily received primary attention in our evaluation of pesticide use patterns on corn, sorghum, and apples (Section V, VI and VII). This question cannot be studied or answered in general terms, but only in relation to specific crops, pests, and pesticides, as the findings detailed below demonstrate.

Overuse

Too high a rate, i.e., use of a pesticide at a rate of application higher than necessary for the intended pest control or suppression purpose.

Examples:

* In many instances, insecticides provide economic control of target pests at rates of application much lower than those required for 99 to 100% kill. When applied at high rates, insecticides often destroy beneficial predators and parasites that would help to suppress pest insects and mites. When their natural enemies are destroyed, these secondary pests may then build up to damaging proportions that require additional applications of chemical insecticides or miticides. Thus, application of insecticides at higher rates than necessary for economic control of target pests is often biologically as well as economically wasteful, and sometimes even counterproductive.

* Pesticide overuse may also occur during application as a result of miscalibration of application equipment, driving properly calibrated equipment at a speed slower than that used in calibrating, double treatment of field or orchard borders, excessive overlapping of application swaths, etc.

Pesticide overuse due to selection of too high a rate of application (first example above) results from management decisions prior to application. This type of overuse is avoidable and may involve substantial quantities of pesticides. It was evaluated in detail in the studies of pesticide use patterns on corn, sorghum, and apples (Sections V, VI and VII).

Pesticide overuse during application (second example above) results most often from improper operation of application equipment. This route of waste was examined in our studies on pesticide losses during and after application as reported in Volume II.

Misuse

Use of a pesticide not registered or otherwise not suitable for the intended purpose, or use of a registered suitable pesticide in an unsuitable manner.

Example:

* Selection of the wrong pesticide, wrong target pest, wrong formulation, and/or wrong application method.

Pesticide misuse as defined in the Federal Insecticide, Fungicide and Rodenticide Act and the 1972 Amendments thereto is illegal and may result in prosecution.

Pesticide misuses occur most often as the result of inadvertent errors on the part of persons supervising or making pesticide applications. Such misuses are avoidable or reducible to the extent that human error can be reduced by education, training, supervision, etc. Compared to the other categories of pesticide wastes and losses, misuses do not involve large quantities of pesticides and were not studied in detail in this project. The misuse category is included among the definitions of pesticide wastes and losses for completeness' sake.

Unwanted, Avoidable Discharge, Deposit or Migration

Unwanted, avoidable discharges of pesticides into the environment due to excessive drift or runoff, improper disposal of pesticides or containers, spills, dumping, etc.

Examples:

* Pesticide spills due to puncturing, breakage, tearing or other failure of containers, leakage of tanks or hoppers, leakage or breaking of parts of application equipment, etc.

* Improper disposal of leftover concentrated or diluted pesticides, or of pesticide containers, especially containers not completely emptied.*

* Excessive, avoidable drift during application of pesticides due to too small particles, too great distance between nozzle and target, unsuitable weather conditions, etc.

* Excessive post-application pesticide loss from target areas inherently subject to runoff due to topography of the area, lack of terracing or contouring, etc.

Pesticide losses of this type occur during or after pesticide application. They are avoidable only in part. Pesticide spills occur most often as a result of operating accidents which are mostly uncontrollable and usually involve relatively small quantities of pesticides. Disposal of pesticide containers and of residues in the pesticide application equipment involve substantial quantities of pesticides, but the techniques used to accomplish these tasks are within the control of pesticide users. Any waste involved in inefficient disposal techniques can be resolved through educating pesticide users as to the proper methods of disposal and as to their importance. Therefore, pesticide spills and disposal did not receive detailed attention in this study; they are briefly discussed in Volume II.

Excessive, avoidable drift during application and excessive, avoidable runoff after application involve substantial quantities of pesticide losses throughout agriculture that can be reduced by proper application techniques and conservation methods. These two mechanisms of pesticide loss were studied in detail, as reported in Volume II.

SECTION III

SUMMARY

The results of this study are summarized below in two sections. In the first section, our findings concerning the efficiency of the use of pesticides on corn, sorghum and apples as influenced by pre-application management decisions are set forth. Our studies showed that the use patterns of different types of pesticides (herbicides, insecticides, fungicides, etc.) and the degree of efficiency with which they are used on the three crops varied considerably. The findings reported in this section are applicable only to the crop/pest/pesticide systems studied.

In the second section, our findings on pesticide wastes and losses during and after application are summarized. In this part of the study, our investigations were not limited to corn, sorghum and apples, and many findings may apply to other crops to which pesticides are applied in a similar manner.

EFFICIENCY OF THE USE OF PESTICIDES ON CORN, SORGHUM, AND APPLES AS AFFECTED BY PRE-APPLICATION MANAGEMENT DECISIONS

Table 1 presents an overview of our findings concerning the efficiency of the use of pesticides on corn, sorghum, and apples as affected by management decisions prior to application.

Herbicides are used extensively on corn and sorghum. In the opinion of weed research and extension scientists working with these crops and of corn and sorghum growers, these herbicide uses are essential to the efficient, profitable production of these crops and involve minimal, if any, pesticide wastage. We found no field research data to show whether or not economic weed control in corn or sorghum could be obtained by substantially lower herbicide inputs.

Table 1. ESTIMATED RATE OF TOTAL VS. NEEDLESS USE OF PESTICIDES ON CORN, SORGHUM, AND APPLES

Pesticide	Crop	% of Crop[a] Treated	% of Quantity Applied Used Needlessly	Quantity Used Needlessly[b] (1,000 lb AI)
Herbicides	Corn	90	Small	Small
	Sorghum	70-80	Small	Small
	Apples	Small	Negl.	Negl.
Insecticides[c]	Corn	50	50[d]	12,800
	Sorghum	60-70	50-60[e]	2,900-3,400
	Apples	> 90	20-30[e]	1,040-1,560
Fungicides	Corn	Negl.[f]	Negl.	Negl.
	Sorghum	Negl.[f]	Negl.	Negl.
	Apples	> 90	Small	Small
Other Pesticides[g]	Corn	Negl.	Negl.	Negl.
	Sorghum	Negl.	Negl.	Negl.
	Apples	Small	Negl.	Negl.

a/ In the case of corn and sorghum, % of acreage harvested for grain.

b/ Estimated % needless uses applied against total quantities of insecticides (and miticides in the case of apples) used on the three crops in 1971 according to the USDA pesticide use survey.

c/ Includes miticides in the case of apples. No substantial quantities of miticides are used on corn or sorghum.

d/ Needless uses consist primarily of insecticide applications to field not needing the treatment.

e/ Needless uses consist of insecticide applications in the absence of established need for treatment, of applying insecticides at higher than minimum effective rates, and of insecticide or miticide applications necessitated by preceding injudicious pesticide use.

f/ Excluding seed treatment.

g/ Includes fumigants, defoliants, desiccants, plant growth regulators, etc.

Source: RvR Consultants, this study.

On apples, herbicides are used only in relatively small quantities. We did not find any indications or evidence of wasteful herbicide use on apples.

Insecticides/miticides are used on an estimated 50% of the U.S. corn acreage harvested for grain, on 60 to 70% of the grain sorghum acreage, and on a very high percentage of all apple orchards. As discussed in the sections dealing with insecticide use practices on the three study crops, we estimate that approximately 50% of the quantities of insecticides applied to corn, at least 50% of the insecticides applied to sorghum, and 20 to 30% of the insecticides applied to apples are used needlessly.

In the case of corn, insecticide treatments are applied to many fields that do not need the treatment. In the case of both sorghum and apples, needless uses include insecticide applications in the absence of an established need for treatment, applications at higher than minimum effective rates, and insecticide or miticide applications that become necessary secondarily as a result of preceding injudicious pesticide applications which destroyed naturally present beneficial predators and parasites.

On all three crops studied, an important prerequisite to actually realizing these potential insecticide savings would be the widespread adoption and implementation of integrated pest management procedures.

Only small quantities of fungicides are used on corn and sorghum. Fungicide uses on these two crops were therefore not studied in detail.

Much larger quantities of fungicides are used on apples. Most of the currently available commercial apple fungicides have to be applied on preventive, preprogrammed application schedules for optimal biological and economic effectiveness. No practical nonchemical methods for the control of fungal diseases of apples are currently available to growers, and no "integrated disease management" programs for apples have yet been developed. Thus, apple growers needing to protect their crop against fungal pathogens do not currently have feasible alternatives to the use of chemical fungicides on preventive treatment schedules. There is no evidence of significant wasteful uses of fungicides on apples.

"Miscellaneous pesticides" including fumigants, defoliants, desiccants, plant growth regulators and others are used only in small quantities or not at all on corn, sorghum or apples. Uses of these pesticides were therefore not studied in depth. The limited information obtained in the course of pursuing the project's major objectives does not include any evidence that these "miscellaneous pesticides" are used on corn, sorghum, or apples in a wasteful or inefficient manner.

Our estimates of the quantities of insecticides applied needlessly to corn, sorghum, and apples (Table 1) are expressed in terms of percent of the total quantity applied, and in terms of pounds of active ingredient. The latter estimate was calculated by applying the estimated percent needless uses against the total quantities of insecticides (and miticides in the case of apples) used on the three study crops in 1971 according to the USDA pesticide use survey.

The potential savings in insecticides/miticides shown in Table 1 are not additive to the estimated losses occurring during and after application of pesticides as summarized in Table 37 (page 112). In both tables, the volume estimates are based on the actual uses of the pesticides concerned in 1971, according to the USDA pesticide use survey. If, for instance, 30% of the quantities of insecticides and miticides used on corn, sorghum, and apples in 1971 would be saved as a result of pre-application management decisions to avoid unnecessary use and overuse, then 30% of the estimated losses during and after application shown in Table 37 would not occur in the first place. Additional savings in pesticide quantities by reduction of drift, runoff and other application and post-application wastes and losses would affect only the remaining 70% of the quantities of these pesticides.

PESTICIDE WASTES AND LOSSES OCCURRING DURING AND AFTER APPLICATION

The results and findings of this part of the study are given in Volume II of this report since the material presented is both technical and extensive. The study approach, the study areas, and a summary of the results and findings of Volume II are presented in Section VIII of this volume. For a summary of the work done in this aspect of the study, the reader is referred to Section VIII, page 106.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

No evidence was found in this study, given the present state of pesticide and pest management technology, that herbicides, fungicides, fumigants, defoliants, desiccants, plant growth regulators and pesticides other than insecticides and miticides are used on corn, sorghum, or apples in an inefficient or wasteful manner. Our findings regarding the use patterns of insecticides and miticides lead to the conclusion that approximately 50% of the quantities of these pesticides currently used on corn and sorghum, and 20 to 30% of the quantities used on apples are used needlessly. At least in part, this is due to the fact that in practice, persons recommending or making pesticide applications often have no certain way of knowing whether a given pesticide use is necessary or not, or whether a given rate of application is too high, too low, or just right.

Reductions in the quantities of insecticides and miticides used on corn, sorghum, and apples approaching 50% would require widespread adoption and implementation of integrated pest management practices, and greatly improved understanding and acceptance of integrated pest management principles and procedures by persons making pest management decisions and pesticide applications.

Thus, a percentage of the quantities of chemical insecticides and miticides used on the three crops is replaceable by integrated pest management. To the degree that chemical insecticides and integrated pest management services are interchangeable, they compete for the same users and dollars.

It does not follow, however, that the pesticide industry and integrated pest management proponents have to be in adversary positions. It would seem to be in the best interest of all concerned, industry, growers, as well as society as a whole, to reduce avoidable wastes and losses of pesticides, and to use these chemicals as efficiently and effectively as possible.

Growers need the best and most economical crop protection, not necessarily large quantities of inexpensive pesticides. The pesticide industry needs a larger operating profit per pound of chemical produced if it is to develop and market more selective pesticides that will be used in smaller quantities. No one wants avoidable, nonbeneficial pesticide residues in the food supply, in the environment, or any place else.

Integrated pest management experts and practitioners are an important element in improving all aspects of crop protection, including efficiency in the use of chemical pesticides.

RECOMMENDATIONS

* Promote further development and implementation of integrated pest management methods and practices.

* Remove legal obstacles to the recommendation and use of pesticides in integrated pest management programs at rates of application lower than those registered by the manufacturer.

* Promote cooperation among all concerned (including government agencies, universities, the pesticide industry, integrated pest management practitioners, and growers) in the development and implementation of better crop protection and pest management systems, including more efficient use of chemical pesticides.

Substantial quantities of pesticides are lost during and after application to corn, sorghum, and apples, and probably many other crops as well. Unwanted overapplication, nonuniform distribution, drift, and runoff are among the most significant loss mechanisms. Wastes and losses of pesticides during and after application due to these factors are avoidable only in part at the present state of pesticide and equipment technology. In addition, efforts to reduce pesticide losses from one of these mechanisms may increase losses from another. For instance, coarse sprays produce less drift, but may require more pesticide to produce the desired degree of plant coverage and control of the target pest. Coarse sprays also are more likely to result in nonuniform distrubution of droplets and uneven rates of pesticide deposits in the target area.

RECOMMENDATIONS

* Promote development of pesticide application methods and equipment that will reduce pesticide wastes and losses during application, in particular, overapplication, nonuniform distribution, and drift.

* Promote soil conservation practices that will reduce post-application pesticide losses due to runoff and erosion.

SECTION V

PESTICIDE USE PATTERNS ON CORN

PRODUCTION OF CORN IN THE UNITED STATES

In terms of total acreage and farm value, corn is the leading agricultural crop in the United States. In 1974, 77.4 million acres were planted to field corn, that is about 25% of the total U.S. harvested cropland acreage, and 3.4% of the total land area of the United States (including Alaska).

Table 2 summarizes the U.S. corn acreage, yield, value, and production during the last 4 years, 1971 to 1974. The corn acreage planted for all purposes ranged from a low of 67 million acres in 1972 to a high of 77.4 million acres in 1974. In each of the 4 years covered in Table 2, about 85% of the total corn acreage planted for all purposes was harvested for grain.

Table 2. U.S. CORN ACREAGE, YIELD, VALUE AND PRODUCTION, 1971 TO 1974

Acreage, yield value, production	Year 1971	1972	1973	1974
Acreage planted for all purposes, 1,000 acres	74,055	64,000	71,600	77,400 b/
Acreage harvested for grain, 1,000 acres	64,047	57,421	61,760	63,746 b/
Yield, a/ bu/acre	88.1	97.1	91.4	72.5 b/
Average farm price, $/bu	1.08	1.57	2.55	3.45 c/
Farm value, $/acre	95.15	152.45	233.07	250.13 b/
Total production, million bushels	5,641	5,573	5,643	4,621 b/

a/ Yield per acre harvested for grain.
b/ Preliminary.
c/ October 1974.
Sources: U.S. Department of Agriculture (1973, 1974a, c).

Corn yields (per acre harvested for grain) during this period ranged from a record high national average of 97.1 bu in 1972 to a low of 72.5 bu in 1974. The average price of corn received by farmers increased from $1.08/bu in 1971 to $1.57 in 1972, and to $2.55 in 1973, an increase of 136% over this 2-year period. Average farm prices for the 1974 crop are not available at this writing (January 1975). The October 1974 farm price for corn was $3.45/bu, compared to $2.17/bu in October of 1973, and $1.19/bu in October of 1972.

The farm value per acre of corn harvested for grain increased from $95.15 in 1971 to $152.45 in 1972, and further to $233.07 in 1973, an increase of 145% from 1971 to 1973. Indications are that in spite of the disappointing corn yield in 1974 due to unfavorable weather, the farm value per acre of corn for grain will be even higher in 1974 than it was in 1973.

Figure 2 presents the U.S. Department of Agriculture's division of the United States into 10 regions.

The total production of corn in the U.S. was about 5.6 billion bushels in 1971, 1972, and 1973, dropping to 4.6 billion bushels in 1974.

Figure 3 presents a breakdown of the U.S. corn acreage planted for all purposes in 1971. Table 3 summarizes the U.S. acreage of corn for grain by major producing states for the last 3 years, 1972 to 1974, showing state totals for all states growing more than 1 million acres in decreasing order of number of acres grown in 1974, and subtotals for the Corn Belt States. In 1974, the five Corn Belt States (Iowa, Illinois, Indiana, Ohio, and Missouri) raised 33.9 million acres of corn for grain, that is 53.1% of the national total. All other states growing more than 2 million acres of corn for grain were also midwestern states, i.e., Minnesota, Nebraska, South Dakota, and Wisconsin. The five Corn Belt States and the six other major midwestern corn-producing states combined raised 52.2 million acres of corn for grain in 1974, that is 82% of the U.S. total.

These data document that while some corn is grown in practically every state in the Union, the production of this crop is heavily centered in the midwestern states.

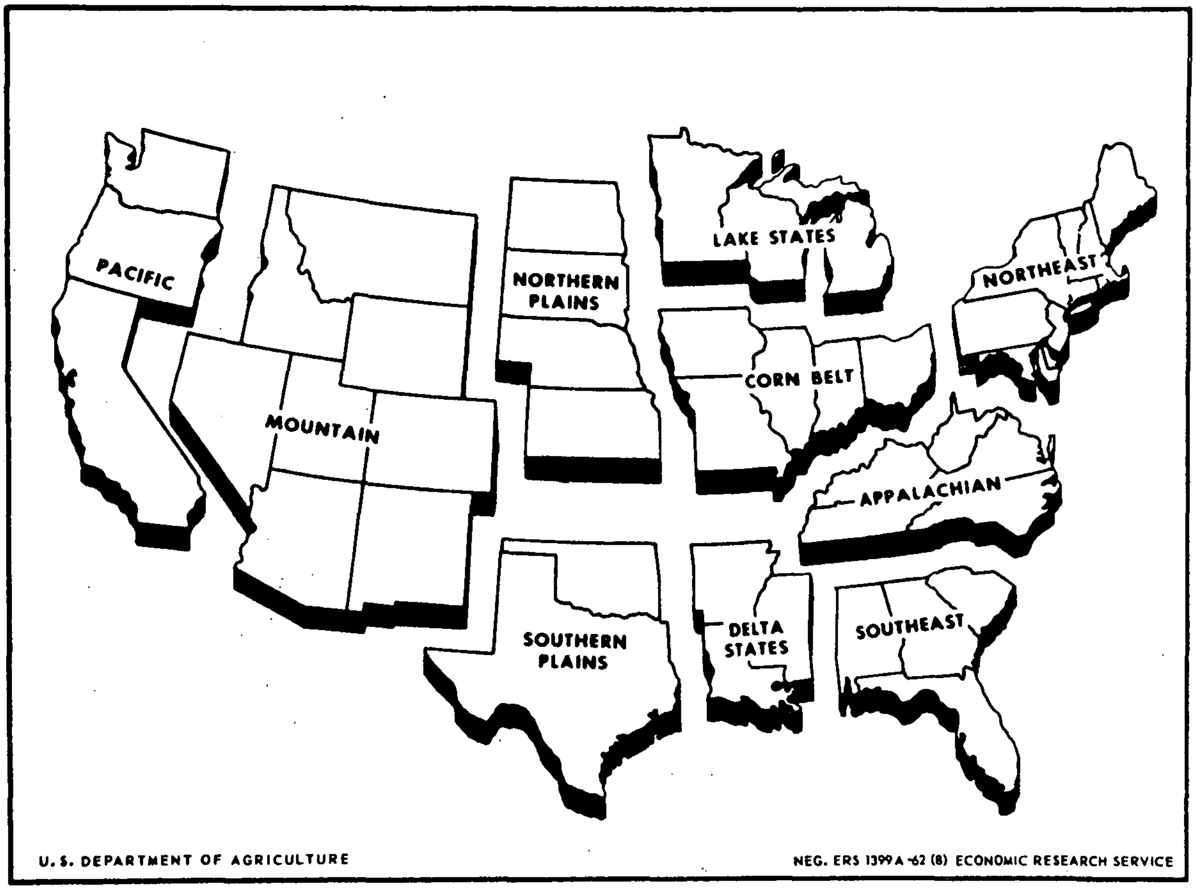


Figure 2. Farm production regions.

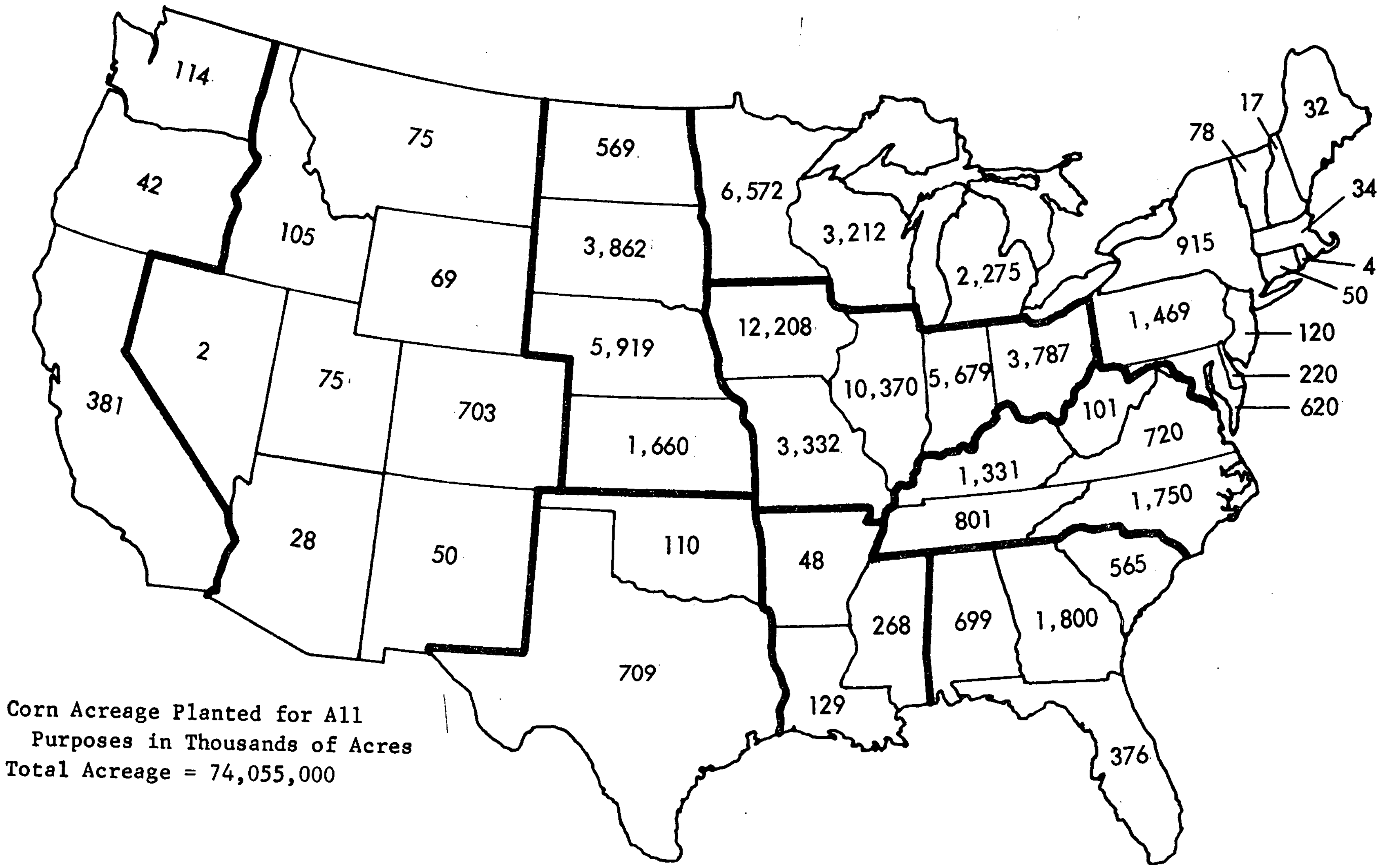


Figure 3. U.S. corn acreage (1971), by state.

