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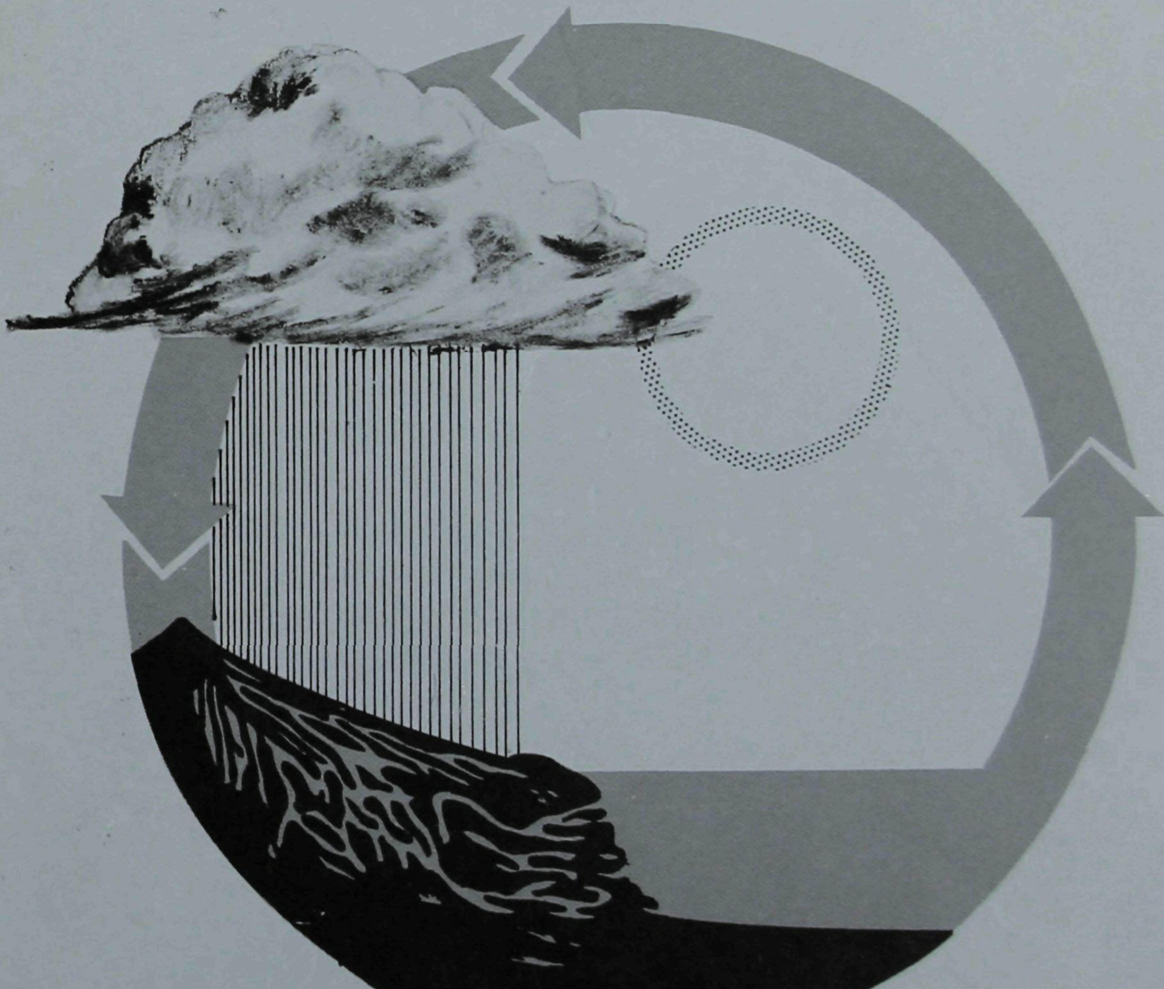

PESTICIDE USAGE AND ITS IMPACT ON THE AQUATIC ENVIRONMENT IN THE SOUTHEAST

PESTICIDE STUDY SERIES - 8

PESTICIDE USAGE AND ITS IMPACT ON THE AQUATIC ENVIRONMENT IN THE SOUTHEAST

This study is the result of Contract No. 68-01-0118 awarded by the OWPO, as part of the Pesticides Study (Section 5 (1) (2) P.L. 91-224) to Teledyne Brown Engineering.