Table 3. CORN ACREAGE[a] IN THE U.S. IN 1972, 1973 AND 1974[b] BY MAJOR PRODUCING STATES[c]

State \ Year	1972	1973	1974[b]
	1,000 Acres		
Iowa	10,600	11,150	11,750
Illinois	9,225	9,670	10,150
Indiana	4,884	5,240	5,500
Ohio	3,090	3,040	3,700
Missouri	2,500	2,600	2,750
Subtotal, Corn Belt	30,299	31,700	33,850
Minnesota	4,899	5,520	5,810
Nebraska	5,135	5,850	5,000
South Dakota	2,414	2,630	2,300
Wisconsin	2,143	2,090	2,090
Georgia	1,490	1,670	1,800
Michigan	1,722	1,690	1,730
North Carolina	1,280	1,400	1,570
Kansas	1,250	1,540	1,400
Kentucky	968	1,010	1,120
Pennsylvania	900	1,040	1,070
Subtotal, major producing states outside Corn Belt	22,201	24,440	23,890
All other states	4,921	5,620	6,006
United States	57,421	61,760	63,746

a/ Corn for grain.
b/ Preliminary.
c/ Corn belt states; all other states growing more than 1 million acres, in decreasing order of number of acres grown in 1974.
Source: U.S. Department of Agriculture (1974c).

QUANTITIES OF PESTICIDES USED ON CORN

The U.S. Department of Agriculture (1974b) conducted a survey on the agricultural uses of pesticides in 1971 (Tables 4 to 7). The Department reports that corn led all other crops by a wide margin in the total volume of herbicides used. American farmers used 101.1 million pounds of herbicides (active ingredient) on corn, that is 45% of the total quantity of herbicides used on agricultural crops in 1971. Corn was second in volume of insecticides used (preceded by cotton); farmers used 25.5 million pounds of insecticide active ingredients on corn in 1971, that is 17% of the total quantity of insecticides used on crops that year. The quantities of fungicides used on corn are so small that they were not disaggregated in the USDA pesticide use report for 1971 (or for 1966). Some miticides (57,000 lb) and fumigants (386,000 lb) were also used on corn in 1971, according to the USDA survey.

Table 4 provides a breakdown of the pesticides used on corn in 1971 by type of pesticide and by farm production regions, following the U.S. Department of Agriculture's division of the United States into 10 regions as shown in Figure 2. In line with the concentration of the production of corn in the Corn Belt, Lake, and Northern Plains States, these three regions accounted for the lion's share of all herbicides, insecticides, and "miscellaneous pesticides" used on corn in 1971. As Table 4 shows in detail, these three regions used 85% of all herbicides, 94% of all insecticides, 87% of all miscellaneous pesticides, and 87% of all pesticides used on corn in 1971, according to the USDA report.

The use of herbicides, insecticides, and miscellaneous pesticides on corn in 1971 by major products and by regions is further detailed in Tables 5, 6, and 7. These use patterns will be examined in greater detail below, in the sections dealing with corn herbicides and insecticides, respectively.

Table 8 presents a comparison of the quantities of pesticides used on corn in the United States in 1964, 1966, and 1971, according to the USDA pesticide use surveys for these years (U.S. Department of Agriculture, 1968, 1970, 1974b). The total quantity of all pesticides used on corn increased from 41.8 million pounds in 1964 to 70.1 million pounds in 1966, and further to 127.0 million pounds in 1971, a more than three-fold increase from 1964 to 1971. The use of corn herbicides increased almost four-fold from 25.5 million pounds in 1964 to 101.1 million pounds in 1971. The quantity of insecticides used on corn increased from 15.7 million pounds in 1964 to 23.6 million pounds in 1966, and to 25.5 million pounds in 1971, an increase of 63% from 1964 to 1971.

Table 4. PESTICIDE USAGE ON U.S. CORN CROP IN 1971 BY REGION

Region	Herbicides		Insecticides		Miscellaneous pesticides		Total pesticides[a]	
	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	5,250	5.2	155	0.6	1	0.2	5,406	4.3
Lake States	21,358	21.1	2,749	10.8	-	-	24,107	19.0
Corn Belt	54,069	53.5	15,314	60.0	-	-	69,383	54.6
Northern Plains	10,700	10.6	5,852	22.9	386	87.1	16,938	13.3
Appalachian	6,166	6.1	375	1.5	-	-	6,541	5.1
Southeast	2,105	2.1	42	0.2	-	-	2,147	1.7
Delta States	474	0.5	37	0.1	-	-	511	0.4
Southern Plains	127	0.1	54	0.2	-	-	181	0.1
Mountain	566	0.6	928	3.6	-	-	1,494	1.2
Pacific	245	0.2	25	0.1	56	12.7	326	0.3
Total	101,060	100.0	25,531	100.0	443	100.0	127,034	100.0

a/ Fungicides used on corn are not listed separately in the USDA report. Fungicides are not included in the pesticide total in this table.

Source: "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

Table 5. HERBICIDES USED ON CORN, BY REGION, 1971[a]
(1,000 lb)

Herbicide	North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Mountain	Pacific	Total
	Regions										
Atrazine	3,600	13,000	23,600	6,300	4,500	350	300	50	250	50	52,000
Propachlor	85	5,250	13,900	2,000	5	-	40	10	-	10	21,300
2,4-D	350	1,250	4,800	1,500	750	200	60	9	200	25	9,144
Alachlor	850	1,000	5,900	100	400	50	20	20	20	-	8,360
Butylate	120	160	3,800	150	195	1,250	-	-	43	100	5,818
Simazine	110	120	500	-	120	50	-	-	-	20	920
Linuron	10	30	600	100	10	5	20	5	20	4	804
Propazine	-	-	190	170	21	185	2	13	-	2	583
EPTC	10	100	50	100	-	10	-	2	10	10	292
Dicamba	3	50	150	60	-	-	-	1	10	10	284
MCPA	2	75	4	75	-	-	-	-	-	3	159
Others	110	323	575	145	165	5	32	17	13	11	1,396
Total	5,250	21,358	54,069	10,700	6,166	2,105	474	127	566	245	101,060

Source: "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

a/ Use of each individual insecticide, by region, is an MRI estimate.

Table 6. INSECTICIDES USED ON CORN, BY REGION, 1971[a,b]
(1,000 lb)

Insecticide	Regions: North-east	Lake States	Corn Belt	Northern Plains	Appalachian	South-east	Delta States	Southern Plains	Mountain	Pacific	Total
Aldrin	-	90	7,350	235	40	20	10	1	10	3	7,759
Bux	5	810	1,370	1,360	-	-	-	30	-	-	3,575
Carbofuran	50	790	1,140	630	20	4	12	-	30	5	2,681
Phorate	2	200	1,700	400	50	1	1	5	300	2	2,661
Diazinon	5	300	800	780	20	1	-	-	80	5	1,991
Carbaryl	20	100	400	1,000	100	2	1	5	20	1	1,649
Parathion	5	50	40	900	25	2	-	5	300	2	1,329
Heptachlor	4	10	1,090	-	-	-	-	-	-	-	1,104
Chlordane	35	200	560	-	30	4	-	3	8	2	842
Disulfoton	8	30	20	120	30	-	-	2	100	2	312
Others	21	169	844	427	60	8	13	3	80	3	1,628
Total	155	2,749	15,314	5,852	375	42	37	54	928	25	25,531

a/ Figures for total use of each insecticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table 7. MISCELLANEOUS PESTICIDES USED ON CORN, BY REGION, 1971[a,b]
(1,000 lb)

Pesticide	Regions										
	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	Total
Dicofol	-	-	-	-	-	-	-	-	-	56	56
Other Miticides	1	-	-	-	-	-	-	-	-	-	1
Miscellaneous Fumigants	-	-	-	386	-	-	-	-	-	-	386
Total	1	0	0	386	0	0	0	0	0	0	443

a/ Figures for total use of each pesticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual pesticide, by region, is an MRI estimate.

Table 8. USE OF PESTICIDES ON CORN IN THE U.S. IN 1964, 1966, AND 1971

Type of pesticide	Year 1964	1966	1971
	(1,000 lb of active ingredient)		
Fungicides	543	N.A.	N.A.
Insecticides[a/]	15,668	23,629	25,531
Herbicides[a/]	25,476	45,970	101,060
Miscellaneous pesticides	76	546[b/]	443[c/]
All pesticides	41,773	70,145[d/]	127,034[d/]

a/ Excluding petroleum.
b/ Includes 117,000 lb miticides, 429,000 lb fumigants.
c/ Includes 57,000 lb miticides, 386,000 lb fumigants.
d/ Excluding fungicides.
N.A. = Not available
Sources: U.S. Department of Agriculture (1968, 1970, 1974b).

During the period 1964 to 1974, the total U.S. acreage of corn harvested for grain was as follows (U.S. Department of Agriculture 1973, 1974a):

Year	1,000 acres
1964	55,369
1965	55,392
1966	57,002
1967	60,694
1968	55,980
1969	54,574
1970	57,358
1971	64,047
1972	57,421
1973	61,760
1974 (Preliminary)	63,746

These data show that the corn acreage in the United States increased by less than 3% from 1964 to 1966, while the use of insecticides increased by 51% (from 15.7 to 23.6 million pounds of active ingredient), and the use of herbicides by 80% (from 25.5 to 46 million pounds of active ingredient). The further increase in the use of herbicides on corn from 1966 to 1971 is equally striking. While the acreage of corn harvested for grain increased by 12% from 1966 to 1971, the use of herbicides increased by 120% (from 46 million pounds in 1966 to 101.1 million pounds of active ingredient in 1971). These data document that the increases in the quantities of pesticides, especially of herbicides, used on corn are primarily due to higher average inputs per acre, and only to a small extent to an increase in corn acreage.

The USDA pesticide use surveys as well as Cooperative Extension Service publications and state pesticide use surveys indicate that the use of pesticides other than herbicides and insecticides on corn is very small or negligible.

The data presented in this section and those on the geographic distribution of corn presented in the preceding section indicate that our study on the efficiency of current pesticide use practices on corn should be focused on the use of herbicides and insecticides on corn in the Midwest.

HERBICIDE USE PRACTICES

The rate of use of herbicides on corn in the United States has increased greatly from 1964 to 1971, as summarized above. In 1964, 25.5 million pounds of herbicide active ingredients were applied to corn, 46.0 million pounds in 1966, and 101.1 million pounds in 1971 (Table 8). Thus, the quantities of herbicides used on corn almost quadrupled from 1964 to 1971, while the corn acreage harvested for grain increased by only 16% during this period.

The U.S. Department of Agriculture (1972) conducted surveys on the use of herbicides on agricultural crops in 1959, 1962, 1965, and 1968. Table 9 presents the results of these surveys for corn. During the 10 year time span covered, the corn acreage receiving herbicide treatments increased from 20 million acres in 1959 to 48.9 million acres in 1968. The percentage of the total corn acreage treated with herbicides increased from 25% in 1959 to 39% in 1962, 68% in 1965, and 76% in 1968. Of the 48.9 million acres of corn treated with herbicides in 1968 according to this survey, 20.4 million acres were treated preemergence only (at an average cost of $4.84/acre); 18.9 million acres were treated postemergence only ($2.46/acre); and 9.6 million acres were treated both pre- and postemergence ($6.15/acre).

Table 9. ESTIMATED EXTENT OF CHEMICAL WEED CONTROL ON CORN IN THE U.S., 1959 TO 1968

Year	1959	1962	1965	1968
Acreage treated with herbicides, 1,000 acres	20,051	25,302	45,012	48,930
Percent of total corn acres harvested for grain	25%	39%	68%	76%

Source: U.S. Department of Agriculture (1972).

More recent data on the extent of use of herbicides on corn in the Midwest were reported by von Rümker and Horay (1974). Of about 300 corn growers in Iowa and Illinois who responded to detailed questions regarding their pesticide use practices, all but two reported using corn herbicides in 1973. About 85% of the respondents from both states believed that all of their corn acres need herbicide treatments each year. Based on these farmer responses, on the findings of other recent pesticide use surveys, and on information from midwestern weed research and extension workers, vom Rümker and Horay (1974) concluded that herbicides are used by close to 100% of all corn growers in the leading midwestern corn-producing states, and that close to 90% of the total corn acreage in the region is treated with herbicides. Since a substantial percentage of the total corn acreage receives both pre- and postemergence treatments, the total number of "gross" acres treated (acres treated more than once counted for each treatment) exceeds the total corn acreage harvested for grain.

Table 5 presents a breakdown of the herbicides used on corn in 1971 by regions and by major individual herbicides. Of the total quantity of herbicides used on corn in 1971 according to the U.S. Department of Agriculture (1974b), about 54% (54.0 million pounds) were used in the five Corn Belt States, and 85% of the total (86.1 million pounds) in the Lake, Corn Belt, and Northern Plains States combined. Much smaller quantities of herbicides were used on corn in all other regions.

One single product, atrazine, accounted for more than 50% of the total quantity of herbicides used on corn, according to the USDA survey. In decreasing order of use volume, atrazine was followed by propachlor (21.3 million pounds), 2,4-D (9.1 million pounds), alachlor (8.4 million pounds), and butylate (5.8 million pounds). All other corn herbicides were used in 1971 in quantities less than 1 million pounds, according to this source.

Herbicides are used on corn for the control of a variety of weeds including pigweeds, crabgrasses, lambsquarters, quackgrass, foxtails, nutsedges, Canada thistle, johnsongrass, barnyard grass, bindweeds, cockleburs, morning glories, panicums, kochia, velvetleaf, and witchgrass. Of the 48 states that participated in the corn phase of the 1968 herbicide use survey by the U.S. Department of Agriculture (1972), 42 states reported an upward trend in herbicide use, six reported a stationary situation, while nine reported a downward trend.

Extension weed scientists and agronomists contacted in the present study reported that 90 to 95% of the corn acres in their respective states were treated at least once with a herbicide, and that at least that many or more corn acres needed the herbicide treatment.

The costs of chemical weed control in corn per acre have increased substantially during the last 10 to 15 years. Increased costs per pound of the herbicides have contributed to this increase only to a minor extent. The major part of the cost increase per acre is due to the fact that weed species that are more difficult to control are gradually becoming more predominant in corn fields, as those species that are easily controlled recede. As a result, herbicide application rates per acre were increased, relatively inexpensive herbicides like 2,4-D were replaced by more expensive preemergence herbicides, postemergence treatments were added to preemergence treatments, and single herbicides are being replaced by combinations of two products. The question how fast this trend will further progress, and what its economic and ecological end point might be apparently has not received much, if any study thus far.

The economic part of the question is not pressing as long as the farm value of the crop increases more rapidly than the cost of using herbicides, as has been the case in recent years (Table 2). Nevertheless, the cost of chemical weed control in corn ($6.00 to $15.00/acre and up for preemergence herbicides) represents a significant fraction of the corn production costs and of the farm value of the crop, providing an economic incentive for corn growers to use herbicides efficiently and at minimum effective rates.

In addition, many herbicides have a limited safety margin between the rate that will kill weeds and the rate that may injure the crop. This is another incentive for growers not to use herbicides at rates higher than necessary.

Several of the U.S. Department of Agriculture/State Cooperative Pilot Pest Management Projects on corn initiated in 1973 include weed phases (Illinois, Indiana, Iowa, Nebraska, and Ohio). Pest management programs for weeds seem to tend in the direction of total farm weed control. For instance, Illinois' summary on its corn pest management project for 1973 states: "More emphasis is needed on weed control in forage crops, small grains, and noncropland along with control programs in corn and soybeans if the weed seed population in the soil is going to be reduced and progress in weed management is to be achieved." This "total farm weed control" concept recently received support from Rodgers (1974), then the President of the Weed Science Society of America, and from other prominent weed scientists.

This approach may require more extensive use of chemical herbicides (and of other weed control measures) at least until the weed seed reservoir in the soil is depleted. No data appear to be available on how many years this may take under field conditions, whether benefits will outweigh costs, and how the desired area-wide simplification of agro-ecosystems might affect other components of the system, such as the soil microflora and fauna, and desirable animal species such as certain birds, game, beneficial insects, and others.

In summary, practically all corn growers and weed research and extension workers believe that chemical herbicides are essential to the efficient and profitable production of corn, that the quantities of herbicides used on corn are needed, and that corn herbicides are used efficiently. Herbicide costs and the possibility of crop injury from overapplication provide practical incentives against unnecessary or wasteful use of corn herbicides. We found no research data to show whether economic weed control could be achieved by substantially reduced rates of chemical herbicides or by other means.

The "total farm weed control" concept promoted in some pest management programs for weeds will require heavier, rather than reduced herbicide inputs at least in the initial weed eradication phase.

INSECTICIDE USE PRACTICES

As documented above in the section "Quantities of Pesticides Used on Corn," the use of insecticides on corn increased by 63% from 1964 to 1971, namely, from 15.7 million pounds of active ingredients in 1964 to 25.5 million pounds in 1971, according to the pesticide use surveys by the U.S. Department of Agriculture (1968, 1970, 1974b). During the same time span, the U.S. acreage of corn harvested for grain increased by only 15.7%. These data indicate that insecticide inputs per acre of corn increased considerably during this 8-year period.

According to the 1971 USDA pesticide use survey, a total of 25.5 million pounds of insecticide active ingredients were used on corn that year (Table 6). Of this total, 9.7 million pounds consisted of chlorinated hydrocarbon insecticides (aldrin, heptachlor, and chlordane); the balance was made up of four organic phosphate and three carbamate insecticides; and other insecticides that were not disaggregated.

Other recent studies indicate that the U.S. Department of Agriculture's estimates on the quantities of insecticides used on corn in 1971 are probably too low. For example, von Rümker and Horay (1974) estimated that 18.5 million pounds of insecticides were used on corn in 1971 in Iowa and Illinois alone, that is 3.2 million pounds in excess of the USDA estimate for the entire Corn Belt (Table 6). In 1971, Iowa and Illinois raised 64% (21.8 million acres) of all corn acres in the Corn Belt (33.9 million acres).

Furthermore, the use of aldrin on corn in 1971 was estimated to be 7.8 million pounds by USDA (U.S. Department of Agriculture, 1974b), but an estimate of 9.4 million pounds for this use was provided by EPA in the recent aldrin/dieldrin cancellation proceedings (Train, 1974). This latter estimate appears to be more authoritative and in better agreement with other information cited above.

In the midwestern corn-growing states, corn may be attacked by a number of soil and foliar insects. Overall, the soil insects are of much greater economic importance than those feeding above ground.

Corn soil insects include three species of corn rootworms, and a number of other insects often referred to as the "soil insect complex." The corn rootworm species occurring in the Midwest are *Diabrotica longicornis*, the northern corn rootworm; *D. virgifera*, the western corn rootworm; and *D. undecimpuncata howardi*, the southern corn rootworm. The northern and western species predominate in Iowa and Illinois. They often occur together and have similar life cycles and habits. Western corn rootworms are completely, and northern rootworms almost completely resistant to chlorinated hydrocarbon insecticides in the principal midwestern corn-producing states. Corn rootworms are usually a problem only on corn following corn, sorghum, or sunflowers. Corn following soybeans or small grains rarely suffers rootworm damage.

The "corn soil insect complex" includes seedcorn maggots, *Hylemya* spp.; the seedcorn beetle, *Agonoderus lecontei*; the slender seedcorn beetle, *Clivina impressifrons*; wireworms (order *Coleoptera*, family *Elateridae*); cutworms (order *Lepidoptera*, family *Noctuidae*); white grubs, *Phyllophaga* or *Lachnosterna* spp.; webworms, *Crambus* spp.; billbugs, *Calendra* spp.; ants (order *Hymenoptera*, family *Formicidae*); and the corn root aphid, *Anuraphis maidiradicis*. These soil insects are most serious on first year corn following legumes, legume grass or grass sods. They are seldom a problem on corn following corn or soybeans in the rotation.

Foliar insects that may attack corn in the Midwest include corn borers (order Lepidoptera, family Pyralididae); the corn earworm, Heliothis zea; corn rootworm beetles, the adult forms of the corn rootworms (Diabrotica spp.) discussed above, the corn leaf aphid, Rhopalosiphum maidis; the corn flea beetle, Chaetocnema pulicaria; the armyworm, Pseudaletia unipuncta; the fall armyworm, Spodoptera frugiperda; and grasshoppers (order Orthoptera, family Locustidae).