For Teledyne Brown Engineering:
Dr. Robert A. Baker, Director, Environmental Sciences

The EPA Project Officer was:
Charles D. Reese, Agronomist

ENVIRONMENTAL PROTECTION AGENCY
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Non-Point Source Control Branch

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The Pesticide Study Series *

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* The Pesticide Study Series has been prepared by the Office of Water Programs Operations of the Environmental Protection Agency. To date, eleven studies have been prepared.

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ABSTRACT

PESTICIDE USAGE IN THE SOUTHEASTERN UNITED STATES AND ITS EFFECT ON THE AQUATIC ENVIRONMENT

The Southeast is a major agricultural region which accounts for a significant portion of the total national production of diverse and important crops. The pests which affect these crops are equally varied and require multiple control methods. Pesticides are currently the most important and extensively used controls. Unfortunately, they have not always been wisely employed. This has led to deleterious effects, with the aquatic environment often serving as the victim. Since undesirable effects on lower forms of life may ultimately be carried over to man, there has been an increasing awareness that judicious pesticide usage is essential. Improved practices, though eagerly sought, are not always readily evident because of gaps in knowledge.

A critical examination was made of pesticide usage and its effect on the aquatic environment in the Southeast. This report summarizes many aspects of existing technology, current regulatory statutes and alternatives. Literature citations are supplemented by reports of actual case studies. From these findings a number of conclusions are drawn and recommendations formulated. Implementation of the recommendations would have marked benefit beyond the Southeast.

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This critical review was conducted by an interdisciplinary team. Teledyne Brown Engineering (TBE) was the prime contractor. Alabama A & M University (A&M) examined the agricultural aspects under a subcontract.

Dr. Robert A. Baker served as project director. Other contributors from TBE and their assignments were: route into water, Dr. M. D. Luh, Robert Corbitt; impact and degradation, Dr. Donald Henley, Dr. Lee Morin, Nancy Schoper, James Breece; and legislative, Dr. Richard Shuford. S. K. Love provided liaison and report draft review.

Dr. Robert R. Bradford served as project coordinator for A & M. Other contributors and their assignments were: inventory of uses, Dr. Om Parkash Vadhwa; applications, Dr. Nirmal S. Dhillon; and, alternatives, Dr. Govind C. Sharma and Dr. Baldev S. Mangat.

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PESTICIDE USAGE IN THE SOUTHEASTERN UNITED STATES AND ITS EFFECT ON THE AQUATIC ENVIRONMENT

Volume I

PART I. INTRODUCTION

This critical review examines pesticide usage and its impact on the aquatic environment in the Southeast: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee. The study is one of a series authorized and required by Section 5 (1) (2) of Public Law 91-224. The southeastern United States is one of the oldest and major agricultural sections of the country. A variety of climatic gradations from temperate to subtropical exist. Diverse soil types are also characteristic of this region. These characteristics allow for production of diverse crops. Of the total national production of tobacco, citrus, peanuts, pecans, cotton and vegetables approximately 85%, 65%, 61%, 28%, and 12%, respectively, are produced in the Southeast.[1] In addition, peaches, corn and soybeans are important crops. These crops serve as hosts and are infested by a variety of pests and consequently require the use of multiple control methods for economic production. Pesticides are currently the most important control method and are used extensively. New hybrid varieties with high production characteristics, monoculturing of crops and minimum tillage practices have further increased the need for pesticides.[2] Eventually these pesticides may enter the aquatic environment. It is to assess the resulting effects, to indicate gaps in the existing knowledge, and to recommend corrective measures that this study is dedicated.

Perhaps the most important factor determining the eventual entry of pesticides into the aquatic environment is the application technique.[3-6] Efficient control depends upon the selection of the correct pesticide, application at the proper time and the use of equipment that can most efficiently place the toxicant in the microenvironment of the pest. Of the total pesticide applied, no more than 2% is effective.[3] The remainder is indicative of the inefficiency of existing application techniques.