Table 10 presents an overview of the insecticides that were recommended against the major corn soil insects in 1974 by extension entomologists in eight midwestern states, detailed by states, insecticides, rates, and target insects. Seven of the eight midwestern states did not recommend any chlorinated hydrocarbon insecticides against corn rootworms, the only exception being Indiana which still recommended aldrin and heptachlor against these insects. Against wireworms and white grubs, aldrin, chlordane and/or heptachlor were recommended in seven of the eight midwestern states; Illinois did not recommend any chlorinated hydrocarbon insecticides against these insects. Against cutworms, aldrin, heptachlor and/or chlordane were recommended in five of the eight midwestern states. Alternative cutworm control recommendations in Illinois, Minnesota, and Nebraska included carbaryl, trichlorfon, diazinon, and/or toxaphene. Against seed beetles and maggots, aldrin and heptachlor seed treatments were recommended in five of the states, while Iowa, Illinois, and Ohio recommended only diazinon seed treatments.

Entomologists at the University of Illinois have studied corn insect infestations, and the effectiveness of insecticides in averting yield losses due to these insects since 1955 (Petty, 1974; Kuhlman et al. 1973, Randell et al. 1974; Wedberg et al. 1975). Estimates on the extent and profitability of the use of insecticides on corn in Illinois in 1972, 1973, and 1974 according to these authors are summarized in Table 11. These estimates indicate that Illinois corn growers realized net returns from the use of insecticides on corn of $22.8 million ($3.55/acre treated) in 1972, $22.2 million ($3.55/acre) in 1973, and $30.7 million ($4.62/acre) in 1974. In each of the 3 years, more than 90% of the total estimated profits resulted from the use of insecticides against soil insects, based on yield increases from use of corn rootworm insecticides. Thus, on the surface, the use of corn soil insecticides appears to be a profitable practice. However, the estimated profits per acre in Table 11 are averages which,

Table 10. INSECTICIDES RECOMMENDED AGAINST CORN SOIL INSECTS IN 1974 BY EXTENSION ENTOMOLOGISTS IN EIGHT MIDWESTERN STATES

	Target insects							
State	Corn rootworms		Wireworms and white grubs		Cutworms		Seed beetles and maggots	
	(Lb of active ingredient per acre)							
Iowa	Carbofuran	0.75-1.0	Aldrin	1.0	Aldrin	1.0-2.0	Diazinon seed treatment	
	Dasanit®	1.0	Chlordane	2.0	Chlordane	2.0-4.0		
	Dyfonate®	1.0	Carbofuran	0.75-1.0	Heptachlor	1.0-2.0		
	Landrin®	1.0	Heptachlor	1.0	Carbaryl bait	1.0		
	Mocap®	1.0	Phorate	1.0	Carbaryl spray	2.0		
	Phorate	1.0			Toxaphene	2.0		
					Trichlorfon	1.0		
Illinois	Carbofuran	0.75-1.0	Carbofuran	2.0	Carbaryl bait	1.0	Diazinon seed treatment	
	Dasanit®	1.0	Diazinon	1.5	Carbaryl spray	2.0		
	Dyfonate®	1.0			Trichlorfon	1.0		
	Landrin®	1.0						
	Phorate	1.0						
Indiana	Carbofuran	0.75	Aldrin	3.0	Adlrin	3.0	Aldrin	
	Dyfonate®	1.0	Heptachlor	3.0	Heptachlor	3.0	Diazinon	
	Phorate	1.0	Diazinon	4.0	Diazinon	4.0	Heptachlor	Seed treatment
	Dasanit®	1.0	Dyfonate®	4.0	Carbaryl spray or bait		Lindane	
	Bux®	1.0	Mocap®	2.0	Trichlorfon spray or bait			
	Mocap®	1.0	Carbofuran	2.0				
	Aldrin	1.0	Phorate	1.0	Toxaphene	2.0		
	Heptachlor	1.0						
	Diazinon	1.0						
Ohio	Carbofuran	1.0	Aldrin	2.0	Carbaryl bait	1.0	Diazinon seed treatment	
	Dasanit®	0.75-1.0	Heptachlor	2.0	Carbaryl spray	2.0		
	Dyfonate®	0.75-1.0			Chlordane	4.0		
	Phorate	1.0			Heptachlor	2.0		
					Toxaphene	2.0		
					Trichlorfon	1.0		
Missouri	Bux®	1.0	Aldrin	3.0-4.0	Aldrin	1.5-2.0	Aldrin	
	Carbofuran	0.75-1.0	Diazinon	3.0-4.0	Carbaryl	1.0-2.0	Diazinon	
	Dasanit®	1.0	Dyfonate®	4.0	Diazinon	3.0-4.0	Dieldrin	Seed treatment
	Diazinon	1.0	Heptachlor	3.0-4.0	Heptachlor	1.5-2.0	Heptachlor	
	Phorate	0.75-1.0			Toxaphene	2.0-3.0	Lindane	
					Trichlorfon	1.0		
Minnesota	Carbofuran	1.0	Aldrin	2.0	Carbaryl	2.0	Aldrin	
	Dasanit®	1.0	Chlordane	4.0	Toxaphene	2.0	Diazinon	
	Diazinon	1.0	Diazinon	1.0-2.0	Trichlorfon	1.5	Dieldrin	Seed treatment
	Dyfonate®	1.0	Dyfonate®	1.0			Heptachlor	
	Phorate	1.0	Heptachlor	2.0				
			Phorate	1.0				
South Dakota	Carbofuran	1.0	Aldrin	2.0	Aldrin	2.0	Aldrin	
	Dasanit®	1.0	Chlordane	4.0	Carbaryl bait	1.0	Heptachlor	
	Dyfonate®	1.0	Heptachlor	2.0	Carbaryl spray	2.0	Lindane	Seed treatment
	Mocap®	1.0			Diazinon	2.0	Diazinon	
	Phorate	1.0			Heptachlor	2.0		
					Toxaphene	2.0		
					Trichlorfon	1.0		
Nebraska	Bux®	1.0	Aldrin	2.0	Carbaryl	1.0	Aldrin	
	Carbofuran	1.0	Chlordane	4.0	Diazinon	4.0	Diazinon	
	Dasanit®	1.0	Heptachlor	2.0			Dieldrin	Seed treatment
	Dyfonate®	1.0					Heptachlor	
	Disyston®	1.0					Lindane	
	Mocap®	1.0						
	Phorate	1.0						

Source: von Rümker et al. (1975).

Table 11. EXTENT AND PROFITABILITY OF THE USE OF INSECTICIDES ON CORN IN ILLINOIS, 1972-1974

Year	Target insects[a]	Acres treated	Estimated profit[b] Total	Estimated profit[b] Per acre
1972	Soil insects	6,085,328	$21,298,648[c]	$3.50[c]
	Cutworms	124,430	746,580	6.00
	European corn borer	69,944	104,916	1.50
	Corn leaf aphid	55,669	389,683	7.00
	Grasshoppers	51,882	51,882	1.00
	Corn rootworm adults	36,002	144,008	4.00
	Armyworm	24,695	37,043	1.50
	Fall armyworm	4,609	11,523	2.50
	Total	6,452,559	22,784,283	3.53
1973	Soil insects	5,738,053	$20,083,186[c]	$3.50[c]
	Corn leaf aphid	137,292	961,044	7.00
	Fall armyworm	124,063	310,158	2.50
	European corn borer	108,284	162,426	1.50
	Cutworms	93,781	562,686	6.00
	Corn rootworm adults	24,642	98,568	4.00
	Armyworm	19,593	29,390	1.50
	Total	6,258,537	22,220,287	3.55
1974	Soil insects	6,014,342	$28,175,647[c]	$4.68[c]
	Corn leaf aphid	201,032	1,409,114	7.01
	European corn borer	126,943	253,886	2.00
	Fall armyworm	113,980	284,950	2.50
	Corn flea beetle	84,314	126,471	1.50
	Cutworms	56,756	340,536	6.00
	Corn rootworm adults	29,980	119,920	4.00
	Armyworm	13,179	19,769	1.50
	Grasshoppers	10,891	16,337	1.50
	Total	6,651,417	30,746,630	4.62

a/ Listed in decreasing order of number of acres treated each year.
b/ Over and above treatment costs.
c/ Based on yield increase from use of corn rootworm insecticides.

Source: Adapted from Kuhlman et al. (1973), Randell et al.(1974), and Wedberg et al. (1975).

as further analysis reveals, consist of much higher net returns from the use of insecticides on corn acres that actually needed the treatment, and minimal or no returns from acres treated unnecessarily.

Table 12 presents an estimate on the use and profitability of soil insecticides for corn rootworm control in Illinois for the 11-year period, 1964 to 1974. The assumptions used by the Illinois authors in calculating these data as summarized in the lower part of the table are very interesting. They are based on reports from county extension advisors and on research and field demonstration studies by Illinois entomologists. According to these sources, only about 40 to 50% of all corn acres treated with soil insecticides during the last 4 years needed the treatment, that is only about 20% of all corn acres harvested for grain in Illinois during that period. The yield loss prevented by the use of insecticides on acres needing the treatment averaged 10.0 bu/acre from 1971 to 1973, and was estimated at 6.2 bu/acre in 1974. The farm price of corn used in the estimate was $1.00/bu for 1971 to 1973, $2.75/bu for 1974. Thus the estimated value of the yield loss prevented on the acres needing the treatment was $7.00/acre for 1971 to 1973, $13.65/acre in 1974. Furthermore, it was estimated that on the acres treated unnecessarily (60% of all treated acres 1971 to 1973, 50% of all treated acres in 1974), growers realized a net return above the cost of the treatment of $1.00/acre in 1971 to 1973, and zero in 1974.

The average net gain for all acres treated, $3.50/acre for the period 1971 to 1973, was calculated as follows: of 6 million acres of corn treated with soil insecticides, only 2.5 million acres = 41-2/3% needed the treatment, returning $7.00/acre net. On the balance of the treated acreage, 3.5 million acres = 58-1/3% of the total treated acreage, net returns from the treatment averaged only $1.00/acre above the cost of treatment. The average net gain for all acres treated, therefore, was:

41.667 x $7.00	$291.67			
58.333 x $1.00	58.33			
	$350.00	:	100	$3.50/acre

The corresponding data for 1974 were computed in the same manner.

The higher average net returns from the use of corn soil insecticides in the earlier years (Table 12) are based on the fact that prior to 1971, corn rootworm populations were considerably higher and thus more damaging, so that the return from using a corn rootworm insecticide was greater. The corn rootworm problem has lessened during the last few years. The re-increase in the average profit per acre in 1974 is due to the increase in the price of corn and thus in the value of the yield loss prevented, rather than to a rebound of corn rootworm damage.

Table 12. ESTIMATED USE AND PROFITABILITY OF SOIL INSECTICIDES FOR CORN ROOTWORM CONTROL IN ILLINOIS, 1964-1974

Year	Corn acres treated with soil insecticides	Average profit[a/] ($/acre)	Total profit ($)
1964	4,091,125	4.00	16,364,500
1965	4,733,784	5.00	23,668,920
1966	5,443,197	5.00	27,215,985
1967	6,204,293	5.00	31,021,465
1968	6,261,869	5.00	31,309,345
1969	6,508,067	5.00	32,540,335
1970	6,610,287	3.75	24,788,576
1971	6,142,039	3.50[b/]	21,497,137
1972	6,085,328	3.50	21,298,648
1973	5,738,053	3.50	20,083,186
1974	6,014,342	4.68[c/]	28,175,647

a/ Assumptions:	1971-1973[b/]	1974[c/]
Cost of insecticide treatment/acre	$3.00	$3.40
Farm price of corn/bu	$1.00	$2.75
Acres needing treatment relative to		
-all corn acres treated	41-2/3%	50%
-all corn acres harvested for grain	20%	20%
On acres needing treatment		
-yield loss prevented/acre	10.0 bu	6.2 bu
-value of yield loss prevented/acre	$10.00	$17.05
-less cost of treatment/acre	$3.00	$3.40
-net return from treatment/acre	$7.00	$13.65
On acres *not* needing treatment net return above cost of treatment/acre	$1.00	None
Average net gain for all acres treated, per acre	$3.50	$4.68

Sources: Randell et al. (1974), Kuhlman (1973, 1975)

The estimates on the economic benefits from the use of insecticides on corn in Illinois discussed above are presented and quoted as given in the sources cited, in contemporary dollars. One might question if estimates of this type should not be given in more rounded, less specific terms, or if dollar figures should be price-adjusted. However, these Illinois data are derived from an ongoing study. They are updated annually, and they are widely accepted and used by entomologists, extension personnel and others in their present form. Therefore, it seemed preferable to present and discuss them in their original, unaltered form in this report.

A breakdown of the types of corn soil insecticides used in Illinois during the same 11-year period, 1964 to 1974, is given in Table 13. In the early days of the use of soil insecticides on corn, chlorinated hydrocarbon insecticides (primarily aldrin) controlled both corn rootworms and the complex of other soil insects. Today, as pointed out above, western and northern corn rootworms are highly resistant to chlorinated hydrocarbon insecticides in many areas. In recent years, organic phosphate and carbamate insecticides have been used primarily against resistant rootworms, and chlorinated hydrocarbons against the other corn soil insects.

The data summarized in Table 13 show that the total corn acreage treated with soil insecticides in Illinois has remained almost level from about 1967 to the present, except for relatively small year-to-year oscillations. The acreage treated with chlorinated hydrocarbon insecticides decreased from 4.0 million acres (98% of all acres treated) in 1964 to 1.9 million acres (31% of all acres treated) in 1974.

Shaw et al. (1975) describe two methods for predicting damage from corn rootworms, i.e., (a) counting adult rootworms per plant on two different dates in August, and (b) counting corn rootworm eggs in soil samples taken in the field in the fall. If one or more adult corn rootworms per plant are found on either count in August, a soil insecticide should be used if the field is again planted to corn the next year. All corn fields with 5 million or more corn rootworm eggs per acre should be treated with a soil insecticide the following year. Careful examinations of rootworm damage and yield loss in corn fields in 1974 showed that there was no damage at 1 million eggs per acre, only slight damage at 9 million eggs per acre, moderate damage at 13 million eggs per acre, and severe damage at 18 million eggs per acre. Thus, the suggestion to treat when there are 5 million or more eggs per acre is conservative.

Table 13. USE OF CORN SOIL INSECTICIDES IN ILLINOIS, 1964 TO 1974

Year	Acres treated with: Chlorinated hydrocarbons	Acres treated with: Organic phosphates and carbamates	Total acres treated
1964	4,009,303	81,822	4,091,125
1965	4,544,432	189,352	4,733,784
1966	5,116,605	326,592	5,443,197
1967	5,601,572	602,721	6,204,293
1968	5,170,726	1,091,143	6,261,869
1969	4,517,931	1,990,138	6,508,069
1970	3,844,740	2,765,547	6,610,287
1971	2,723,119	3,418,920	6,142,039
1972	1,933,089	3,852,239	5,785,328[a]
1973	1,737,510	3,960,543	5,698,053[a]
1974	1,886,042	4,128,300	6,014,342

a/ These figures vary slightly from those reported in Table 11 for reasons not known, but the variations are not large enough to be of significance to the objectives of this study.

Source: Adapted from Kuhlman et al. (1973), Wedberg et al. (1975).

Field observations in 1973 and 1974 by these authors indicate that over one-half of the corn fields in Illinois have rootworm counts of less than 5 million eggs per acre.

Shaw et al. (1975) also studied wireworm damage to corn. By using a bait method as a diagnostic tool, 21 corn fields were examined in 1974. Wireworm larvae were found in only two of the 21 fields baited. One of these had only one larvae on the six baits placed in each field, that is considerably below the suggested treatment threshold of four or more larvae per six baits. The second field had a total of 41 larvae on the six baits, and use of a soil insecticide was recommended in this case. The survey indicates that only a small percentage of all corn fields in Illinois require the use of insecticides against wireworms.

In May and June of 1974, Shaw et al. (1975) investigated many reports of black cutworm (Agrotis ypsilon) damage in corn received from farm advisers in west-central and southern Illinois. From these reports, 15 fields in 10 different counties were selected for observation. For each field, information was obtained on the 1973 crop preceding corn in the rotation, tillage practices, field drainage, percent cutworm damage in the highest damage area within each field, and cutworm control measures taken. Characteristics that appeared to be common to fields with a black cutworm problem included the following:

* Cutworm problems in previous years (11 of 15 fields).

* Considerable surface debris and litter from no-till, minimum-till, or chisel plowing (14 of 15 fields).

* Soybeans preceded corn in the rotation (11 of 15 fields).

* Bottomland or low elevation location (13 of 15 fields).

* Poor drainage (14 of 15 fields).

The authors suggest that fields with all of these characteristics have a high potential for black cutworm infestation and damage. In greenhouse experiments, they tested the theory that a large number of black cutworm larvae could be killed with systemic insecticide placed in the seed furrow at planting time. A 10% granular formulation of carbofuran applied in this manner at the rate of 1 lb of active ingredient per acre killed 100% of small first and second instar larvae, and 60% of larger third, fourth, and fifth instar larvae within 48 hr after the larve were released on the treated plants. A band application of carbofuran at the same rate of active ingredient per acre was considerably less effective, particularly on the smaller larvae.

The data summarized in Table 11 show that an estimated 124,430 acres of corn were treated for cutworms in Illinois in 1972, 93,781 acres in 1973, and 56,756 acres in 1974. The net return estimates indicate that cutworm treatments were among the more profitable uses of corn insecticides.

The corn acreage treated for the control of all foliar insects of corn combined amounted to less than 10% of the acreage treated against soil insects in Illinois in each of the 3 years covered in Table 11. Among the foliar insects, control of the corn leaf aphid was considered to be relatively most profitable (net return $7.00/acre), followed by control of corn rootworm adults (net return $4.00/acre). Insecticides used against the remaining foliar insects of corn, i.e., the European corn borer, the corn flea beetle, grasshoppers, and armyworms yielded rather low economic benefits and accounted for only small percentages of the total corn acres treated with insecticides.

Comparable, detailed studies and historic data on the usefulness of insecticides on corn are, to the best of our knowledge, not currently available for any other corn-producing state. However, several other, although less detailed, estimates on the use of corn soil insecticides from other sources tend to support the findings of the Illinois entomologists. In 1973, von Rümker and Horay (1974) investigated the use patterns of corn insecticides in Iowa and Illinois in connection with a study on farmers' pesticide use decisions and attitudes on alternate crop protection methods. Responses from about 300 corn growers in Iowa and Illinois who were interviewed in this study indicated that 53% of the respondents in Iowa and 70% of those in Illinois used corn insecticides in 1973. Interestingly, only about one-half of the corn insecticide users, that is only about one-third of all corn growers interviewed, believed that all of their corn acres need insecticide treatments each year. Those growers who felt that not all of their corn fields needed insecticide treatments were then asked: "How do you decide which corn acres to treat and which not?" Responses to this question included the following:

* "Treat only corn on corn."
* "Treat only corn on sod."
* "Treat only corn on soybeans."
* "Treat only the seed."
* "Don't know how to tell if I need control chemicals, so I apply to all acres."

According to these authors (von Rümker and Horay, 1974), Iowa extension entomologists estimated that in 1973, about 5 million acres of corn in Iowa were treated with soil insecticides, 2.5 million of these (50%) with chlorinated hydrocarbons (aldrin 80%; heptachlor 16%; chlordane 4%). The entomologists felt that in 1973, chlorinated hydrocarbon insecticides (for the control of corn soil insects other than corn rootworms) were actually needed on about 1 million acres, that is about 40% of the acreage actually treated with these products.

In the present study, extension entomologists from four midwestern states provided the information on the number of corn acres treated with soil insecticides compared to acres needing treatment and to total corn acres in their respective states (Table 14). The responses from Illinois, Iowa and Indiana combined indicate that in those three states, about 54% (17.5 of 32.4 million acres) of the corn acreage harvested for grain received soil insecticide treatments. An estimated 45% of the treated acres needed the treatment, that is about 23% of the total acreage.

Table 14. CORN ACRES TREATED WITH SOIL INSECTICIDES IN SELECTED STATES COMPARED TO ACRES NEEDING TREATMENT AND ACRES HARVESTED FOR GRAIN, 1974

State	Acres harvested for grain	Acres treated with soil insecticides	Acres needing treatment	Acres needing treatment as percent of	
		(1,000 Acres)		Acres treated	Acres harvested
Illinois	10,150	6,000	2,000	33%	20%
Iowa	11,750	5,250	4,000	76%	34%
Indiana	5,500	2,600	300	12%	5%
Nebraska	5,000	3,690	N.a.	N.a.	N.a.
Totals	32,400	17,540			
-excl. Nebraska	27,400	13,850	6,300	45%	23%

Sources: Wedberg et al. (1975); Kuhlman (1975); Extension Entomologists in Iowa, Indiana and Nebraska (1975)

N.a. = Not available.

The data presented in this section suggest that substantial quantities of the insecticides used on corn for the control of corn rootworms and other soil insects are applied needlessly. Based on the thorough studies conducted in Illinois and the data from several other states discussed above, especially those summarized in Table 14, we estimate that about 50% of the quantities of soil insecticides that were used on corn during the last few years could be saved. In terms of the total quantity of insecticides that were used on corn in 1971 according to the USDA Pesticide Survey, 25.5 million pounds of active ingredients (Table 4), such savings would amount to about 12.8 million pounds.

Important prerequisites to improving the efficiency in the use of corn soil insecticides by avoiding unnecessary treatments include development and implementation of practical methods for diagnosing corn soil insect problems, and for predicting treatment needs. The progress reported in this regard by Shaw et al. (1975) is indeed encouraging.