Careful selection of existing application techniques would considerably reduce the amount of toxicant required for effective pest control; with a concommitant decrease in contamination of the ecosystem. Major benefits would accrue from improved pesticide delivery systems.

An understanding of the movement of pesticides from application to entry into the aquatic environment involves physical, chemical and biological considerations of the pesticide, the application process, and the air, soil and aquatic systems.[7-9] Overland drainage, irrigation return flows, atmospheric transport, intentional dumping and accidental spills are involved.[7,10-13]

Once pesticides enter the aquatic environment they may exert short-term or long-term detrimental effects. Biological organisms concentrate pesticides through direct and indirect mechanisms.[14,15] The mechanisms result in biomagnification with each successive step in the food chain. Short-term effects or acute toxicities are reflected environmentally as "kills". The toxic concentrations required to produce kills are, in certain instances, considerably less than laboratory established LC_{50} (median lethal concentration) values.[16] Long-term effects include subtle alterations in predator-prey relationships, decreased floral and faunal fecundity and specific physiological alterations which reduce the ability of organisms (target and non-target) to compete.[17-19] Synergistic effects occur in biological organisms when pesticides act in combination with other biological, physical or chemical factors.[20,21] Two or more contaminants or a single contaminant together with a naturally occurring material may react to give an effect far greater than the sum of their individual effects. This is an especially important consideration in Southeastern waters. These waters are rich in organic matter which tends to complex with normally insoluble chemical substances such as certain pesticides.[22] The complexed material is readily distributed within the aquatic environment.

This increases the opportunity for exposure to and concentration by aquatic life forms. Eventually this constitutes a health hazard to man via contaminated water and food.

The degradation of certain pesticides may lead to even more toxic reaction products.[25,26] Others may either degrade to harmless products or remain unaffected. The surface waters of the Southeast often contain chlorinated hydrocarbons and other pesticides[27] that are persistent and resist biological or chemical degradation. Degradation of other pesticides is affected by many factors. They may be in solution, associated with suspended matter, or entrained in sediment. Each of these aquatic compartments is characterized by a unique combination of biological and chemical interrelationships which may modify the degradation process. Most available information on pesticide degradation mechanisms and rates has been obtained, chiefly, through laboratory study. Extrapolation of such results to field conditions is not valid because of the complicating effect of environmental and other factors.

Public concern for the environment challenges the efficiency and effectiveness of our form of legal and administrative framework. Among the concerns is adequacy and effectiveness of existing state statutes regulating the sale and use of pesticides. The provisions of the Federal Insecticide, Fungicide and Rodenticide Act,[28] (FIFRA) as amended and the Miller Amendment to the Federal Food, Drug and Cosmetic Act,[29] as amended, provide the foundation for a comparative analysis of the pesticide laws and regulations of the Southeastern states: Alabama,[30] Florida,[31] Georgia,[32] Kentucky,[33] Mississippi,[34] North Carolina,[35] South Carolina,[36] and Tennessee.[37] State laws regulating pesticides fall into three classifications. These are statutes:

- requiring economic poisons to be registered,
- governing pesticide application and use controls, and
- providing for the detection of pesticide residues on crops.

Four factors serve as indicators of effectiveness. These are:

- adequacy of statutory authority to control areas of potential abuse of public health and the environment,
- relative economic burden imposed on the private sector by the statutes to achieve compliance,
- relative ease of public administration, and
- the ecological sensitivity of present statutes.

Many methods of pest control have been advanced as knowledge of biology, ecology and agriculture increases. Within the last three decades, overemphasis on the use of pesticides has caused unintentional side effects and provided only a temporary solution to the pest control problem. In many cases pest control, with minimum damage to the environment, can be achieved by alternative procedures. These could utilize proper agricultural management, physical, genetic, biological and nonhazardous chemical methods. Eradication of the screwworm from the Southeast[38] by male sterilization techniques is an example of a successful alternative.

Parts II and III summarize the conclusions and specify recommendations derived from the critical review, respectively. The detailed findings, analyses and other supporting information are contained in Part IV. This is divided into seven study areas:

- Pesticide Usage
- Application Techniques
- Route into Aquatic Environment
- Impact of Pesticides on the Aquatic Environment
- Degradation of Pesticides
- Regulations and Laws
- Alternatives

A comprehensive bibliography is appended to each of the study areas.

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PART II. SUMMARY AND CONCLUSIONS

Most pesticides used in the southeastern United States are directed towards the following major pests:

- Insects: Cotton boll weevil, cotton bollworm, tobacco budworm, tobacco hornworm, scale insects of citrus, cabbage hopper, pink bollworm, codling moth and mealy bugs.
- Weeds: Broad leaf weeds, rag weed, Johnson grass, pigweed, crab grass, barn-yard grass, green and yellow foxtail, water hyacinth and goose weed.
- Disease: Citrus melanose, citrus and apple scab, leaf spot disease of peanuts, wild fire of tobacco and cotton, anthracnose of tobacco and cotton, root rots of corn, fire blight of apple, downy mildew of beans, and leaf spot of apples, beans and cotton.

An accurate inventory of pesticides usage is presently not obtainable because distributors, sellers or users of pesticides are not required to report specific information to any responsible agency regarding pesticides sold or applied. The most recent information available from U. S. Department of Agriculture concerning quantities of pesticides used by farmers on a regional level is five years old (1966). Certain information is available for pesticide usage in a few states (e. g. Kentucky and Tennessee) where special surveys were conducted. These surveys represent only a one year compilation. Recommended application rates for the different pesticides are available for all states.

In the Southeastern states, the most widely used insecticides are Toxaphene, Aldrin, Chlordane and DDT. Use of Parathion and Malathion is increasing. The most commonly used are Treflan, Dalapon, 2, 4-D, Atrazine. Sulfur compounds, copper sulfate, Thriam, Maneb, and Zineb constitute the major fungicides used. Insecticide applications to cotton exceed the combined total for all other major crops. A similar situation exists for fungicides applied to citrus.

Practically all Southeastern soils used for agricultural purposes are subject to moderate or severe runoff and erosion. Soils in most of Florida are an exception because lack of adequate drainage is a severe problem.

Presently, 63 percent of all pesticides are applied by aircraft. The remainder is applied with ground equipment. Most pesticides are applied as sprays, either to the plant foliage or to the soil surface. Some pesticides are incorporated in the soil. To minimize contamination of the ecosystem by pesticides, improvement in spray application and soil incorporation equipment is required.

Pesticide usage could be significantly reduced and still provide an effective pest control program if the pesticides are uniformly distributed and the major portion reached its intended target. The initial problem is to atomize relatively non-volatile pesticide formulations into uniformly sized droplets which are sufficiently numerous that the pest cannot avoid contacting a lethal dose. The second problem involves deposition of small particles or droplets on the target. One of the methods that could improve deposition of pesticides is electrostatics. The third problem involves incorporation or injection of some soil-applied pesticides. These processes involve optimum depth considerations. All of these problems merit intensive research and development.

The efficiency of a spray application is related to optimum droplet size, uniformity in spray coverage produced, and degree to which drift and runoff is minimized. Ninety percent or more of spray droplets produced by existing aerial and ground equipment are not of the optimum size. This portion of the spray constitutes the major source of pesticidal pollution.

After two decades of intensive use, pesticides are found throughout the world. They are present in the aquatic environment and in the atmosphere, even in places far from any spraying sites. The persistent nature of certain pesticides permits them to be carried from the air and soil into the aquatic environment. There they can move from one organism to another via the food web or be cycled in the aquatic environment.

Physical and chemical properties of pesticides govern their movement from one system to another. Sorption and desorption are the processes which limit the rate of movement of pesticides from the soil into the aquatic environment. Specific sorption and desorption mechanisms for each pesticide under environmental conditions are not known. These mechanisms are influenced by the clay and organic content, temperature, degree of cation saturation within the soil, and by climatic conditions. These factors also influence pesticide sorption-desorption at the benthic level of the aquatic environment.