As long as the average cost of applying a soil insecticide to an acre of corn is not much higher than the farm price per bushel of corn, there is no great economic incentive for corn growers to avoid unnecessary corn insecticide applications. However, this situation may change in the event that the relatively inexpensive chlorinated hydrocarbon insecticides would no longer be available. For instance, the grower cost of aldrin 20% granules at 1.5 lb of active ingredient per acre is about $2.20/acre, while carbofuran granules at 1.0 lb of active ingredient per acre will cost about $7.50/acre in 1975, according to pesticide trade sources. Against wireworms and white grubs, carbofuran may have to be used at up to 2.0 lb of active ingredient per acre, which would cost the grower $15.00/acre. Thus, while there has not been a strong economic incentive against wasteful use of corn soil insecticides in the past, this situation may change in the future.

SUMMARY

Corn, the leading agricultural crop in the United States by acreage as well as by farm value, is produced primarily in 11 midwestern states including the five "Corn Belt States," i.e., Iowa, Illinois, Indiana, Ohio, and Missouri. Fungicides and "miscellaneous pesticides" including miticides, fumigants, defoliants, desiccants, plant growth regulators and others are used on corn either in very small quantities or not at all and were therefore not studied in detail in this project.

The quantities of herbicides used on corn in the U.S. quadrupled from 1964 to 1971. More than 100 million pounds of herbicide active ingredients were used on corn in 1971, according to a report by the U.S. Department of Agriculture. It is estimated that close to 90% of the total U.S. corn acreage harvested for grain is treated with chemical herbicides at present. A significant fraction of this acreage receives more than one herbicide treatment. Weed research and extension specialists and corn growers are convinced that chemical herbicides are essential to the efficient, profitable production of corn, and that by and large, corn herbicides are used effectively and without waste.

The costs of chemical weed control per acre of corn have increased substantially during the last 10 years and continue to rise. In large part, this increase is due to a gradual change in corn weed populations. Weeds that are more difficult to control are becoming more prevalent as those species that are easily controlled recede. However, the farm value of corn has also increased substantially. Consequently, there do not appear to be significant economic constraints on corn growers' herbicide use practices.

Pest management programs for weeds are included in several of the corn pilot pest management programs that were initiated in 1973. The "total farm weed control" concept is being considered in some of these programs. This approach will require increased use of chemical herbicides (and of other weed control measures) at least during the weed eradication phase. Minimum and no-tillage practices are also likely to require increased chemical herbicide inputs. We found no data from any of these studies demonstrating or suggesting that economic weed control could be obtained by substantially lower herbicide inputs, or by other means.

Thus, there do not seem to be any near-term prospects for a reduction in the rate of use of corn herbicides, and there are currently no strong economic incentives for corn growers to move in this direction.

The use of insecticides on corn also increased substantially during the last 10 years, although not nearly to the same degree as that of herbicides. Corn is subject to attack by a considerable number of soil and foliar insects. Soil insects are much more important economically than those feeding above ground. More than 90% of the quantities of insecticides used on corn are used against soil insects. In the Midwest, corn rootworms are largely resistant against chlorinated hydrocarbon insecticides; they are controlled by organic phosphate and carbamate insecticides. Up to the present, chlorinated hydrocarbon insecticides, primarily aldrin, were the insecticides of choice against the remaining corn soil insects such as wireworms, cutworms, white grubs, seed beetles and maggots, and others.

Approximately 50% of all corn acres harvested for grain currently are treated with insecticides. It is estimated that less than half of this acreage, or about 20% of the total corn acreage harvested for grain, actually requires insecticide treatments. Thus, it appears that at least 50% of the quantities of soil insecticides used on corn could be saved.

One important prerequisite to eliminating unnecessary insecticide treatments on corn is the development and implementation of practical methods for diagnosing corn soil insect problems, and for predicting treatment needs. Progress in this direction is being made in several corn pilot pest management programs.

The chlorinated hydrocarbon insecticides used on corn are relatively inexpensive. At current prices, the cost of an aldrin application at 1.5 lb of active ingredient per acre of corn, about $2.20, is equivalent to the farm price for 2/3 bu of corn. Thus, there is no compelling economic reason for corn growers to worry whether or not such a treatment is needed. However, most of the organic phosphate and carbamate insecticides are considerably more expensive, providing a greater built-in economic incentive to avoid unnecessary use.

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SECTION VI

PESTICIDE USE PATTERNS ON SORGHUM

PRODUCTION OF SORGHUM IN THE UNITED STATES

Sorghum is a major feed crop in the United States. Table 15 summarizes the U.S. sorghum acreage, yield, value, and production during the last 4 years, 1971 to 1974. The sorghum acreage planted for all purposes ranged from a low of 17.3 million acres in 1972 to a high of 20.8 million acres in 1971. In each of the 4 years covered in Table 15, about 80% of the total sorghum acreage planted for all purposes was harvested for grain.

Sorghum yields (per acre harvested for grain) ranged from 44.9 bu in 1974 to 60.5 bu in 1972. The average price of sorghum received by farmers doubled between 1971 and 1973, increasing from $1.06/bu in 1971 to $2.13/bu in 1973. The farm value per acre of sorghum harvested for grain increased from $56.92 in 1971 to $82.89 in 1972, and further to $125.24 in 1973.

The total production of grain sorghum during the 4-year period ranged from a low of 609.3 million bushels in 1974 to a high of 936.6 million bushels in 1973.

Figure 4 presents the geographic distribution of the U.S. sorghum acreage planted for all purposes in 1971. The leading sorghum producing states in the U.S., in decreasing order of acreage, are: Texas, Kansas, Nebraska, and Oklahoma. All other states planted less than 1 million acres of sorghum for all purposes in 1971.

Table 15. U.S. SORGHUM ACREAGE, YIELD, VALUE AND PRODUCTION, 1971-1974

Acreage, yield, value, production	Year			
	1971	1972	1973	1974
Acreage planted for all purposes, 1,000 acres	20,756	17,300	19,300	17,700[b]
Acreage harvested for grain, 1,000 acres	16,301	13,368	15,940	13,583[b]
Yield,[a] bu/acre	53.7	60.5	58.8	44.9[b]
Average farm price, $/bu	1.06	1.37	2.13	c/
Farm value, $/acre	56.92	82.89	125.24	c/
Total production, million bussels	875.8	809.3	936.6	609.3[b]

a/ Yield per acre harvested for grain.
b/ Preliminary.
c/ Not available at this time (January 1975).

Sources: U. S. Department of Agriculture (1973, 1974a,c).

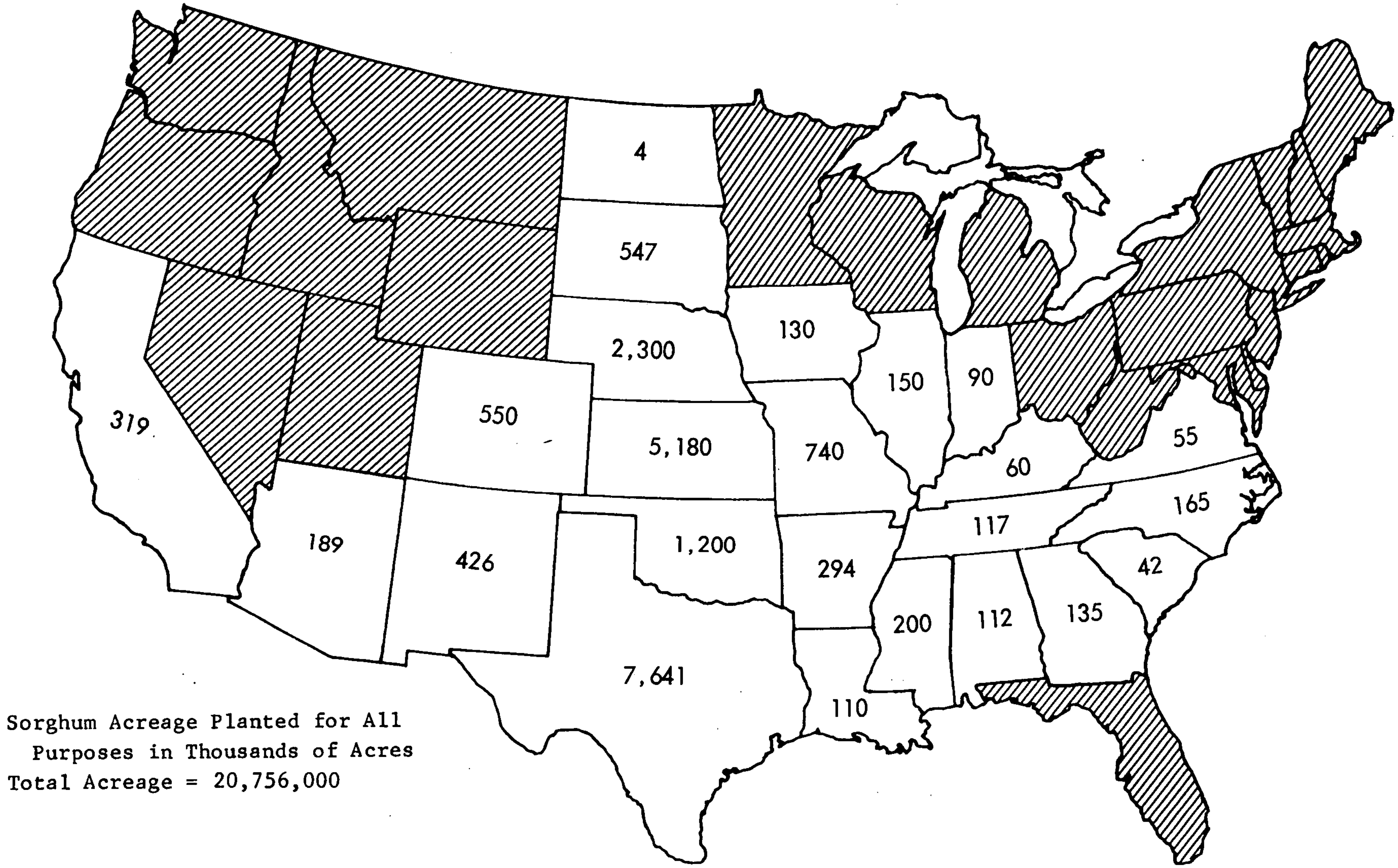

Figure 4. U.S. sorghum acreage (1971), by state.

QUANTITIES OF PESTICIDES USED ON SORGHUM

The U.S. Department of Agriculture (1974b) conducted a survey of the use of pesticides by American farmers in 1971. According to this source, sorghum ranked fifth among individual crops in total volume of herbicides used (preceded by corn, soybeans, cotton, and wheat), and fourth in volume of insecticides used (preceded by cotton, corn and peanuts). The use of fungicides, miticides, fumigants, desiccants, plant growth regulators and other pesticides on sorghum is so small that these uses were not disaggregated in the USDA pesticide use report for 1971 (or for prior years).

Further details on the use of pesticides on sorghum in 1971 are provided in Tables 16 and 17. These data are based on the 1971 pesticide use survey (U.S. Department of Agriculture, 1974b). The USDA report does not break down individual pesticide uses on sorghum by regions and therefore had to be supplemented by estimates in Table 17.

Table 16 shows that farmers used 11.5 million pounds of herbicides, and 5.7 million pounds of insecticides on sorghum in 1971. About 81% of all herbicides, and about 74% of all insecticides applied to sorghum were used in the Northern and Southern Plains States, in line with the geographic distribution of the sorghum acreage throughout the U.S. (Figure 4). The Corn Belt States used 10.2% of all herbicides, and 1.6% of all insecticides used on sorghum. Figure 4 suggests that these uses occurred primarily in the State of Missouri. Small quantities of sorghum herbicides and insecticides were used in the remaining sorghum-producing states.

The use of herbicides on sorghum in 1971 by major products and by geographic regions is detailed in Table 17 and will be further discussed below in the section on sorghum herbicide use practices.

Table 18 presents a comparison of the quantities of pesticides used on sorghum in the United States in 1964, 1966, and 1971 according to the USDA pesticide use surveys for these years (U.S. Department of Agriculture, 1968, 1970, 1974b). The total quantity of herbicides used on sorghum increased by 100%, from 2.0 million pounds in 1964 to 4.0 million pounds in 1966, then to 11.5 million pounds in 1971, an almost three-fold further increase from 1966 to 1971. The use of insecticides on sorghum increased from 767,000 lb in 1966 to 5.7 million pounds in 1971, a more than seven-fold increase. (Disaggregated data on the use of insecticides on sorghum in 1964 are not available from the USDA survey.)

Table 16. PESTICIDE USAGE ON U.S. SORGHUM CROP IN 1971

	By Region[a/]					
	Herbicides		Insecticides		Total Pesticides[b/]	
Region	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	14	0.1	--	0.0	14	0.1
Lake States	--	0.0	--	0.0	--	0.0
Corn Belt	1,176	10.2	94	1.6	1,270	7.4
Northern Plains	5,834	50.6	1,301	22.7	7,135	41.3
Appalachian	310	2.7	28	0.5	338	2.0
Southeast	125	1.1	406	7.1	531	3.1
Delta States	287	2.5	339	5.9	626	3.6
Southern Plains	3,486	30.2	2,927	51.1	6,413	37.1
Mountain	251	2.1	398	7.0	649	3.7
Pacific	55	0.5	236	4.1	291	1.7
Totals	11,538	100.0	5,729	100.0	17,267	100.0

a/ Source: "Farmers Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Fungicides and miscellaneous pesticides are not listed separately in the above report, and are not included in this table.

Table 17. HERBICIDES USED ON SORGHUM, BY REGION, 1971[a,b]

(1,000 lb)

Herbicide	Region: North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tains	Pacific	Total
Atrazine	5	-	400	2,600	160	75	115	700	110	10	4,175
Propazine	-	-	350	500	20	5	30	1,680	-	-	2,585
2,4-D	4	-	200	1,000	60	20	45	600	100	10	2,039
Propachlor	3	-	100	1,250	-	-	50	20	-	10	1,433
Norea	-	-	50	200	50	5	10	100	-	3	418
Arsenicals	-	-	10	-	10	10	20	100	20	15	185
MCPA	-	-	10	70	-	-	-	20	14	5	119
Others	2	-	56	214	10	10	17	266	7	2	584
Total	14	0	1,176	5,834	310	125	287	3,486	251	55	11,538

a/ Figures for total use of each herbicide and regional totals were obtained from "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual herbicide, by region, is an MRI estimate.

Table 18. USE OF PESTICIDES ON SORGHUM IN THE U.S. IN 1964, 1966, AND 1971

Type of pesticide	Year 1964	Year 1966	Year 1971
	1,000 lb of active ingredients		
Fungicides	N.A.	N.A.	N.A.
Insecticides[a/]	N.A.	767	5,729
Herbicides[a/]	1,966	4,031	11,538
Miscellaneous pesticides	N.A.	40	N.A.
All pesticides	1,966[b/]	4,838[c/]	17,267[d/]

a/ Excluding petroleum.
b/ Herbicides only.
c/ Excluding fungicides.
d/ Insecticides and herbicides only.
N.A. = Not available
Sources: U.S. Department of Agriculture (1968, 1970, 1974b)

During the period 1964 to 1974, the total U.S. acreage of sorghum harvested for grain was as follows (U.S. Department of Agriculture, 1973, 1974a):

Year	1,000 Acres
1964	11,742
1965	13,029
1966	12,813
1967	14,988
1968	13,890
1969	13,437
1970	13,568
1971	16,301
1972	13,368
1973	15,940
1974 (Preliminary)	13,583

These data indicate that the sorghum acreage increased by only 9% from 1964 to 1966, while the use of herbicides more than doubled (Table 18). From 1966 to 1971, the sorghum acreage increased by 27%, while the use of insecticides increased more than seven-fold, and the use of herbicides nearly tripled.

During the last 3 years, the sorghum acreage harvested for grain has decreased somewhat from the record high acreage in 1971.

Thus, while the sorghum acreage appears to be on a slightly upward trend, with considerable year-to-year variations, the use of insecticides and herbicides on sorghum has increased dramatically.

The USDA pesticide use surveys, supported by Cooperative Extension Service publications from the principal sorghum-growing states, indicate that the use of pesticides other than insecticides and herbicides on sorghum is very small or negligible. Therefore, our study of the efficiency of current pesticide use practices on sorghum was focused on insecticides and herbicides.

HERBICIDE USE PRACTICES

The quantities of herbicides used on sorghum in the U.S. have increased greatly from 1964 to 1971, as documented in the preceding section. In 1964, almost 2.0 million pounds of herbicide active ingredients went on sorghum, 4.0 million pounds in 1966, and 11.5 million pounds in 1971 (Table 18).

The U.S. Department of Agriculture (1972) conducted surveys of the extent of weed control with herbicides in 1959, 1962, 1965, and 1968. Table 19 summarizes the results for sorghum. During the 10-year period covered, the sorghum acreage receiving herbicide treatments increased continually, from 2.1 million acres in 1959 to 7.4 million acres in 1968. The percentage of the total sorghum acreage treated with herbicides increased from 14% in 1959 to 42% in 1968. Of the 7.4 million acres of sorghum treated with herbicides in 1968 according to this survey, 2.9 million acres received only preemergence treatments (at an average cost of $6.30/acre); 4.0 million acres received only postemergence treatments ($3.00/acre); and 500,000 acres received both pre- and postemergence treatments ($7.80/acre).

More recent data on the extent of use of herbicides on sorghum in the U.S. from published sources are not available at this time, to the best of our knowledge. It is estimated that currently, about 70 to 80% of the total U.S. sorghum acreage receives herbicide treatments. This percentage is believed to be even higher for irrigated sorghum.

Table 19. ESTIMATED EXTENT OF CHEMICAL WEED CONTROL ON SORGHUM IN THE U.S., 1959 TO 1968

Year	1959	1962	1965	1968
Acreage treated with herbicides, 1,000 acres	2,093	2,665	5,391	7,363
Percent of total sorghum acres harvested for grain	14%	23%	32%	42%

Source: U.S. Department of Agriculture (1972).

Table 17 presents a breakdown of the herbicides used on sorghum in 1971 by regions and by major individual herbicides. Of the total quantity of herbicides used on sorghum in 1971 according to the U.S. Department of Agriculture (1974b), 81% were used in the northern and southern plains states, paralleling the geographic distribution of the U.S. sorghum acreage (Figure 4). An additional 1.2 million pounds of herbicides (10% of the total) were used in the Corn Belt States. The remaining quantities of sorghum herbicides went into six of the remaining seven regions; no sorghum herbicides were used in the Lake States.

Atrazine and propazine, two chemically related triazine herbicides, were used on sorghum in larger quantities than all other herbicides combined (6.8 million pounds = 59% of the total). 2,4-D (2.0 million pounds) and propachlor (1.4 million pounds) were next, while less than 1 million pounds of active ingredient were used of all remaining sorghum herbicides.

Herbicides are used on sorghum for the control of a considerable variety of weeds including pigweeds, crabgrasses, lamb's-quarters, foxtails, johnsongrass, barnyard grass, field bindweed, cocklebururs, and morning glories. Of 27 states that responded regarding sorghum in the 1968 herbicide use survey by the U.S. Department of Agriculture (1972), 19 reported an upward trend in herbicide usage, while eight said their use trend was stationary.

Several extension agronomists whom we contacted in the present study indicated unanimously, and independently of one another, that in their states (including Missouri, Oklahoma, and Colorado), there are many more sorghum acres needing herbicide treatment than are actually being treated.

The Kansas sorghum pest management project in 1973 included a weed element (Mock, 1974a). Objectives for this part of the program included identification of weed species, collection of detailed information on soil type, cropping history, and previous weed control practices, and comparative studies on the effectiveness, costs, and environmental effects of alternative weed control practices including herbicides only, combinations of herbicides and tillage, and tillage only. Sorghum fields were surveyed for species and density of weeds once early in the growing season, and a second time about 3 weeks later. A total of 9,230 acres of sorghum in 86 fields of 51 participating producers were surveyed in 1973. Rough pigweed, also known as redroot pigweed (*Amaranthus retroflexus*), and barnyard grass (*Echinochloa crus-galli*) were found to be the two most abundant weed species. Sixteen additional broadleaf weeds, and 10 additional grass weeds were identified and recorded.

The Kansas Pest Management Project Annual Report for 1973 (Mock, 1974a) states that the benefits to sorghum producers from the weed program are less instantaneous than those from the insect management phase. Program leaders anticipate that identification of existing weed problems will result in better tailored control recommendations for future seasons. In the 1974 sorghum weed management program, all participating farmers were encouraged to leave one area in each field receiving weed control measures untreated in order to obtain information on the effectiveness of different weed control practices. The results of the 1974 program are not available at this time.

Our search of the literature and contacts with extension agronomists in leading sorghum-producing states in this project have not revealed any indications that herbicide treatments are applied on more sorghum acres than needed. One way in which the use of herbicides on sorghum might be improved is the determination of minimum effective rates for individual users. Table 20 summarizes the rates of application of the four leading sorghum herbicides recommended by the Extension Services in the four leading sorghum-producing states. Some of the recommendations span a two to three-fold range. This degree of latitude is probably required to cover all extremes of soil, weather and other use conditions. However, it is often difficult for individual sorghum

Table 20. RATES OF APPLICATION OF MAJOR SORGHUM HERBICIDES RECOMMENDED IN TEXAS, OKLAHOMA, KANSAS AND NEBRASKA[a]

State	Herbicide			
	Propazine[b]	Atrazine[b]	2,4-D[c]	Propachlor[b]
	(lb active ingredient/acre)			
Texas[e]	1.2-3.2	1.2-3.0	0.5-1.0	2.25-2.9[d]
Oklahoma[f]	1.2-3.2	1.0-3.0	0.5-0.75	NR
Kansas[g]	1.25-2.4	2.0-2.4	0.3-0.5	4.0-5.0
Nebraska[h]	NR	2.0-2.4	0.5	4.0

a/ Rates recommended for broadcast treatment. Band application will reduce amount of herbicide needed.
b/ Preplant or preemergence.
c/ 2,4-D amine postemergence.
d/ Recommended only in combination with propazine in Texas.
e/ Texas A&M University (1973b).
f/ Oklahoma State University (1974).
g/ Nilson et al. (1974).
h/ Furrer et al. (1972).
NR = Not recommended.

growers to determine application rates optimal for their specific situations. Thus, there seems to be a definite need for the type of information to be obtained in the 1974 Kansas sorghum weed management program, as discussed above.

Depending on the product and rate of application, preemergence treatments of atrazine or propazine, the two most widely used sorghum herbicides, range in cost from about $4.50 to $13.00 and more per acre. These costs are substantial in relation to the farm value of sorghum (Table 15) and represent a powerful deterrent to unnecessary and inefficient use of herbicides.

In summary, there is no evidence that chemical herbicides are used on sorghum on more acres than needed. The wide ranges in the rates of application per acre recommended for leading sorghum herbicides suggest the possibility that some users apply higher rates per acre than required for optimal economic returns, and that more specific weed control recommendations, tailored to individual farmers' needs, may result in herbicide savings. However, we found no field research data to prove or disprove this supposition.

The rather high costs of herbicides in relation to the farm value of sorghum, plus the risk of crop injury from overtreatment are practical deterrents to the inefficient and wasteful use of sorghum herbicides.

INSECTICIDE USE PRACTICES

As documented in the section "Quantities of Pesticides Used on Sorghum," the use of insecticides on sorghum increased more than seven-fold from 1966 to 1971, while the sorghum acreage harvested for grain increased by only 27% during the same time.

Disaggregated data on the use of individual insecticides on sorghum are not provided by the U.S. Department of Agriculture (1974b) from its 1971 pesticide use survey. We therefore asked extension entomologists in the leading sorghum-producing states for information on the most important sorghum insecticides in their respective areas. Replies received indicate that in 1973 and 1974, the total quantity of insecticides used on sorghum consisted of the following individual products:

disulfoton	about 50% of total
parathion	about 25% of total
phorate	about 10% of total
other insecticides	about 15% of total

Until recently, sorghum was a crop that required little, if any use of insecticides. After the introduction of hybrid grain sorghum varieties in the late 1950's, the sorghum midge, Contarinia sorghicola, became a problem in some sorghum growing areas, especially the Texas High Plains. Texas Agricultural Experiment Station and Extension Service entomologists soon determined that early, uniform planting of grain sorghum on an area-wide basis would cause sorghum blooming to occur early in the season, before midge populations reached damaging levels. Other insect pests of grain sorghum such as the corn earworm (Heliothis zea), the corn leaf aphid (Rhopalosiphum maidis), the fall armyworm (Spodoptera frugiperda), the false chinch bug (Nysius ericae) and others require insecticidal control only occasionally (Latham, 1974; Teetes et al. 1974).

Beginning in 1968, a rapidly increasing percentage of the grain sorghum acreage in the major producing states required insecticidal treatment against a new, more virulent strain of the greenbug, Schizaphis graminum. The rapid spreading of this new strain, known as biotype "C," throughout the Plains States soon caused insecticide applications on sorghum to become a standard practice. Initially, many sorghum growers made preventive, early season insecticide applications against the greenbug. The Texas Grain Sorghum Producers Association has estimated that the expenditures for insecticides used on grain sorghum in the Texas High Plains increased from an average of $100,000/year prior to 1968 to over $14 million in 1969. It is estimated that in 1971, Texas High Plains grain sorghum producers spent about $10 million for insecticides, applying approximately 3 million pounds of active ingredients to 2.5 million acres of the crop (Teetes et al. 1974).

It soon became apparent that indiscriminate, preventive early season insecticide applications for greenbug may contribute to subsequent increases in mite populations due to destruction of predators which would normally hold these mites in check. Moreover, there are indications that the Banks grass mite, Oligonychus pratensis, is becoming increasingly resistant to the pesticides used on sorghum in northern Texas, Oklahoma, and Kansas. This mite is virtually impossible to control with chemicals in southern Texas where production of corn and grain sorghum has decreased greatly for this reason (Teetes et al. 1974).

Furthermore, it was feared that the intensive use of insecticides on grain sorghum may upset the natural balance of predators and parasites on cotton in areas where cotton and sorghum are grown in close proximity, as in northern Texas. At present, there are no serious insect pest problems on cotton in the Texas High Plains and consequently, insecticides have not been widely applied to cotton, and cotton pests are kept in check by their natural enemies. Grain sorghum in this area is believed to serve as a major source of the natural enemies which later are active in cotton. Thus, indiscriminate use of insecticides on sorghum may well have repercussions also on cotton, both directly through insecticide drift, and indirectly by destroying parasites and predators before they migrate from sorghum to cotton.

These factors demonstrated the need for a pest management approach. A sorghum pest management program was established as a joint effort of the Texas Agricultural Experiment Station, the Texas Agricultural Extension Service and the Texas Grain Sorghum Producers Board, the State sorghum commodity organization. The program was initiated in 1973 in the community of Edmonson in Hale, Castro and Swisher counties in the Texas High Plains. Sorghum producers in the program area are progressive farmers who employ production methods representative of the Texas High Plains area. The entire grain sorghum acreage in the program area was under irrigation, some double-row and narrow-row sorghum was grown, and fertilizer and herbicide uses were extensive. The program objectives included maintenance of natural control of greenbugs by beneficial insects to the greatest possible extent, and application of reduced, selective rates of insecticide when pest populations reach economic threshold levels, to reduce control costs and preserve as many beneficial insects as possible (Latham, 1974).

In 1973, the 1st year in which the pest management program was in operation, a total of 18,346 acres of sorghum grown by 68 producers were in the program. Research and extension entomologists who have been closely associated with the greenbug situation throughout the Texas High Plains indicate that the greenbug populations on sorghum in the area in 1973 were the highest since 1969, due to an abnormally dry period during May and June of 1973. It is remarkable that in spite of the unusually heavy greenbug infestation pressure in 1973, pest management program participants used fewer insecticide applications and smaller quantities of insecticides than in 1972, a relatively light infestation year. The data summarized in Table 21 show that the number of insecticide applications per acre was reduced by 23%, the average rate of insecticide applied per acre by 72%, and the cost per acre by 50%, considering only the cost of insecticide and application, by 39% if growers' contributions to scouting costs of $0.50/acre are added to the cost of insecticide and application. Savings in insect control costs of this order are significant in relation to the farm value of sorghum (Table 15).

All participants in the Edmonson (Hale County) pest management program in 1973 used disulfoton in either the granular or liquid formulation for greenbug control. Table 22 presents a complete breakdown of the treatments applied (in terms of formulation and of active ingredient per acre), acres treated, total quantity of insecticide used, and insecticide costs per acre.

Table 21. USE OF INSECTICIDES FOR GREENBUG CONTROL IN THE TEXAS SORGHUM PEST MANAGEMENT PROGRAM IN 1973 COMPARED TO PRE-PROGRAM USE (1972)

	1972	1973	Reduction
Average number of applications per acre	1.20	0.93	23%
Pounds active insecticide applied per acre	1.04	0.29	72%
Cost per acre a/	$4.35 b/	$2.16 b/	$2.19 = 50%
		$2.66 c/	$1.69 = 39%

a/ Average of quoted price of four aerial applicators.
b/ Cost of insecticide and application.
c/ Cost of insecticide, application, and 50¢/acre for scouting.
Sources: Latham (1974); Teetes et al. (1974).

Table 22. USE OF DISULFOTON AGAINST THE GREENBUG ON SORGHUM IN THE HALE COUNTY, TEXAS PEST MANAGEMENT PROGRAM, 1973[a]

Rate of application/acre: Formulation	Rate of application/acre: AI (oz)	Acres treated	Percent of program acreage	Total insecticide (lb AI)	% Total insecticide	Insecticide cost/acre[b]
7 lb 15G[c]	16.8	2,713	14.8	2,849	56.1	$2.94
5 lb 15G	12.0	882	4.8	662	13.0	2.10
1/2 pt 6LC[d]	6.0	649	3.5	243	4.8	0.90
1/4 pt 6LC	3.0	420	2.3	79	1.6	0.45
1/6 pt 6LC	2.0	2,338	12.7	292	5.8	0.38
1/8 pt 6LC	1.5	9,057	49.4	883	17.4	0.28
1/10 pt 6LC	1.2	887	4.8	66	1.3	0.18
No Treatment		1,400	7.6	0	0	0
Totals		18,346	100.0	5,074	100.0	

a/ All treatments gave better than 95% control of the greenbug for the remainder of the season.
b/ Average of prices quoted by four aerial applicators.
c/ 15G = 15% granular.
d/ 6LC = 6 lb/gal liquid concentrate.
AI = Active ingredient.
Sources: Latham (1974), Teetes et al. (1974).

Only 15% of the total program acreage were treated at the highest rate of disulfoton, 7 lb 15% granular (16.8 oz active ingredient) per acre, but this accounted for 56% of the total quantity of insecticide used in the program area. By contrast, a total of 9,944 acres (54% of the program acreage) were treated at the two lowest rates, 1/8 and 1/10 pt 6 lb/gal concentrate (1.5 and 1.2 oz active ingredient) per acre; these treatments accounted for only 18.7% of the total quantity of disulfoton used in the program area. Growers who applied disulfoton at these low rates realized a reduction of 90 to 94% in the cost of insecticide per acre compared to the growers who used the insecticide at the highest rate.

All treatments detailed in Table 22 gave better than 95% control of the greenbug for the remainder of the season. A questionnaire survey of program participants and comparisons of their average yields with county averages showed that the participants did not have any sorghum yield losses from the greenbug in 1973, indicating that the pest management program recommendations adequately protected sorghum yields.

Another important consideration is the effect of insecticides applied for greenbug control on subsequent buildup of spider mites, especially the Banks grass mite. Table 23 summarizes the observations made in the Hale County, Texas, sorghum pest management program in this regard in 1973. Spider mites including the Banks grass mite are considered secondary pests on sorghum in this area. However, once these mites are released from natural control by destruction of their parasites and predators, they may cause more damage to the crop than the greenbug. The data in Table 23 indicate that the use of disulfoton at high rates necessitated subsequent treatment for control of spider mites on 9.2% of the acreage, while only 2.6% of the acres treated at the low greenbug control rates required subsequent chemical control of spider mites. Thus, there appears to be a direct correlation between the use of high rates of disulfoton for greenbug control and the need for subsequent spider mite control.

The Texas High Plains Sorghum Pest Management Program was continued in 1974, but results from the 1974 season are not available at this time. Entomologists connected with the program report that 1974 was an even worse year than 1973 in regard to greenbug infestations. Normal rainfall during the early part of the growing season did not occur, and greenbug infestations reached economic damage thresholds about 2 weeks earlier than usual, with no help whatsoever from spring rain storms that sometimes knock down greenbug populations. Field as well as laboratory observations indicate that the greenbug may be developing resistance to

Table 23. EFFECTS OF DISULFOTON APPLICATIONS AGAINST GREENBUG ON SORGHUM ON SUBSEQUENT TREATMENTS AGAINST SPIDER MITES[a]

Rate of application/acre		Acres treated for	Subsequently treated for spider mites	
Formulation	AI (oz)	greenbugs	Acres	%[d]
7 lb 15G[b]	16.8	2,713	370	13.6
5 lb 15G	12.0	882	0	0
1/2 pt 6LC[c]	6.0	649	60	9.2
1/4 pt 6LC	3.0	420	0	0
1/6 pt 6LC	2.0	2,338	115	4.9
1/8 pt 6LC	1.5	9,057	200	2.2
1/10 pt 6LC	1.2	887	0	0
No treatment		1,400	30	2.1
Total at high rates		4,664	430	9.2
Total at low rates		12,282	315	2.6
Total program acres		18,346	775	4.2

a/ Observations from the Hale Company, TX sorghum pest management program, 1973.
b/ 15G = 15% granular.
c/ 6 LC = 6 lb/gal liquid concentrate.
d/ % of acres treated for greenbugs.
AI = Active ingredient.
Source: Latham (1974).

the organophosphate insecticides currently used against it. In one location, 95% control of greenbugs was previously obtained at 1 to 2 oz active ingredient of disulfoton per acre while recently, a rate of 2.0 lb active ingredient per acre was required to kill a residual greenbug population. In laboratory tests, a 37-fold increase in tolerance to organophosphate insecticides was found (McIntyre, 1974).

These recent developments have caused considerable concern among the pest management program organizers and participants; their extent and possible effect on the future of sorghum pest management in this area remain to be determined at this time.

Kansas, the second largest sorghum-producing state in the U.S. (Figure 4), also had a sorghum pest management program in 1973, involving 98 producers and 22,406 acres of sorghum in the three southwestern Kansas counties of Haskell, Meade, and Stevens.

In the Kansas program, the use of insecticides was recommended only as labeled because legal considerations did not permit a different course, in the opinion of state and program officials. Secondly, the question whether high or low rates of insecticide favor the development of resistance in target insects is still unresolved among experts. For these reasons, the main emphasis in the Kansas sorghum pest management program was placed on using insecticide at labeled rates, but only when needed (Mock, 1974a, 1974b).

Greenbug infestations developed early in the season in 1973 in the program area and were more severe than in average years. Populations of natural enemies of the greenbug, including lady beetles and lacewings, were high in many fields and in some cases delayed for 10 to 14 days the buildup of greenbugs to economic injury levels. Between mid-July and 5 August, chemical insecticides were applied to about 70% of the program acreage. Other sorghum pests became economically important only occasionally. Corn leaf aphids, armyworms and thrips were problematic only in a few fields.

Mock (1974a) reports that based on a preliminary analysis of scouting data, program participants made an average of 0.77 insecticide applications per field, whereas only 0.5 applications were needed. Comparing insecticide use practices, costs, or yields of sorghum within the program area to those of nonparticipating growers in the same area is of doubtful value, according to Mock (1974a). All Kansas extension personnel involved in the pest management program serve all growers in the area, whether or not they participate in the special program. Therefore, a concerted effort was made to educate the entire community and to encourage others to adopt the same practices employed by the pest management program participants. Thus, it is difficult to identify genuine nonparticipants for purposes of making comparisons with participants.

In one of the three counties involved in the pest management program in 1973 (Meade), a buildup of a parasitic wasp, Lysiphlebus testaceipes, was recognized by the field scouts in late July. Greenbug numbers were peaking at this time, but parasitism increased rapidly, and within 10 days of their first appearance, the parasites had decimated greenbug populations, and many fields did not require insecticide treatment. If the pest management program had not been in action, many farmers would undoubtedly have failed to recognize the parasitism and the degree of natural control it afforded, and would have treated needlessly. Instead, only about 50% of the total program acreage in Meade County was treated with insecticides once, and none of the acreage required a second treatment. By contrast, more than 90% of the program acreage in Haskell and Stevens Counties was treated, and a small percentage of the acreage in these counties required a second insecticide application. We calculated from these data as reported by Mock (1974a) that over the entire program area, about 27% fewer acres were treated with insecticides than would have been the case if the program participants in Meade County had not had the benefits of the program.

These data indicate that under the sorghum growing conditions of southwestern Kansas, implementation of pest management procedures could reduce the number of sorghum acres receiving insecticide treatments. No effort was made in this program to determine minimum effective rates of insecticides and consequently, there are no Kansas data on possible reductions in the rate of sorghum insecticides currently recommended and used.

Nebraska, third in U.S. sorghum acreage behind Texas and Kansas (Figure 4), also initiated a sorghum pest management program in 1973. The program was located in Clay County and included 71 cooperators growing 6,865 acres of sorghum. Insecticide use practices of program participants were compared with a sampling of Clay County farmers not in the program in 1973. Preliminary results of this comparison are summarized in Table 24 (U.S. Department of Agriculture, 1974d).

Table 24. USE OF INSECTICIDES ON SORGHUM IN CLAY COUNTY, NEBRASKA, BY PEST MANAGEMENT PROGRAM PARTICIPANTS AND NONPARTICIPANTS, 1973

Relationship to program	No.	Acres grown[a/]	Acres treated with insecticides: At planting	Acres treated with insecticides: Post-emergence	Acres treated with insecticides: Total
Participants	71	6,865	1,131 (16.5%)	772 (11.2%)	1,903 (27.7%)
Nonparticipants	47	5,940	585 (9.8%)	1,677 (28.2%)	2,262 (38.0%)

a/ Acres in the program for participants; all acres grown for nonparticipants.
Source: U.S. Department of Agriculture (1974d).

The pest management project was not underway until 1 April 1973 and could therefore not exert any influence on grower decisions on insecticide use at planting time. Program participants actually treated a higher percentage of their sorghum acreage with insecticides at planting than nonparticipants. However, the impact of the pest management program is demonstrated, in the opinion of Nebraska entomologists, in the postemergence insecticide uses. Program participants made postemergence insecticide treatments on 11.2% of their acreage, while nonparticipants treated 28.2%. Combining both planting time and postemergence treatments, program participants treated 27.7% of their sorghum acres with insecticides, while nonparticipants treated 38.0%. Thus, program participants treated 37% fewer sorghum acres than nonparticipants.

The Nebraska Cooperative Extension Service recommended planting time applications of disulfoton and phorate against greenbugs and corn leaf aphids on sorghum at the rate of 1.0 lb active ingredient per acre in 1974 (Roselle et al. 1974a). These recommendations have been dropped from the 1975 "Insect Control Guide for Corn and Sorghum in Nebraska," (Roselle et al. 1974b), with the explanation: "There is evidence that planting time applications may cause development of resistant greenbugs, complicating chemical control later in the season." Post-plant applications of disulfoton and phorate at 4 to 8 oz active ingredient per acre were recommended in Nebraska in 1974 and will continue to be so recommended in 1975.

As in the Kansas program, no efforts were made in Nebraska in 1973 to determine minimum effective rates of insecticides on sorghum and consequently, no data on this topic are available from the program.

Oklahoma, the fourth-largest sorghum-producing state by acreage, also had a sorghum pest management program in 1973. However, we were unable to obtain data on insecticide use patterns and insecticide use efficiency from that program from published or unpublished sources. Oklahoma's 1974 sorghum greenbug control recommendations generally follow the product label, except that disulfoton is recommended at only 4 to 6 oz active ingredient per acre as a foliar spray (label = 4 to 8 oz active ingredient per acre).

Table 25 summarizes the rates of application of disulfoton, the leading sorghum insecticide, for the control of greenbugs and mites on sorghum recommended by different sources, including the EPA Compendium of Registered Pesticides, the product label, and the Extension Services in the states of Texas, Kansas, Nebraska, and Oklahoma. These rates are compared to minimum effective rates and rates used in pest management programs.

The disulfoton use patterns recommended in the product label are practically identical to those summarized in the EPA Compendium. Comparing these recommendations to those of the four states studied, it is interesting to note that only Kansas and Oklahoma still recommend disulfoton applications at planting time, while Texas and Nebraska do not recommend this practice because it may cause development of resistant greenbugs, prevent buildup of beneficial predators and parasites, and/or result in buildup of mites.

The rates of disulfoton recommended for post-plant foliar application against the greenbug in Kansas and Nebraska are identical to the product label. Oklahoma's recommendations reduce the upper limit of the range for this use pattern to 6 oz active ingredient per acre, a reduction of 25% compared to the label limit, 8 oz active ingredient per acre. The disulfoton rates suggested in Texas for foliar application against the greenbug are considerably lower (about 63%) than the labeled rate. An even lower rate, 1.2 oz of active ingredient per acre (reduction of 70 to 85% compared to the label) provided better than 95% control of greenbugs in field tests in Texas in 1973.

Table 25. RATES OF APPLICATION OF DISULFOTON AGAINST GREENBUG AND MITES ON SORGHUM RECOMMENDED BY PUBLIC AGENCIES AND IN SELECTED PEST MANAGEMENT PROGRAMS

Target pest	Greenbug		Mites a/	
Type of treatment	At planting, side dress or over row	Foliar application	Foliar application	
	Ounces active ingredient/acre			Reduction
Rate recommended				
- in EPA Compendium c/	12-16	4-8	8	
- in Product Label d/	12-16	4-8	8-16	
Texas				
Rate suggested by Ext. Service e/	-		8	0-50% versus Label
		1.5-3		63% versus Label
Min. effective rate f/		1-2		75% versus Label
Avg. field use rate				
- 1972 (pre-PM) f/	- - - - - - - - -16.6- - - - - - - - - - - - - - - -			
- 1973 (Pest Mgmt) f/	- - - - - - - - - 4.6- - - - - - - - - - - - - - - -			72% versus pre-pest mgmt.
Kansas				
Rate recommended by Ext. Service g/	16 at planting 8-16 post pltg.	4-8	-	-
Insecticide b/ use in Pest Mgmt. Program h/				Participants treated abt. 27% fewer acres than nonparticipants
Nebraska				
Rate recommended by Ext. Service i/	-	4-8	-	-
Insecticide b/ use in Pest Mgmt. Program j/				Participants treated abt. 37% fewer acres than nonparticipants
Oklahoma				
Rate suggested by Ext. Service k/			8-16	-
	16	4-6- - - - - - - - - - - - - - - - -		0 to 25% versus Label

a/ Primarily Banks grass mite.
b/ All insecticides.

Sources:

c/ U.S. Environmental Protection Agency (1972).
d/ Chemagro Div., Mobay Chem. Corp. (1974).
e/ Texas A&M University (1973a).

Sources (continued)
f/ Latham (1974), Teetes et al. (1974).
g/ Brooks and Gates (1974).
h/ Mock (1974a).
i/ Roselle et al. (1974b).
j/ U.S. Dept. of Agriculture (1974d).
k/ Oklahoma State University (1974).

Foliar applications of disulfoton against mites (including the Banks grass mite) are recommended only in Texas and Oklahoma.

In the 1973 sorghum pest management program in the Texas High Plains, program participants used an average of 4.6 oz of active disulfoton per acre, compared to 16.6 oz active ingredient per acre in 1972. This reduction (72%) is especially remarkable because there was greater insect infestation pressure in 1973 than in 1972, as discussed above.

For the Kansas and Nebraska sorghum pest management programs, pesticide use data are not available by individual products, but only for all sorghum insecticides combined. In the Kansas program, participants treated about 27% fewer acres of sorghum with insecticides than nonparticipants. In Nebraska, 37% fewer acres were treated in the program area as compared to nonparticipants.