Pesticide movement into the soil environment is influenced by sorption, thermal and biomass characteristics, and general chemical composition. Knowledge of the chemical and physical nature of pesticides, facilitates a prediction of their fate. Common fates in the soil environment are sorption and desorption, photo-and oxidative decomposition, hydrolytic and biochemical degradation, leaching, and phyto-assimilation. Organic matter favors sorption of both non-ionic and ionic pesticides. The soils of the Southeast are characterized by high clay content and primarily sorb ionic pesticides. Many of the pesticides applied to the soil are strongly sorbed and do not percolate through the soil. Pesticides normally are confined to the top few inches of the soil.

Pesticides in the soil are generally in contact with water. The quantity of water may significantly alter their reactions. For example, phytoactivity is greatly enhanced in moist soil. Solubilities, partitioning (soil, water, and air), and interaction of these properties alter the reactions of individual pesticides.

The sorption process and its binding power must be examined relative to leaching. Leaching of pesticides deserves greater attention because this is the process of most rapid movement from the soil into the aquatic environment.

The direct movement of pesticides from the soil surface to a waterway requires consideration of climatic conditions before, during, and after application. Principal consideration should be given to volatilization losses, movements into the soil, persistence at the site of application, and movement of the remaining fraction to uncontaminated areas.

Pesticides move into the aquatic environment from the land even though universally present in the air. Movement from land may take several forms but overland drainage is the most significant. Good conservation practices reduce overland drainage. The occurrence of pesticides in waterways is primarily attributed to their sorption by runoff particles. Deposition and subsequent desorption of the sorbed particles will provide a continuous source of pesticide to the aquatic environment.

Considerations should be given to rainfall as a climatic factor influencing pesticide movement into water. Pesticides movement into and over the soil is of a uniform nature during periods of low rainfall intensity. This also occurs during overhead and flood irrigation practices. High rainfall intensity and furrow irrigation, however, produce disproportionate pesticide movements. This movement can result in waterway contamination.

Pesticides enter the soil environment through mechanical incorporation or infiltration processes. Incorporation (or induced turnover) is favored since it reduces atmospheric and runoff contamination. However, plant uptake and persistence of pesticides are increased.

Information on pesticide decontamination is needed. Sorption by activated carbon is the only method presently available for removing pesticides from water. However, suitable methods for disposal of the sorbed materials has not been developed. Thermal, photochemical and biological degradation are considered as possible decontamination methods in instances where concentrated pesticides occur. Photochemical, biological and sorption processes offer potential for removal of low-level concentrations in waterways.

Current agricultural application practices result in contamination of the aquatic environment through atmospheric processes. Those processes which contribute to contamination include volatilized fallout and washout, drift from dusting and spraying operations, and wind-blown, pesticide-treated soils. Other aerial or atmospheric routes include incineration of pesticide-contaminated materials and direct application of pesticides into the aquatic environment.

Case studies have documented that runoff, accidental spills, and intentional pesticide dumping are prevalent means of entry into the aquatic environment. Non-selective toxicity and subtle long-term effects can create ecological imbalances. Therefore, there is an urgent need to use existing and safer pesticide alternatives, to better educate pesticide users regarding potential hazards, and to limit usage of persistent pesticides.

Aquatic vegetation can sorb large quantities of pesticides. These sorbed substances can be metabolically degraded or stored. The stored compounds may either become part of a food web or be returned to the sediment. Information is not available on sorption capacities and degradation of pesticides by aquatic vegetation of the Southeast. Fish and filter-feeding sedentary invertebrates sorb pesticides directly from the water. Residue levels closely correlate with surface water concentrations, which relate to seasonal agricultural practices and rainfall.

Pesticides such as DDT, Dieldrin, Endrin, Toxaphene, Mirex and BHC are bioconcentrated. Food chain studies have been primarily focused on DDT without regard for other stable chlorinated hydrocarbons. Herbicides, in general, are less toxic to fauna than other pesticidal categories.

This is attributed to the fact that these compounds degrade rapidly and do not bioconcentrate. The effects of herbicides on nontarget aquatic plant communities have not been specifically identified. However, it is known that the reduction of consumer populations is accompanied by a shift in plant species to hardier algae that are not consumed by grazers.