The purpose of the EPA Compendium cited in Table 25 and in the text above is to ensure that the total amount applied will not exceed the tolerance established for a particular pesticide. The Compendium is not designed to recommend application rates.

These data indicate that substantial quantities of the insecticides used on sorghum against the greenbug could be saved if the preventive, planting time use of insecticides at high rates of application would be replaced by postemergence, foliar application of insecticides only as needed, and at the minimum rates required for yield protection. Based on the foregoing discussion and the data summarized in Table 25, we estimate that such savings could amount to 50 to 60% of the quantities of insecticides currently used on sorghum. In terms of the total quantity of insecticides used on sorghum in the U.S. in 1971 according to the USDA pesticide use survey, 5,729,000 lb of active ingredients (Table 16), savings of 50 to 60% would represent 2.9 to 3.4 million pounds of insecticides.

One element of uncertainty is the potential development of resistance of the greenbug to chemical insecticides. Experiences obtained on other crops (examples include cotton, deciduous and citrus fruits, certain vegetables, and others) indicate, however, that insect resistance problems cannot be overcome, at least not for long, by increasing the rates and frequency of pesticide applications. Thus, the threat of greenbug resistance to insecticides would seem to reinforce, rather than to weaken the need for pest management programs on sorghum.

SUMMARY

Sorghum, a major U.S. feed crop, is produced primarily in the states of Texas, Kansas, Nebraska, and Oklahoma. The use of herbicides and insecticides on sorghum has increased substantially during the last 10 years. Fungicides and "miscellaneous pesticides" such as fumigants, defoliants, desiccants, plant growth regulators and others are used on sorghum either in very small quantities or not at all and were therefore not studied in detail in this project.

Herbicides are used on an ever increasing percentage of the total grain sorghum acreage (currently about 70 to 80%). Extension agronomists and weed scientists believe that many additional sorghum acres should be treated with chemical herbicides. There are no indications that herbicides are currently used on more sorghum acres than needed. Some sorghum growers may be applying herbicides at higher rates per acre than required for optimal economic returns because of lack of individualized information on optimal choice of product(s) and application rate for their specific situations.

The costs of chemical weed control in sorghum are significant in relation to the farm value of the crop, an effective economic deterrent to the inefficient or wasteful use of sorghum herbicides.

The use of insecticides on sorghum has increased rapidly since 1968 when a new, more virulent strain of the greenbug, *Schizaphis graminum*, spread throughout the major grain sorghum-producing areas. Preventive, high rate, early season insecticide applications against greenbugs may accelerate the development of resistant strains. In addition, such treatments have been shown to destroy natural parasites and predators, thus contributing to subsequent increases in mites, especially the Banks grass mite, *Olygonychus pratensis*. In areas where both cotton and sorghum are grown, sorghum is believed to be a major source of predators and parasites which later in the season migrate from sorghum to cotton. Decimation of these beneficial insects may thus affect not only sorghum, but also cotton.

Based on careful analysis of pertinent literature, of current sorghum insecticide use patterns, of the results to date of three sorghum pest management programs, and on consultations with entomologists in the leading sorghum-producing states, we estimate that 50 to 60% of the quantities of insecticides currently used on sorghum could be saved if pest management principles and methods would be universally adopted and practiced by grain sorghum producers. Such savings would amount to about 2.9 to 3.4 million pounds of insecticides, based on the 1971 pesticide use survey by the USDA.

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SECTION VII

PESTICIDE USE PATTERNS ON APPLES

PRODUCTION OF APPLES IN THE UNITED STATES

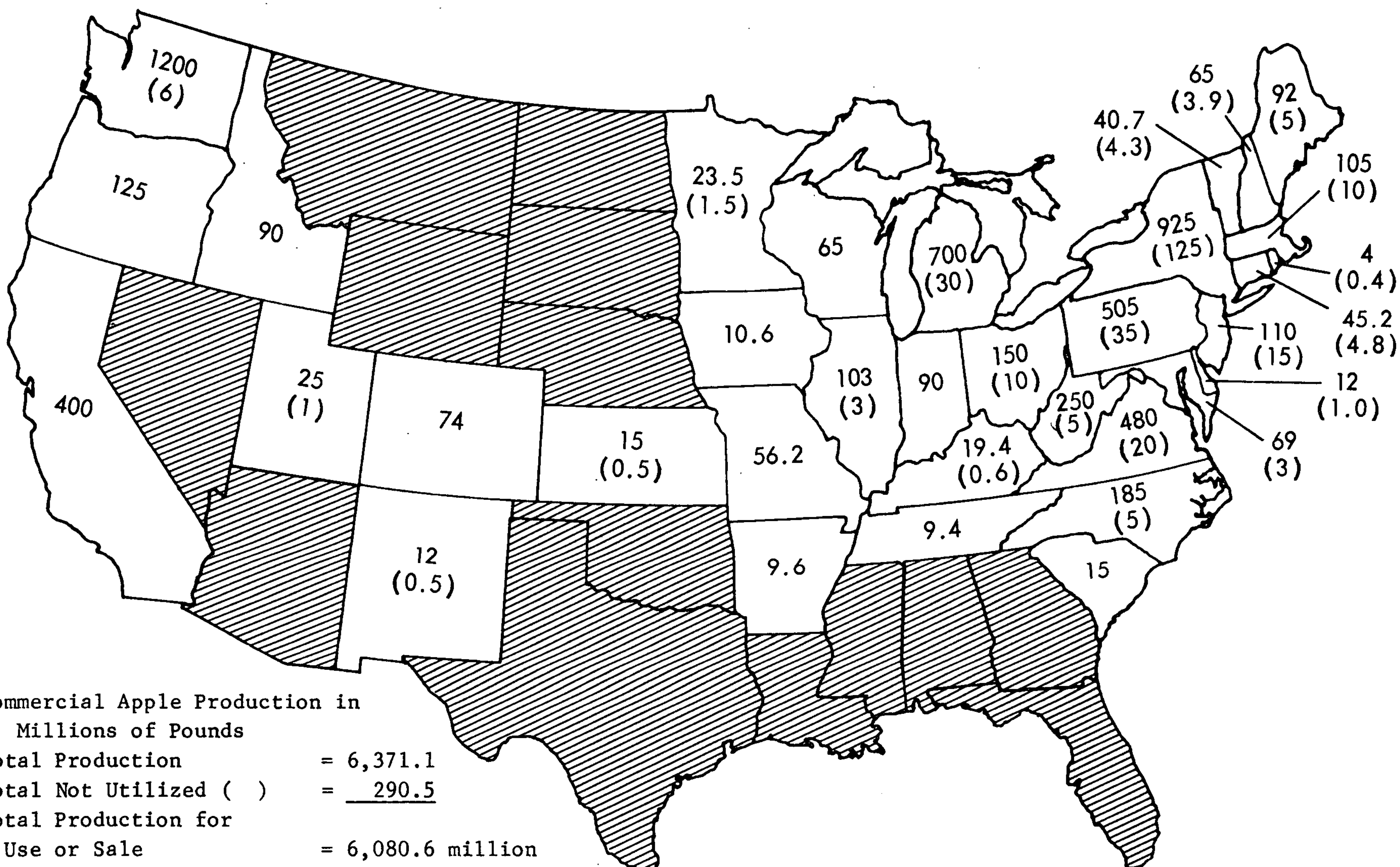
Apples are one of the major fruit crops grown in the United States. Apples were produced commercially on about 526,000 acres in the United States in 1969, the latest year for which acreage statistics for apples have been published (U.S. Bureau of the Census, 1973). In 1973, the total utilized U.S. production of apples was 6.2 billion pounds. The farm value of the 1973 apple crop was about $512 million. The average grower price for all sales of apples in 1973 was estimated at $0.088/lb (U.S. Department of Agriculture, 1974a). Thus, the average value of production of apples was about $1,000/acre at 1973 grower prices.

Figure 5 presents a breakdown of the commercial apple production in the U.S. by states for 1971. The total utilized commercial production of apples in 1971, 6.1 billion pounds, is very close to the 1973 production, 6.2 billion pounds. Thus, the data presented in Figure 5 may be considered to be representative of the geographic distribution of the production of apples in the U.S. for the years 1971 through 1973.

As Figure 5 indicates, the leading apple producing states in the U.S., in decreasing order of volume of production are: Washington, New York, Michigan, and Pennsylvania. All other states produced less than 500 million pounds of apples in 1971.

QUANTITIES OF PESTICIDES USED ON APPLES

The U.S. Department of Agriculture (1974b) conducted a survey on the use of pesticides by American farmers in 1971. According to this source, apples ranked sixth among individual crops in total volume of insecticides used (preceded by cotton, corn, peanuts, sorghum, and soybeans), and second in volume of fungicides used (preceded only by citrus



Commercial Apple Production in
Millions of Pounds

Total Production	=	6,371.1
Total Not Utilized ( )	=	290.5
Total Production for Use or Sale	=	6,080.6 million pounds

Figure 5. U.S. commercial apple production (1971), by state.

fruits). The use of herbicides on apples was very small; only 0.09% of all herbicides used in agriculture in the U.S. were used on apples in 1971.

Table 26 presents a breakdown of the pesticides used on apples in the U.S. in 1971 by type of pesticides and by regions. Farmers used 7.2 million pounds of fungicides, 4.8 million pounds of insecticides, 548,000 lb of miscellaneous pesticides, and 197,000 lb of herbicides (all quantities in terms of active ingredients) on apples in 1971.

The Northeastern Region accounted for 40.8% of all fungicides, 65.0% of all herbicides, and 49.8% of all insecticides used on apples. The Pacific Region used the largest share (56.6%) of all "miscellaneous pesticides," used on apples in 1971. About two-thirds of this pesticide category consisted of miticides in 1971. The heavy use of "miscellaneous pesticides" in the Pacific Region is indicative of the serious mite problem on apples in this area.

Of all pesticides used on apples, 43.7% were used in the Northeastern Region, 24.6% in the Midwestern states (Lake States, Corn Belt, and Northern Plains), 16.5% in the Pacific Region, the balance in the remaining apple-producing regions of the U.S. The use of fungicides, insecticides, herbicides, and miscellaneous pesticides on apples in 1971, according to the USDA (1974b) survey, is further detailed in Tables 27 through 30. For each of the four pesticide categories, use data are presented by major products and by geographic regions.

Table 31 presents a comparison of the quantities of pesticides used on apples in the United States in 1964, 1966, and 1971 according to the U.S. Department of Agriculture's pesticide use surveys for these years (U.S. Department of Agriculture, 1968, 1970, 1974b). The total quantity of all pesticides used on apples decreased from 19.6 million pounds (active ingredients) in 1964 to 18.5 million pounds in 1966, and further to 12.8 million pounds in 1971. The quantities of fungicides used on apples changed relatively little, while the quantities of insecticides declined substantially during this 8-year period, i.e., from 10.8 million pounds (active ingredients) in 1964 to 8.5 million pounds in 1966, and further to 4.8 million pounds in 1971.

Table 26. PESTICIDE USAGE ON U.S. APPLE CROP IN 1971 BY REGION

	Fungicides		Herbicides		Insecticides		Misc. Pesticides		Total Pesticides	
Region	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%	1,000 lb	%
Northeast	2,943	40.8	128	65.0	2,403	49.8	116	21.1	5,590	43.7
Lake States	1,026	14.3	-	-	349	7.2	29	5.3	1,404	11.0
Corn Belt	853	11.8	11	5.6	831	17.2	36	6.6	1,731	13.5
Northern Plains	12	0.2	-	-	5	0.1	-	-	17	0.1
Appalachian	1,353	18.8	1	0.5	359	7.4	27	4.9	1,740	13.6
Southeast	67	0.9	6	3.0	32	0.7	7	1.3	112	0.9
Delta States	-	-	-	-	-	-	-	-	-	0
Southern Plains	-	-	-	-	-	-	-	-	-	0
Mountain	16	0.2	-	-	44	0.9	23	4.2	83	0.7
Pacific	937	13.0	51	25.9	808	16.7	310	56.6	2,106	16.5
Totals	7,207	100.0	197	100.0	4,831	100.0	548	100.0	12,783	100.0

Source: "Farmers' Use of Pesticides in 1971 Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

Table 27. FUNGICIDES USED ON APPLES BY REGION, 1971[a,b]
(1,000 lb)

Fungicide	Regions										
	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	Total
Captan	1,250	800	400	-	900	-	-	-	2	40	3,392
Other Dithiocarbamates	800	20	200	10	200	-	-	-	2	65	1,297
Dinocap, Dodine, Quinones	600	160	50	1	3	10	-	-	2	95	921
Other Inorganics	65	-	1	-	-	15	-	-	-	460	541
Zineb	50	1	100	-	180	5	-	-	4	170	510
Other Organics	80	30	5	1	9	10	-	-	1	40	176
Maneb	25	-	50	-	40	-	-	-	5	5	125
Ferbam	70	15	-	-	20	5	-	-	-	8	118
Other Copper Compounds	1	-	45	-	-	15	-	-	-	50	111
Copper Sulfate	2	-	2	-	1	7	-	-	-	4	16
Total	2,943	1,026	853	12	1,353	67	0	0	16	937	7,207

a/ Figures for total use of each fungicide and regional totals were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual fungicide, by region, is an MRI estimate.

Table 28. INSECTICIDES USED ON APPLES BY REGION, 1971[a,b/]
(1,000 lb)

Insecticide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Inorganics	900	10	500	-	140	3	-	-	-	300	1,853
Azinphosmethyl	500	100	60	-	100	7	-	-	2	200	969
Other Organophosphorus	300	80	35	1	40	2	-	-	3	160 180	641
Carbaryl	300	100	100	-	30	1	-	-	2	50	583
Chlordane	200	50	100	-	10	2	-	-	4	7	373
Parathion	60	5	10	3	15	5	-	-	15	25	138
Endosulfan	100	2	10	-	10	2	-	-	10	2	136
Ethion	35	-	-	-	1	5	-	-	3	25	69
Malathion	-	-	5	-	10	2	-	-	-	4	21
Diazinon	6	2	4	1	-	-	-	-	-	5	18
Bidrin	-	-	4	-	2	-	-	-	3	3	12
Methoxychlor	1	-	2	-	1	-	-	-	1	2	7
Dieldrin	1	-	-	-	-	-	-	-	1	3	5
Other Organochlorine	-	-	-	-	-	-	-	-	-	2	2
Endrin	-	-	-	-	-	2	-	-	-	-	2
TDE (DDD)	-	-	-	-	-	1	-	-	-	-	1
Heptachlor	-	-	1	-	-	-	-	-	-	-	1
Total	2,403	349	831	5	359	32	0	0	44	808	4,831

a/ Figures for total use of each insecticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971 - Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table 29. HERBICIDES USED ON APPLES BY REGION, 1971[a,b]
(1,000 lb)

	Regions										
Herbicide	North-east	Lake States	Corn Belt	Northern Plains	Appa-lachian	South-east	Delta States	Southern Plains	Moun-tain	Pacific	Total
Other Organic	65	-	1	-	1	-	-	-	-	28	95
Simazine	20	-	5	-	-	1	-	-	-	10	36
Dalapon	25	-	1	-	-	3	-	-	-	5	34
2,4-D	15	-	3	-	-	1	-	-	-	4	23
Dinitro Group	2	-	-	-	-	1	-	-	-	3	6
Diuron	1	-	-	-	-	-	-	-	-	1	2
Trifluralin	-	-	1	-	-	-	-	-	-	-	1
Total	128	0	11	0	1	6	0	0	0	51	197

a/ Figures for total use of each herbicide and regional total were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).
b/ Use of each individual herbicide, by region, is an MRI estimate.

Table 30. MISCELLANEOUS PESTICIDES USED ON APPLES BY REGION, 1971[a,b]
(1,000 lb)

Pesticide	Northeast	Lake States	Corn Belt	Northern Plains	Appalachian	Southeast	Delta States	Southern Plains	Mountain	Pacific	Total
Miticides											
Dicofol	1	-	-	-	-	-	-	-	2	3	6
Omite	69	10	28	-	9	-	-	-	2	160	278
Others	32	-	-	-	10	2	-	-	9	30	83
Fumigants	-	-	-	-	-	-	-	-	-	-	0
Defoliants and Desiccants	-	-	-	-	-	-	-	-	-	-	0
Rodenticides	5	-	-	-	-	-	-	-	-	2	7
Plant Growth Regulators	9	19	8	-	8	5	-	-	10	115	174
Repellents	-	-	-	-	-	-	-	-	-	-	0
Total	116	29	36	0	27	7	0	0	23	310	548

a/ Figures for total use of each pesticide and regional totals were obtained from "Farmers' Use of Pesticides in 1971-Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Department of Agriculture (1974b).

b/ Use of each individual insecticide, by region, is an MRI estimate.

Table 31. USE OF PESTICIDES ON APPLES IN THE U.S. IN 1964, 1966, AND 1971

Type of pesticide	1,000 lb of active ingredients		
	1964	1966	1971
Fungicides[a/]	7,700	8.496	7,207
Insecticides[b/]	10,828	8,494	4,831
Herbicides[b/]	N.A.	389	197
Miscellaneous pesticides[c/]	1,037	1,119	548
All pesticides	19,565[d/]	18,498	12,783

a/ Excluding sulfur.
b/ Excluding petroleum.
c/ Includes miticides (100% of total in 1964; about 2/3 of total in 1966 and 1971); fumigants (about 1/3 of total in 1966, none in 1964 or 1971); plant growth regulators (none in 1964 or 1966, about 1/3 in 1971).
d/ Excluding herbicides.
N.A. - not applicable
Sources: USDA 1968, 1970, 1974b.

The volume of commercial apple production in the United States during the last 10 years was as follows (USDA 1973, 1974a):

1964	3,120,000 tons
1965	3,001,000 tons
1966	2,825,000 tons
1967	2,793,000 tons
1968	2,723,000 tons
1969	3,355,000 tons
1970	3,129,000 tons
1971	3,040,000 tons
1972	2,935,000 tons
1973	3,102,000 tons

These production data indicate year-to-year changes in the quantities of apples produced in the U.S., probably due largely to different weather conditions, but no definite trends. By contrast, as pointed out above, the USDA pesticide use data indicate a definite downward trend in the quantities of insecticides and "miscellaneous pesticides" used on apples. This reduction in the use of pesticides, especially insecticides, was thus not correlated with changes in the volume of production of apples, but appears to be due to changes in pesticide use practice.

This assumption is borne out by information from the field. For instance, Eves and Chandler (1973) report that the average costs for pesticides in the State of Washington were $86/acre in 1967, and $48/acre in 1973. This decline in costs probably represents an even greater decline in the quantities of pesticides used because the unit costs of pesticides have increased during this period. Likewise, Brann (1974), advised that apple growers in New York are using substantially smaller quantities of pesticides, especially insecticides, on apples in the 1970's than they were using in the 1960's.

As with other crops, wasteful use of pesticides on apples, such as misuse, overuse, and/or unnecessary use may occur through poor management decisions. The data just quoted suggest that substantial progress has already been made during the last 10 years in correcting wasteful pesticide use practices on apples, and in using pesticides more efficiently. In the following subsections, current pesticide use practices on apples will be examined, focusing on opportunities to further improve pesticide use efficiency, and to further reduce wasteful pesticide uses.

FUNGICIDE USE PRACTICES

Table 31 indicates that the quantities of fungicides used on apples in the U.S. changed relatively little from 1964 (7.7 million pounds) to 1971 (7.2 million pounds). In 1971, close to 50% of the total quantity of fungicides used on apples (3.4 million pounds) consisted of captan (Table 27). Dithiocarbamate fungicides (maneb, zineb, ferbam, and others) accounted for an additional 2 million pounds, or 28% of the total quantity of fungicides used on apples. The balance is made up of a number of additional organic and inorganic fungicides.

The fungicides used most frequently on apples according to Table 27 are used primarily for the control of apple scab (*Venturia inaequalis*). Other diseases of apples caused by fungal pathogens requiring control include powdery mildew (*Podosphaera leucotricha*), several species of rusts, rots, and several others.

Apple scab is the single most important fungus disease of apples. The key to successful prevention of economic damage from apple scab is to control primary infections. To be effective, fungicides must be present on susceptible apple tissues before fungus infection takes place, or within a very short period (generally less than 24 hr) after infection. Therefore, most fungicides are used on apples preventively or protectively, that is before lesions caused by the fungal pathogen(s) becomes visible. Preventive or preprogrammed pesticide applications, prior to established need, are potentially wasteful. However, in the case of the fungus diseases of apples, the infection mechanisms of the fungal pathogens, combined with the capabilities of the most widely used fungicides, make it necessary to apply these fungicides on preventive application schedules in areas where climatic conditions and previous experience indicate that fungal infections are likely. Fungicide applications against apple scab are usually started at the "delayed dormant" or "green tip" stages of development of the host, and continued on regular spray schedules into the summer. In the opinion and experience of plant pathologists and apple growers alike, this application pattern is necessary if fungicides are to be used successfully in protecting apples from scab and other fungus diseases. There is little, if any, indication that the fungicides most often used on apples at present could be used with equal success in a basically different manner, in curative (in contrast to preventive) spray programs, or in greatly reduced quantities.

Furthermore, there are no practical, nonchemical alternatives available for control of the apple diseases controlled by these fungicides. No predators, parasites, or other biological agents are known that could be employed in "integrated apple disease management" programs. Thus, at the present state of the art, no practical, proven alternatives to the use of chemical fungicides on preventive, preprogrammed application schedules are available to growers for the control or management of apple diseases.

For these reasons, these use patterns of fungicides on apples cannot be considered to be wasteful, but appear to be necessary as dictated by the biology of the fungal pathogens involved, and the capabilities of the presently used fungicides.

INSECTICIDE USE PRACTICES

Of the 4.8 million pounds of insecticides used on apples in the United States in 1971 (Table 28), 1.9 million pounds, or 38% of the total, consisted of inorganic chemicals, primarily lead arsenate. Among the synthetic organic insecticides, azinphosmethyl (tradename: Guthion®) was used in larger quantities than any other single product; its volume, 969,000 lb, accounted for more than one-half of the quantity of all organophosphate insecticides, or about one-third of all synthetic organic insecticides used on apples. Carbaryl (tradename: Sevin®) was the next largest apple insecticide used in 1971; its volume, 583,000 lb, amounted to about 20% of all organic insecticides. Several smaller volume organic insecticides accounted for the balance of all insecticides used on apples in 1971.