Considerable emphasis has been placed on testing fish for acute toxicity. Acute toxicity levels have been established for several individual species under laboratory conditions. These values serve only as quantitative indices of toxicity under specific conditions and do not reflect accurate responses under varying natural environmental conditions. There is a need for toxicological information on lower life forms obtained under dynamic test conditions. In such studies, continuous flow of natural waters under environmental conditions at the site, should be emphasized. Resulting information would be of greater value in assessing the effect of contaminants such as pesticides than that obtained under static, monospecific test conditions. More emphasis should be placed on the chronic effects of pesticides. Toxicological information must be developed for the lower and intermediate aquatic organisms as well as for fish. Population changes in lower food chain organisms will ultimately be reflected in the long-term stability of higher consumers, e.g., fish.

Quantitative data on residue transfers in fresh water and marine food webs are not available. There is a lack of information on the complex species interrelationships within the food web. Some forms establish an intake, storage and elimination equilibrium.

The presence of PCB compounds in Southeastern water, its biota and its sediment is widespread. These compounds are stable, bioconcentrate in tissues and interfere with calcium deposition in birds. This effect has been demonstrated with DDT.

Pesticide synergisms with such factors as temperature, water hardness, and stage of biological development have been established in species native to the Southeast. Synergisms, resulting from multiple pesticide residues, have not been investigated although many pesticides are applied in combination to ensure control of target species.

Chlorinated hydrocarbon residues at microgram per liter concentration are not completely removed by standard water treatment practices. The adverse effects of long-term, low-level, pesticide exposure in humans is not known. Monitored pesticide residues in fish, shellfish, and ducks are not directly useful in assessing quantities of pesticides reaching humans via these foods. Analyses are typically on a whole-product basis and not the edible portions only.

The most frequently occurring pesticides in Southeastern waters are chlorinated hydrocarbons whose persistence may be in the order of years. In general, organophosphates, carbamates, and herbicidal compounds disappear from the water within a matter of a few weeks or months. Available data on degradation rates, mechanisms, and products are very limited. Information is based on laboratory studies which cannot be extrapolated to natural environmental conditions. For example, halogenated herbicides are readily degraded through photo-induced mechanisms. How these mechanisms relate to degradation of herbicides in the natural environment has not been established.

The sorption of pesticides by suspended material and substrates in natural waters is an important factor in the degradation process. It may facilitate chemical reactions and translocation of pesticides to the estuary or to areas favorable for degradation.

Information on the occurrence and distribution of pesticides reveals that, while no concentrations may be detected in the water, concentrations in the micrograms per kilogram range are found in the sediments of small ponds and estuaries. The transport of pesticides in the aqueous medium, including that which is associated with particulate matter and sediments, has not been defined. Pesticides concentrations which reach bottom sediments may be cycled into the overlying water. Cycling can result from fall and spring overturns following thermal de-stratification or from the release or desorption of pesticides from the sediments.

The chemical degradation products of certain chlorinated hydrocarbons and carbamates are many times more toxic than the parent compounds. Such toxicities are vital considerations of impact on non-target organisms.

The provisions of registration statutes of the Southeastern states are quite similar to the statutory provisions of the original Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). All states have not kept pace in modifying their statutes to comply with changes in the FIFRA in terms of coverage of categories of pesticides. The states took an excessive amount of time to enact comparable legislation to the FIFRA to regulate intrastate commerce of pesticides. Amendments have required several years before enactment.

There are significant differences in scope of coverage in some state pesticide laws compared to the coverage of the amended FIFRA. There are also considerable differences in the enforcement authorities granted to the state administering agencies. The penalties enacted for violations are weak and are not deterrents to violations. On the other hand, the volume of litigation does not indicate that a strong penalty deterrent is required.

Two major loopholes exist in the present registration statutes. First, the exemption of officials of state and federal agencies from registering products used in their official activities provides an opportunity for the aquatic environment to be subject to pesticide contamination. This occurs without any possibility of assessing the type and volume of chemicals entering the waters. Second, the registration statutes do not provide coverage of an important consumer protection need. This relates to the packaging aspect of pesticide containers to provide for child safety.

Some of the Southeastern states are ahead of the federal government in the enactment of pesticide application and use controls. Until recently these controls have been limited to regulation of aerial applicators in only four of the eight states. There is no federal statute governing aerial applicators despite the fact that the aircraft are regulated by the Federal Aviation Administration.