About one-half of all insecticides used on apples in 1971, 2.4 million pounds (active ingredients), were used in the Northeastern Region. An additional 1.2 million pounds, or 25% of the total, were used in the Midwest (Lake States, Corn Belt, and Northern Plains). The Pacific Region used 808,000 lb of insecticides on apples in 1971 (17% of the total), the balance was used in the other apple growing areas, primarily the Appalachian Region.

Comparing these figures to the geographical distribution of apple production in the U.S. (Figure 5), it is evident that the production of apples in the Northeastern Region requires relatively heavier inputs of insecticides than the Pacific Region.

In the past, insecticides were usually applied to apples on preventive, preprogrammed spray schedules. After some time, it became apparent that this practice was very detrimental to beneficial parasites and predators. In the absence of the latter, plant-feeding mites became a severe problem in many apple-producing areas, especially in the Pacific

Northwest. At first, the use of miticides was stepped up, but several species of mites soon became highly resistant to practically all available miticides. This chain of events prompted the development of more selective apple pest control or management procedures, with emphasis on the selection of insecticides, miticides, and application rates and schedules designed to preserve beneficial predators and parasites to the greatest possible extent. As pointed out above, this development has already resulted in a substantial reduction of the total quantities of insecticides used on apples from 1964 to 1971 (Table 31).

In recent years, Integrated Pest Management (IPM) programs were established in several apple-growing states. The objectives of these programs include identification, quantification, and documentation of the pest problems on apples in the area, and development of solutions to these problems by integrating biological, chemical, and other control methods to the greatest degree possible. The ultimate practical objective is, of course, to increase apple growers' profits.

One of the IPM programs on apples was initiated in 1972 in the Yakima Valley in the State of Washington. Apples are grown on about 36,000 acres in the Yakima Valley, that is about 40% of the total acreage of apples in the state (Table 32). In 1973, 665 acres of apples were included in this program. In the program area as well as in neighboring apple orchards, populations of codling moths, mites, and other apple pests were monitored regularly by mite counts, sex pheromone traps, and intensive field observation. Participating growers received specific spray recommendations from IPM program personnel.

Table 32. APPLE ACREAGE IN WASHINGTON

Total acres of apples in state, 1969[a]	92,244
Total acres of apples in Yakima Valley[a]	36,236
Acres in IPM program in Yakima Valley, 1974[b]	661

a/ 1969 *Washington tree fruit census*.
b/ Eves (1974).

Table 33 summarizes the results of this program in 1973 and 1974 as compared to the pesticide use experience on 2,193 comparable acres of apples not under IPM in 1973. In the non-IPM area, a total of 9.31 lb of pesticide active ingredient was applied per acre, at a cost of $59.80/acre. In the IPM area, total pesticide inputs were 3.93 lb/acre ($28.00) in 1973, and 4.5 lb/acre ($29.00) in 1974. Thus, total pesticide inputs in the IPM program in the 2 years averaged 4.2 lb of active ingredient per acre, a reduction of about 55% from the 9.31 lb active ingredient per acre in the non-IPM area. Cost savings per Table 13, all computed on the basis of 1972 prices, were comparable to the savings in quantities. In reality, IPM program participants savings in pesticide costs were even greater than indicated by the data in Table 33 because pesticide costs increased from 1972 to 1974.

Table 33. USE OF PESTICIDES ON APPLES IN THE LOWER YAKIMA VALLEY UNDER IPM VERSUS NON-IPM PROGRAMS

Program	Acres in program	Acres sprayed against: Aphids (%)	Acres sprayed against: Mites (%)	All pesticides used: Pound active ingredient per acre	All pesticides used: Cost ($/acre)[a]
Non-IPM, 1973	2,193	100	100	9.31	59.80
IPM, 1973	225	0	0	3.93	28.00
IPM, 1974	661	25	28	4.5	29.00

a/ Basis 1972 prices.
Source: Eves (1974), and Eves and Chandler (1973).

In 1973, no insecticide sprays against aphids or mites were needed in the IPM area, and in 1974, only about one-fourth of the IPM program acreage required such treatments, while in the non-IPM area in 1973, 100% of the acreage was treated against aphids and mites. Project personnel report that when Guthion® is applied against the codling moth at "standard" rates, buildup of mites to damaging proportions often follows, necessitating one or more applications of miticides. Conversely, when used at the minimum rate required for codling moth control, Guthion® permits survival of mite predators, mites are kept at low levels, and chemical miticides are required only occasionally.

Integrated pest management programs on apples in Pennsylvania have been described by Asquith (1972). The Pennsylvania program is also centered on the integration of the biological control of mites with the chemical control of other apple pests. Three different spray schedules are outlined by Asquith. Table 34 summarizes the results of these schedules in terms of total cost per acre, and in terms of the rates of Guthion® (azinphosmethyl) recommended in each schedule. Data on Guthion® were included in Table 34 because it is the organic insecticide most widely used on apples, as documented above (Table 28). Table 34 indicates that the cost of all pesticides combined in the full schedule was $85.15/acre, compared to $60.23 (29% reduction) in the "alternate middles schedule," and $46.12 (46% reduction) in the integrated pest management schedule. The "full schedule" recommends Guthion® applications totaling 6.0 lb 50% wettable powder (WP) per acre per season. In the "alternate middles schedule," this quantity is reduced to 4.0 lb 50 WP (33% reduction), while in the IPM schedule, only 2.0 lb of Guthion® 50 WP are recommended per acre per season, a reduction of 67% from the full schedule.

Table 35 summarizes the rates of application of Guthion® 50% wettable powder for use on apples recommended by different sources, including the EPA Compendium of Registered Pesticides, the product label, and the Cooperative Extension Services in the states of Washington, New York, Pennsylvania, and Michigan. These rates are compared to rates recommended in IPM programs, and minimum effective rates, that is, rates giving economic control in IPM programs.

According to the EPA Compendium (U.S. Environmental Protection Agency, 1972; page III-D-43.1, issued 30 June 1972), Guthion® may be used on apples at the rate of 6.0 lb active ingredient (12.0 lb 50% wettable powder) per acre per application, up to eight times per season, equal to a maximum permissible rate of application of 48 lb active ingredient (96 lb 50 WP) per acre per season. As pointed out previously in the section on sorghum, the EPA Compendium is intended to ensure that the total amount of pesticide applied will not exceed the tolerance; it is not designed to recommend application rates.

The product label (Chemagro Corporation, 1970) recommends 2.0 to 2.5 lb 50 WP/acre/application. The Extension Services' standard recommendations are similar to those on the product label, with a few exceptions. Washington State (1974) recommends up to 3.0 lb 50 WP/acre/application. Pennsylvania (1974) recommends Guthion® only in combination with other insecticides such as lead arsenate, dimethoate, demeton, Imidan, or Zolone. Guthion® as one component of such combinations is recommended at the rate of 0.8 lb 50 WP/acre/application. In New York (Arneson et al., 1974) and Michigan (Jones et al., 1974), the "standard" rate of Guthion recommended is 2.0 lb 50 WP/acre/application.

Table 34. USE OF PESTICIDES ON APPLES IN PENNSYLVANIA UNDER IPM VERSUS NON-IPM PROGRAMS

Program	Cost of all pesticides: $/acre	Cost of all pesticides: Reduction versus full schedule	Rate of Guthion® recommended: Lb 50 WP/acre /season	Rate of Guthion® recommended: Reduction versus full schedule
Full schedule	85.15	-	6.0	-
Alternate middles spray schedule	60.23	29%	4.0	33%
Integrated pest management	46.12	46%	2.0	67%

Source: Asquith (1972).

Table 35. RATES OF APPLICATION OF GUTHION® 50% WETTABLE POWDER ON APPLES RECOMMENDED BY PUBLIC AGENCIES AND IN SELECTED INSECT CONTROL PROGRAMS

Type of recommendation or use	Guthion® 50% WP rate per application		Reduction compared to "standard"
	Per 100 gal.[a]	Per acre	
Rate recommended			
- in EPA Compendium[e]		max. 12.0	
- in Product Label[f]	0.5-0.625[b]	2.0-2.5	
Washington			
Rate recommended by Ext. Service[g]	0.25-0.5[c]	1.5-3.0	"standard"
Rate recommended in IPM Program[h]		1.25	17-58%
Rate giving economic control in IPM Program[h]		0.5-1.0	33-83%
New York			
Rate recommended by Ext. Service[i]	0.5[b]	2.0	"standard"
Rate used in 1973 IPM Program[j]		1.43	29%
Pennsylvania			
Rate recommended by Ext. Service[k]			
- "Standard Program"	0.25[d]	0.8	"standard"
- "Pest Management Program"	0.08-0.17[d]	0.25-0.5	38-69%
Michigan			
Rate recommended by Ext. Service[l]	0.5[b]	2.0	"standard"
Rate used in 1972 IPM Program[m]		0.43-0.87	57-79%

a/ 100 gal. dilute spray.
b/ Basis 400 gal. dilute spray/acre.
c/ Basis 600 gal. dilute spray/acre.
d/ Basis 50 gal. 6 x conc. spray = 300 gal. dilute spray/acre.

Sources:
e/ U.S. Environmental Protection Agency (1972).
f/ Chemagro Corporation (1970).
g/ Washington State University (1974).
h/ Eves (1974).
i/ Arneson et al. (1974).
j/ Brann (1974).
k/ Pennsylvania State University (1974).
l/ Jones et al. (1974).
m/ Thompson et al. (1972).

In Washington State, IPM program participants are using Guthion® successfully at the rate of 1.25 lb 50 WP/acre, a reduction of 17 to 58% compared to the standard. IPM program personnel report that economic control has been obtained at Guthion® rates of 0.5 to 1.0 lb 50 WP/acre, a reduction of 33 to 83% from the standard (Eves, 1974).

In New York, participants in the IPM program in 1973 used Guthion® at an average rate of 1.43 lb 50 WP/acre/application, a reduction of 29% compared to the "standard" (Brann, 1974).

In Pennsylvania, the "pest management program" recommended by Pennsylvania State University (1974) in its 1974 tree fruit production recommendations calls for the use of Guthion® (in combination with at least one other insecticide) at the rate of 0.25 to 0.5 lb 50 WP/acre, a reduction of 38 to 69% against the rates recommended in the "standard program." The rates of other insecticides with which Guthion® is to be combined are similarly reduced in the "pest management program."

In Michigan, Guthion® was used at the rate of 0.43 to 0.87 lb 50 WP/acre in the 1972 and 1973 IPM programs, a reduction of 57 to 79% compared to the standard recommended rate (Thompson et al., 1972; Thompson et al., 1973).

In Table 35, the rates of Guthion® recommended in IPM programs, or found to be economically effective are, on the average, about 50% lower than the "standard" recommended. rates. However, it would be unrealistic to anticipate that the rates of Guthion® currently used on apples in the field could be reduced by 50% across the board. In field practice, Guthion® as well as other apple insecticides are already widely used at rates lower than the "standard." Thus, the potential savings in insecticides suggested by Table 35 have in part already been realized during the past few years, as demonstrated by the decline in the total quantities of insecticides used on apples since 1964. On the other hand, the Guthion® rate data in Table 35 pertain only to single applications. Additional savings in total insecticide inputs would be possible if the number of insecticide applications per season could be reduced. Another possibility of reducing insecticide inputs consists of treating only so-called "hot spots" within orchards, rather than entire blocks. Improved pest monitoring procedures make this approach possible. Further savings in total pesticide input are realized when mite predators are allowed to survive in sufficient numbers to keep detrimental mites under control, thus reducing or eliminating the need for chemical miticides.

In discussing the potential for futher insecticide use reductions with experts in the field, entomologists working on apple insects in New York State pointed out that apple growers in their state have already been using pesticides only "as needed" during the last few years. They see only limited room for saving additional pesticide quantities and costs, of the order of about 10%. Looking for savings greater than 15% would be unrealistic, in their opinion. Somewhat greater reductions in pesticide inputs and costs appear to be possible in Pennsylvania.

Michigan State University's reports on their apple pest management programs for 1972 and 1973 (Thompson et al., 1972; Thompson et al., 1973) do not specify actual or potential savings in pesticide inputs to be expected from the program, and Michigan's 1974 fruit spraying calendar (Jones et al., 1974) does not include separate "standard" and "pest management" spraying schedules.

Entomologists in Washington State believe that substantial reductions in pesticide inputs could be achieved with increased adoption of IPM practices (Eves and Chandler, 1973; Eves, 1974). However, since the Pacific Region uses smaller quantities of pesticides per unit of apple production, savings in that region will have a smaller effect on the total quantities of pesticides used on apples than pesticide use reductions in the Northeastern Region with its heavier use of apple pesticides.

The data in Table 31 show that the quantities of insecticides used on apples in the U.S. have declined substantially between 1964 and 1971. From the information presented above, we estimate that an additional 20 to 30% of the quantities of insecticides that were used on apples in 1971 could be saved, and that this fraction of the total current volume of use of these chemicals might, therefore, be considered inefficient or wasteful. Specifically, this estimate is based on:

* The data summarized in Table 35, showing that the minimum effective rates of Guthion®, a major apple insecticide, are about 50% lower on the average than the "standard" recommended rates.

* The fact that further insecticide inputs could be saved by avoiding insecticide application in the absence of established need for treatment, and by avoiding insecticide or miticide applications necessitated by preceding injudicious pesticide use.

* The opinions of research and extension entomologists working on apple insects in the states of Washington, New York, Pennsylvania and Michigan as discussed above.

* The historical use patterns of insecticides on apples in the U.S. as summarized in Table 31.

Further reductions in the quantities of insecticides used on apples of the order of 20 to 30% would require widespread implementation of integrated pest management practices, vastly improved understanding of IPM principles and procedures by persons making pest management decisions and pesticide applications, and several other prerequisites.

If the USDA estimate on the quantities of insecticides used on apples in 1971, 4.8 million pounds (active ingredient), is representative of the current level of use, a 25% reduction would correspond to 1.2 million pounds. If the USDA estimate is low, then the quantity of insecticides that would be saved by a 25% reduction would, of course, be even greater.

HERBICIDE USE PRACTICES

In 1966, 389,000 lb of herbicides (active ingredient) were used on apples, and 197,000 lb in 1971 (Table 31). In both years, these totals included simazine, dalapon, 2,4-D, and several other organic herbicides not disaggregated in the USDA pesticide use reports (U.S. Department of Agriculture, 1970, 1974b).

Herbicides are used in apple orchards to reduce or remove unwanted vegetation under and around the trees. Heavy growth in these areas may harbor mice, snakes, borers, and other vermin. Weeds compete with trees for water, nutrients, and especially in young plants, light. They may reduce yield and quality of the apple crop and interfere with operations such as fertilization, spraying, harvesting, etc.

Chemical herbicides are used in apple orchards because they are often less expensive and more effective than hand labor or mechanical means of weed removal. The danger of damaging trees by using the wrong products, or by over-application represents a built-in safeguard against misuse and overuse. The herbicides are nearly always applied by ground equipment. Spray drift is rarely, if ever, a problem.

Thus, the use of chemical herbicides in apple orchards does not appear to be wasteful. The quantities of herbicides used for this purpose in 1971 according to the USDA (1974b), 197,000 lb, are relatively small, representing only about 0.09% of the total quantities of herbicides used on agricultural crops in the United States in 1971.

USE OF MITICIDES, FUMIGANTS, AND PLANT GROWTH REGULATORS

Miticides, fumigants, and plant growth regulators are included in a category called "miscellaneous pesticides" in the USDA pesticide use surveys. The use of these products on apples totaled 1,037,000 lb of active ingredient in 1964, 1,119,000 lb in 1966, and 548,000 lb in 1971 (Table 31). As indicated in footnote 3 of Table 31, the 1964 total consisted almost entirely of miticides, including dicofol (Kelthane®), tetradifon (Tedion®), Aramite, and others, unspecified organic miticides. In 1966 and 1971, about two-thirds of all "miscellaneous pesticides" used on apples consisted of miticides. Principal miticides used in 1966 were dicofol, tetradifon, and chlorobenzilate. In 1971, Omite® was the leading miticide.

Miticides

The use of all miticides on apples declined from 1,031,000 lb of active ingredient in 1964 to 673,000 lb in 1966, and further to 367,000 lb in 1971, according to the USDA farm pesticide use surveys. This decline is due primarily to the fact that mites developed resistance to one chemical miticide after another, as indicated by the rapid turnover of products in this group. Integrated pest management programs recently established on apples in several states emphasize biological control of mites. It is anticipated that increased adoption of such programs will result in further reductions in the use of miticides on apples. For instance, in the IPM program in the Lower Yakima Valley in the State of Washington, IPM program participants applied no miticides in 1973, while nonparticipants sprayed 100% of their apple acreage against mites. In 1974, only 28% of the IPM program acreage required miticide treatments (Table 33).

In retrospect, it appears that the extensive use of miticides on apples in the 1960's was economically as well as ecologically inefficient and wasteful. The failure of chemical miticides in major apple-producing areas, especially the Pacific Northwest, prompted the development and implementation of integrated pest management programs. As the miticide use data indicate, these measures have resulted in very substantial reductions in the total quantities of miticides used on apples. Further decreases in the use of miticides on apples are likely to occur with increased adoption of integrated pest management programs.

Fumigants

According to the USDA farm pesticide use surveys, fumigants were used on apples to a significant extent only in 1966. In that year, 395,000 lb of fumigants were included in the total quantity of "miscellaneous pesticides" used on apples. The fumigant total consisted of 269,000 lb of sulfur dioxide and 126,000 lb of other, unspecified fumigants.

Soil fumigation is often recommended in situations where a new orchard is being planted in an old orchard site, for the control of nematodes and other soil-borne pathogens. In such instances, fumigants are applied directly to the soil in the area to be protected. The use of fumigants is a relatively expensive practice, a built-in deterrent to wasteful use. There are no indications that the relatively small quantities of fumigants used on apples are wasteful or inefficient. There are no effective nonchemical methods available to growers for the destruction of soil-borne orchard pathogens that would injure the roots of newly planted apple trees, reduce growth and, in some cases, even kill young trees.

Plant Growth Regulators

Plant growth regulators have been developed and registered for use on apples during the last few years, and as the USDA pesticide use surveys indicate, the use of appreciable quantities of these substances on apples was registered for the first time in the 1971 use statistics. Plant growth regulators are used on apples for several different purposes, including chemical thinning, increase of branch angles, bloom promotion, delay of water core, promotion of color, and prevention of preharvest drop. Misuse or overuse of these substances can produce substantial damage to the quality and/or quantity of the apple crop, or even to the trees themselves. Thus, there is little room for error in the use of plant growth regulators, and it is not likely that they will be used wastefully by apple growers.

SUMMARY

There are no indications that significant quantities of fungicides, herbicides, fumigants or plant growth regulators are used on apples in a wasteful manner.

Most of the commercial fungicides currently available for use on apples have to be applied on preventive, preprogrammed application schedules for optimal biological and economic efficiency and effectiveness. No effective nonchemical methods for the control of fungal diseases of apples are currently available to growers, and no "integrated disease management programs" for apples have been developed at the grower level.

Herbicides, fumigants, and plant growth regulators are used on apples only in relatively small quantities, and in an efficient and effective manner.

The quantities of insecticides and miticides used on apples declined substantially (about 55%) during the last 10 years. In many apple-growing areas, unilateral reliance on chemicals for the control of apple insects and mites resulted in failure, primarily in the form of unmanageable mite problems. This spawned the development and necessitated the adoption of integrated apple pest management methods. There are indications that substantial further reductions (25 to 50%) in the quantities of insecticides and miticides currently used on apples are possible. Further improvement and large-scale implementation of integrated pest management methods are among the prerequisites needed to make such potential reductions in insecticide inputs a reality.

In relation to the quantities of insecticides (4,831,000 lb) and miticides (367,000 lb) used on apples in 1971 according to the USDA pesticide survey (Tables 28 and 30), savings of the order of 20 to 30% would amount to 1.0 to 1.6 million pounds of insecticide and miticide active ingredients.

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SECTION VIII

WASTES AND LOSSES OCCURRING DURING AND AFTER PESTICIDE APPLICATION

This section presents a summary of the topics discussed in Volume II of this report. Volume II is a detailed discussion of the wastes and losses of pesticides that occur both during and after pesticide application which were examined in this study. The summary given here is divided into the following sections:

* Study Approach;
* Study Areas; and
* Summary of Discussions in Volume II.

Each of these sections are presented below.

STUDY APPROACH

The approach taken in this aspect of the study differed from that used in the studies reported in Sections V, VI, and VII of this volume. Identification of factors that cause pesticide waste and loss both during and after crop treatment was not limited to the three study crops but was made for agriculture in general since many of the techniques used to treat corn, sorghum, and apples are used throughout the agricultural community. Each subject was discussed with reference to agriculture in general when examining the problem areas that cause inefficient pesticide use.

In line with the objective to quantify pesticide waste and losses in as much detail as possible, quantitative aspects of each subject examined were given prime attention throughout this phase of the study. When determining the quantities of pesticides lost or wasted, only the three study crops were considered and all quantities were determined for each crop for the year 1971, the latest year meaningful pesticide use statistics are available.

The information needed for this phase of the study was obtained from a thorough search of the literature, questionnaires, personal, and telephone interviews with persons knowledgeable on the subject matter, and correspondence with agricultural engineers and pesticide equipment manufacturers.

STUDY AREAS

A survey of pesticide wastes and losses caused primarily by physical factors, indicated that substantial losses could occur both during application and postapplication. At the time pesticides are applied, three mechanisms cause the greatest loss and waste of pesticides; they are: (a) nonuniform pesticide distribution on the crop; (b) overapplication of pesticides; and (c) pesticide drift away from the crop area. After application takes place one of the major pesticide loss mechanisms is transport of the pesticides from the crop by surface runoff and soil erosion. These areas were examined in detail in this study and the discussion of each area is given in Volume II of this report. For the sake of completeness, the wastes and losses of pesticides caused by the miscellaneous discharges of spills and disposal are also described briefly.

The major study areas of this aspect of the study, then, were:

1. Pesticide Wastes and Losses Occurring During Application.

   * Nonuniform Distribution;

   * Overapplication; and

   * Drift.

2. Pesticide Losses After Application and by Miscellaneous Discharge.

   * Runoff and Soil Erosion;

   * Spills; and

   * Disposal.

A summary of the discussions of each of these areas are presented in the next section.

SUMMARY OF DISCUSSIONS AND FINDINGS IN VOLUME II

The topics of discussion and findings on pesticide wastes and losses during and after application are summarized below. The material covered in Volume II of the study deals with agriculture in general and is not limited to corn, sorghum, and apples (except when quantities of pesticides lost or wasted are determined). Many of the findings may apply to other crops to which pesticides are applied in a similar manner.

Each topic discussed in Sections III and IV of Volume II is summarized below and the major findings are given.

Pesticide Wastes and Losses Occurring During Application

The waste of pesticides at the time of application is a result of two major mechanisms: overapplication and nonuniform distribution. Loss of pesticides at the time of application are primarily a result of pesticide drift away from the target area. Both the waste and loss potential of pesticides during application through these mechanisms were examined in this study.

Waste Potential During Application - Waste during application may result from overapplication or nonuniform distribution of pesticides during crop treatment. Overapplication is defined as physically applying pesticides at a rate higher than that intended. Nonuniform distribution means distributing the pesticide unevenly so that some areas of the field receive heavy dosages of pesticide while other areas receive light dosages.

Both overapplication and nonuniform distribution are caused by faulty equipment characteristics and/or erroneous equipment operation. Some of the physical elements of pesticide application equipment that affect the application rate and the uniformity of chemical disbursement are the metering devices, nozzles, and spray tank agitation systems. Some of the more common errors made in operating the application equipment are improper calibration, uneven driving speeds, improper sprayboom height, and choice of unsuitable pesticide formulations. The unique problems of nonuniform aircraft spray disbursement patterns involve both technical and operational aspects.

Overapplication results from:

* Faulty metering devices.
* Nozzle wear with wettable power sprays.
* Improper equipment calibration.

* Driving too slow when turning around, encountering obstacles, or driving up a slope.

* Pesticide formulations mixed in a higher concentration than intended.

Nonuniform distribution results from:

* Faulty metering devices.

* Clogged nozzles.

* Improper spray atomization.

* Inadequate tank agitation systems when spraying emulsions or wettable powders.

* Uneven driving speeds.

* Improper spray boom height, either too low or too high.

* Poor aircraft spray patterns.

The variables which cause these two problems defy quantification in the strict sense. However, these problems are important enough to warrant concern. Overapplication and nonuniform distribution are both current and future problems that must be dealt with if the efficiency of pesticide applications in agriculture is to be enhanced.

<u>Loss Potential During Application</u> - Pesticides are lost into the environment at the time of application when they drift away from the crop being treated and impact away from the target area. Under certain circumstances, these losses are substantial and may pose both an immediate and long-term hazard to the surrounding environment. Drift is neither accidental nor entirely uncontrollable, and its occurrence reduces the efficiency of agricultural pesticide applications.

Drift is a rather complex physical event which is influenced by a variety of interrelated factors. The potential for the occurrence of spray or solid particle drift depends primarily upon meteorological conditions, properties of the particle itself, and operational application techniques. Important factors affecting drift are wind speed and turbulence; particle size and density; evaporation rate of the liquid; spray nozzles and discharge pressures; distance between application equipment and target; and volumes of pesticide formulations applied.

This study took all of these factors into account and estimated the likelihood of drift for various types of equipment and application techniques commonly used in agriculture, paying particular attention to field crops and orchards. The estimations developed in this study are given in Table 36. The biggest drift hazards occur as a result of using dusts and aerial spraying.

In addition to examining drift losses in agricultural chemical crop-treating operations in general, the estimates developed in the study were applied to the three study crops. Between some hard facts and some assumptions in cases where information was unavailable, the losses due to pesticide drift during application were estimated for the applications made to the U.S. corn, sorghum, and apple crops in 1971, the most recent year for which pesticide use statistics on these crops are available. The estimates for pesticide drift loss are included in Table 37, both as percentages and as quantities of active ingredient used that year.

Herbicide losses were low on a percentage basis, but the quantities lost were the largest for the four groups of pesticides. Insecticide losses were the highest in the apple orchards primarily due to the use of dusts and orchard airblasters. Sorghum losses were greater than those of corn since most insecticides used on sorghum are applied by air, whereas corn insecticides are applied to the soil, mostly preemergence. Fungicides and other pesticides are not used on corn and sorghum to any significant extent, while fungicides are used extensively on apples. Again, drift losses were high in the apple orchards for fungicides since some are applied as dusts, and about half as sprays from airblasters.

Pesticide Losses After Application and by Miscellaneous Discharge

Pesticide losses that occur after application that were examined in this study are the result of pesticide transport away from the crop by the natural forces of runoff and soil erosion. Losses which occur through miscellaneous discharges are the result of spills and disposal techniques. Each of these pesticide loss routes are discussed below.

Loss Potential After Application - Pesticide quantities deposited in the target area may impact on the target crop, on the ground, or on other nontarget surfaces in the target area. A portion of the deposit on the crop may be washed off and impact on the ground secondarily at various times after application.

Table 36. LIKELIHOOD OF PESTICIDE DRIFT DURING CROP TREATMENT IN AGRICULTURE BY METHOD OF APPLICATION

Formulation	Equipment type	Pesticide application method[a]	Target	Spray application volume[b]	Estimated percent drift over 1,000 ft from target[c]
Dust	Aircraft, venturi	Air, foliar	Trees	-	70-90
	Airblaster	Ground, foliar	Trees	-	60-80
Spray	Tractor, boom sprayer	Ground, foliar	Plants	ULV	5-10
		Ground, foliar	Plants	LV	1
		Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
		Ground, band	Soil	ULV	Negligible
		Ground, band	Soil	LV	Negligible
	Tractor, boomless sprayer	Ground, broadcast	Soil	LV	Negligible
		Ground, broadcast	Soil	HV	Negligible
	Spray gun	Ground, foliar	Trees	HV	3-5
	Orchard airblaster	Ground, foliar	Trees	ULV	40-70
		Ground, foliar	Trees	LV	10-40
	Aircraft, boom sprayer	Air, foliar	Trees	ULV	40-60
		Air, foliar	Trees	LV	10-40
		Air, foliar	Plants	ULV	40-60
		Air, foliar	Plants	LV	10-40
		Air, broadcast	Soil	LV	10-40
Granular	Aircraft, venturi	Air, broadcast	Soil	-	1-2
	Spreader, centrifugal	Ground, broadcast	Soil	-	1
	Spreader, boom	Ground, broadcast	Soil	-	1
		Ground, band	Soil	-	Negligible
	Planter	Ground, band	Soil	-	Negligible

a/ Air refers to pesticide application by aircraft, ground refers to pesticide application by ground rigs.
b/ HV = High Volume; LV = Low Volume; ULV = Ultra-Low Volume.
c/ Assumes a 3 to 5 mph wind; neutral atmospheric stability (S.R. = 0), air temperatures above 60°F; and a relative humidity of 50% or less.

Table 37. ESTIMATED LOSSES DURING AND AFTER APPLICATION OF PESTICIDES TO CORN, SORGHUM AND APPLES (1971)

Pesticide and loss route	Corn		Sorghum		Apples	
	% loss[a]	Lb lost (000)	% loss[a]	Lb lost (000)	% loss[a]	Lb lost (000)
Herbicides						
Drift	0.8-3.0	800-3,000	1.0-3.9	120-450	Negligible	
Runoff	0.5-3.2	500-3,200	0.6-3.4	70-390	Negligible	
Total	1.3-6.2	1,300-6,200	1.6-7.3	190-840	Negligible	
Insecticides						
Drift	0.2-0.7	50- 180	6-25	360-1,400	21-42	1,000-2,000
Runoff	0.3-1.3	80- 330	Negligible		Negligible	
Total	0.5-2.0	130- 510	6-25	360-1,400	21-42	1,000-2,000
Fungicides						
Drift	Negligible		Negligible		21-42	1,500-3,000
Runoff	Negligible		Negligible		Negligible	
Total	Negligible		Negligible		21-42	1,500-3,000
Other pesticides						
Drift	Negligible		Negligible		Negligible	
Runoff	Negligible		Negligible		Negligible	
Total	Negligible		Negligible		Negligible	

a/ Percent loss refers to the percentage of the amount applied.

The principal mechanisms of pesticide transport away from treated fields after application are: (a) surface runoff including both sediment and water; (b) volatilization; and (c) leaching to groundwater. The magnitude of the losses varies with each pesticide and environmental conditions. Generally, surface runoff and volatilization are the dominant mechanisms for pesticide loss from cropland. Degradation by chemical, physical, or biological processes is not a transport or "avoidable loss" mechanism within the definitions established for this study and was therefore not included in its scope. Volatilization is a process which is beyond the control of the farmer once the pesticide has been properly applied (and soil incorporated, if required). Since this study deals with avoidable losses of pesticides, only surface runoff was studied in detail.

The primary objective in examining the incidence of runoff was to quantify the pesticide losses involved. After defining the variables that affect the amount of runoff that occurs with rainfall and soil management practices in agriculture, two methods were used to try to estimate the quantities of pesticides lost in runoff from the study crops. The first method involved estimating the amount of runoff occurring on the crops and the concentrations of pesticides involved. The second method consisted of estimating the total pesticide loss as a percentage of the amount applied and relating this to the amounts applied to the study crops in 1971.

The first method proved unsatisfactory. Statistics were developed for runoff losses only since soil losses cannot be reasonably estimated for a large crop due to the complexity of the many variables involved. Both annual runoff maps and rainfall maps were used to estimate the runoff from the corn and sorghum crops (apples were not included since soil-applied pesticides are used in small quantities in orchards). Concentrations of herbicides and insecticides in runoff water were determined from field studies reported in the literature. However, quantification of the pesticide losses on the two crops was not undertaken by this method since the variables involved required too many assumptions. There is no current method of accurately determining the amount of runoff from crops, and the work done in this study helps to show why.

The second method was used to quantify the herbicide losses from the corn and sorghum crops in 1971 and the quantities determined are shown in Table 37. The percentages of pesticides lost as a percent of the amount applied were determined from field studies reported in the literature. These percentages were then used with the amount of herbicides actually applied to corn and sorghum in 1971 to determine the loss.

Table 37 shows that herbicide losses from corn and sorghum crops amounted to 3% or less of the amount actually applied to the soil. However, this amounts to as much as 3 million pounds of active ingredient, a substantial quantity.

Miscellaneous Pesticide Discharges - Pesticide losses due to spills and improper disposal were not evaluated in detail in this study. Losses from these two mechanisms reduce the overall efficiency of agricultural pesticide use. However, spills are primarily accidents and disposal techniques are within the control of man. Pesticide accidents as well as losses due to improper disposal of pesticides or containers can be reduced or avoided by improved operator training, performance and supervision.

APPENDIX

CRITERION SCHEME FOR THE SELECTION OF SURVEY CROPS

Many of the parameters to be studied in this project cannot be studied theoretically or in a vacuum, but as they apply to specific crop/pest/pesticide systems. Thus, it is important to select crops suitable as "study systems."

A criterion scheme was developed, in accordance with the provisions of the project work statement (Article I), for this selection. Criteria considered important and evaluated below include the following:

* Volume of use of pesticides on the crop;

* Existence of integrated pest management programs on the crop;

* Crop acreage; and

* Crop farm value.

The question of whether or not integrated pest management programs are in progress on candidate crops is important because these programs will provide information on minimum levels of pesticide use (dosage rate per application, frequency of applications) needed for economic pest control, as opposed to labeled or recommended rates. This type of information is essential to Task 5, The Study of Pesticide Wastes Caused by Management Factors, and is generally not available for crop/pest/pesticide systems that have not yet been studied from the standpoint of integrated pest management.

The volume of use of pesticides by crops and by pesticide category in 1971 has been summarized in Table A-1. This three-part table covers uses of herbicides, insecticides and fungicides, respectively, on those individual crops that account for about 80% of the total use. In each category, crops were ranked in decreasing order of volume of pesticide used, highest volume equals one.

In Table A-2, the number of USDA integrated pest management programs in 1972 and 1973 have been summarized for all crops included in Table A-1. The crops were then ranked in decreasing order of number of IPM programs, largest number of programs equals one.

In Table A-3, the U.S. acreage and farm value of these crops in 1972 (the latest year for which USDA statistics are available) are listed and ranked, largest acreage and largest farm value equals one.

In Table A-4, all rankings from Tables A-1 through A-3 are summarized, totaled, and averaged.

Table A-1. USE OF PESTICIDES ON SELECTED CROPS BY PESTICIDE CATEGORY, 1971

Herbicides				Insecticides				Fungicides			
Crop	MM lb AI	% of total	Rank	Crop	MM lb AI	% of total	Rank	Crop	MM lb AI	% of total	Rank
Corn	101	45	1	Cotton	73	47	1	Vegetables	10	24	1
Soybeans	37	16	2	Corn	26	17	2	Citrus	9	24	2
Cotton	20	9	3	Vegetables	11	7	3	Apples	7	18	3
Wheat	12	5	4	Soybeans	6	4	4	Peanuts	4	11	4
Sorghum	12	5	5	Apples	5	3	5				
Vegetables	6	2	6	Tobacco	4	3	6				
Peanuts	4	2	7	Citrus	3	2	7				
Subtotals	192	84			128	83			30	77	
All other crops	34	16			26	17			10	23	
All crops	226	100			154	100			40	100	

Source: Andrilenas, P., "Farmers' Use of Pesticides in 1971--Quantities," Agricultural Economic Report No. 252, Economic Research Service, U.S. Dept. of Agriculture (1974).

Table A-2. USDA IPM PROGRAMS BY CROPS, 1972 AND 1973

Crop	Number of programs 1972	1973	Rank
Cotton	14	14	1
Corn	-	6	2
Vegetables	4	4	3
Apples	2	4	4
Sorghum	-	4	5
Peanuts	-	2	6
Citrus	-	1	8
Tobacco	1	1	7
Wheat	-	-	10
Soybeans	-	-	10

Sources: Good, J. M., "1972 Benefit Summaries of Pest Management Projects," Extension Service, U.S. Department of Agriculture, unpublished report (1974).

Good, J. M., "1973 Summaries," U.S. Department of Agriculture and Cooperative Extension Service Pilot Pest Management Projects, Extension Service, U.S. Dept. of Agriculture, unpublished report (1974).

Table A-3. U.S. ACREAGE AND FARM VALUE OF SELECTED CROPS, 1972

Crop	Acreage[a/] 1,000 acres	Acreage[a/] Rank	Farm value 1,000 dollars	Farm value Rank
Cotton	13,517	5	2,014,230[d/]	5
Corn[b/]	57,289	1	7,017,381	1
Soybeans[c/]	47,755	2	4,451,797	2
Wheat	47,301	3	2,575,089	3
Sorghum[b/]	13,546	4	1,041,326	7
Peanuts	1,486	7	477,524	9
Vegetables	3,210	6	2,023,498	4
Apples	N.A.	N.A.	371,455	10
Citrus	N.A.	N.A.	828,021	8
Tobacco	843	8	1,442,801	6

a/ Acreage harvested.
b/ For grain.
c/ For beans.
d/ Including lint and seed.

Source: U.S. Department of Agriculture, "Agricultural Statistics 1973," U.S. Government Printing Office, Washington, D.C. (1973).

Table A-4. RANKING SUMMARY BY CROPS

Crop	Table A	Table B	Table C	Table D	Table E	Table F	Total, averaged	Overall rank A-F	Overall rank A, B, and D only
Cotton	3	1	5	1	5	5	3.3	2	1.5
Corn	1	2	5	2	1	1	2.0	1	1.5
Soybeans	2	4	5	10	2	2	4.2	4	4
Wheat	4	10	5	10	3	3	5.8	5	9
Sorghum	5	10	5	5	4	7	6.0	6	6
Peanuts	7	10	4	6	7	9	7.2	10	7.5
Vegetables	6	3	1	3	6	4	3.8	3	3
Apples	10	5	3	4	N.A.	10	7.0	8	5
Citrus	10	7	2	8	N.A.	8	7.0	8	10
Tobacco	10	6	5	7	8	6	7.0	8	7.5

Source: Tables A1-A3.

The averaged totals were then again rated by "overall rank." In the last column in Table A-4, the results of ranking only three criteria, i.e., volume of herbicide use, volume of insecticide use, and number of IPM programs, are given. The rationale for this column is as follows:

* Fungicides represent only a small share of the total volume of pesticides used on U.S. crops. Therefore, their importance would be overrated if they would be weighted in this ranking system equally with herbicides and insecticides which are used in much larger volume.

* Total acreage and farm value of a given crop are of lesser importance to the objectives of this study than the other parameters.

Regardless of whether one considers the overall ranks from Tables A-1 to A-3 or from Table A-1, Columns 1 and 2, and Table A-2, the system suggests that the following crops should be considered as candidate study systems: corn, cotton, vegetable, soybeans, sorghum, and apples.

These tentative choices were discussed with the EPA project officer, Mr. Allan Zipkin, at a project meeting at Kansas City on 13 August 1974. Mr. Zipkin advised that EPA realizes the importance of cotton as a pesticide-consuming crop. However, a considerable number of studies have already been performed on cotton, and EPA would be more interested in gathering data on other crops. For these reasons, confirmed in a subsequent telephone conversation between Mr. Zipkin and Dr. von Rümker, cotton was eliminated from further consideration.

Soybeans rated somewhat higher than sorghum in the criterion scheme. Nevertheless, it was decided to give preference to sorghum as a study crop because a preliminary survey of available data indicates that some interesting studies on recommended versus needed rates of insecticides have recently been performed on this crop.

The criterion scheme further indicates that vegetables should receive consideration. However, the high ranking of vegetables in comparison to the other crops is somewhat misleading because, in contrast to all other crops in the ranking system, vegetables are not a single crop, but a group consisting of some 20 major and additional minor crops. To determine if a single vegetable crop might be a suitable study crop, the 1972 acreage and farm value of the 25 vegetable crops considered to be "commercial vegetables" by the U.S. Department of Agriculture were analyzed (Table A-5). In each part of the table, the first 10 crops were ranked in decreasing order of acreage and farm value, respectively, highest acreage and highest farm value equals one.

Table A-5. U.S. ACREAGE AND FARM VALUE OF COMMERCIAL VEGETABLE CROPS, 1972

	Acreage		Farm value	
Crop	1,000 acres	Rank	1,000 dollars	Rank
Artichokes	11.1		8,222	
Asparagus	119.1	8	67,921	
Beans, lima	74.6		18,837	
Beans, snap	341.9	4	107,484	5
Beets	12.7		3,741	
Broccoli	46.8		39,099	
Brussels sprouts	6.6		7,916	
Cabbage	105.6	9	79,978	10
Cantaloupes	97.6	10	94,772	8
Carrots	73.4		95,649	7
Cauliflower	28.2		30,346	
Celery	32.6		104,891	6
Corn, sweet	604.9	1	134,815	4
Cucumbers	178.0	7	90,769	9
Eggplant	3.1		4,568	
Escarole	9.9		9,167	
Garlic	5.1		7,206	
Honeydew melons	12.4		13,082	
Lettuce	219.1	6	277,320	2
Onions	93.3		139,919	3
Peas, green	377.7	3	57,500	
Peppers, green	47.7		58,096	
Spinach	37.8		16,532	
Tomatoes	403.6	2	492,440	1
Watermelons	267.5	5	63,228	
Totals	3,210.3		2,023,498	

Source: U.S. Department of Agriculture, "Agricultural Statistics 1973," U.S. Government Printing Office, Washington, D.C. (1973).

Considering acreage (probably more important regarding pesticide use volume than farm value of the crop), candidate vegetable crops and their usefulness for purposes of this study are as follows:

Sweet corn leads all other vegetable crops in acreage. However, since field corn in already included in the study, we question the desirability of studying sweet corn in addition.

Tomatoes are next. However, EPA has recently funded another study on tomatoes which will probably cover at least some of the parameters to be investigated in this project. We therefore recommend against tomatoes.

Peas, beans, next in line, as well as watermelons, cucumbers, asparagus and cantaloupes are relatively healthy crops which do not generally require high pesticide inputs. Recommend against their selection for this study.

Lettuce and cabbage appear to us to be the relatively most suitable candidate study crops. These crops would then have to be compared against apples, the next candidate crop in line from Table A-4. Among apples, lettuce, or cabbage, we feel compelled to give preference to apples, for the following reasons:

* Apples are an economically more important crop than either lettuce or cabbage in terms of farm value.

* More pesticides are used on apples than on either lettuce or cabbage. The lettuce acreage is 6.8%, the cabbage acreage 3.3% of the total acreage of all commercial vegetables. Assuming an average rate of use of pesticides on all vegetables, about 1 million pounds of insecticides would be used on lettuce and cabbage combined. Even if a relatively higher rate of insecticide use on these two crops is assumed, their combined insecticide use volume would still not approach that of apples, 5 million pounds (Table A-1, Column 2).

* Lettuce and cabbage, like corn and sorghum, are annual row crops. By contrast, apples are a perennial tree crop. Thus, including apples would add an additional dimension to the study, which would not be provided by lettuce or cabbage. Pesticide application methods and equipment for tree crops are different from those for field and row crops.

In summary, based on the criterion scheme and related considerations discussed above, and on our several communications on this matter with the EPA project officer, we propose to select the following three crops as "study systems" for this project:

* Corn;

* Sorghum; and

* Apples.

This selection is, of course, not meant to be absolutely exclusive. As project time and resources permit, we may well study and report on relevant problems pertaining to other crops, especially vegetable crops, in line with EPA's expressed interest in more information on food crops.