Two information systems used, or which should be used, for decisions affecting the federal pesticide program are either woefully inadequate or warrant some improvement. Only a small number of the incidences of pesticide poisonings which occur are being reported (allegedly 10-15 percent) to the National Clearinghouse for Poison Control Centers. This level of reporting is inadequate to base federal or state policy decisions. The South Carolina community pesticide surveys for two separate years would indicate that the 10-15 percent figure for the nation is a reliable estimate of the situation in the Southeastern states.

One aspect of the National Transportation Safety Board's reporting system on aerial application accidents needs improvement. This relates to the toxicological effects on pilots.

The Southeastern states registration statutes are slightly less adequate than the FIFRA. There are some states with application and use controls offering limited protection of the aquatic environment. The pesticide laws and common law principles applicable to the use of pesticides do a reasonably adequate job of protecting persons and property from injury. There is a need for improvement in the administration of present controls. Present state registration laws are inadequate with respect to protection of the environment. On the whole, environmental protection is just now being written into the statutory language of the Southeastern states in the form of application and use laws.

Cultural methods of control (sanitation, tillage, dates of planting etc.) along with the use of resistant crop varieties is the farmers first line of defense against pests. These practices considerably reduce but do not eliminate the need for other pest control methods. For certain pests, such as many plant viruses and nematodes, chemical treatment is neither feasable nor economical. In such cases, physical, mechanical, and regulatory (quarantine and certification) methods are utilized to reduce or prevent pest populations.

Many major economic pests in the United States have been introduced from other countries without their natural parasites and predators. In some cases importation and release of natural enemies have proven to be effective in suppressing the pests. Broad-spectrum pesticide applications have the adverse effect of destroying the natural enemies of insects. This eliminates a natural check on pest populations in agricultural ecosystems.

Efforts toward the development of biological control agents (virus, bacteria, protozoa, fungi, nematode attacking insects) may result in safer and specific pest control practices. Similarly numerous insect hormones (e.g. juvenile and ecdysone) have the potential of being utilized as selective insecticides.

Many insect attractants have been characterized and developed to lure insects into traps containing pesticides, pathogens and chemosterilants. Chemical and electromagnetic radiation (light traps) attractants also provide for early detection and location of insect infestation. This is an important component in integrated and pest surveillance programs.

Eradication of selected insect species has been achieved by releasing sterile males to compete with the fertile ones in the natural environment. This method of pest eradication is successful only if the natural insect population is low. In such cases, the sterile males "overwhelm" the fertile males. Expanded use of this technique has been restricted by high cost and logistic factors. Sterilization of the natural pest population by chemosterilants could reduce such time and cost factors.

Integrated control is a pest population management system that employs several suitable techniques to reduce pest populations and maintain them at levels below those causing economic injury. Integration provides the best solution to a pest problem because all possible controls are first evaluated. This approach requires ecological information, pest threshold, and economic injury levels.

To date, public and private efforts in pest control have been directed toward development of pesticides with little effort being directed to alternatives. There is little inducement for industry to develop alternative methods until large-scale pilot studies have been proven successful. Pesticides will continue to be used in the foreseeable future. Alternative methods, if further developed and applied, can reduce excessive dependence on broad-spectrum pesticides.

The aquatic environment in the Southeast is being subjected to unnecessary pesticidal pollution. In many instances, there are deficiencies in fundamental information which preclude creation of adequate preventive and corrective measures. Programs and practices need to be implemented which maximize the benefits of pesticide use while minimizing its impact on the aquatic environment.

PART III. RECOMMENDATIONS

The recommendations derived are the consequence of a critical review of the information available on pesticide use and environmental pollution in the Southeast. The scope of these recommendations frequently transcends regional boundaries.

The national data collection systems supporting the federal pesticide program should be improved. The federal government should encourage legislation at the state and federal levels to make mandatory reporting by physicians of treatment of pesticide poisonings. The U. S. Public Health Service should promote effective diagnosis and reporting of pesticide poisonings among its physicians and physicians at large. The National Transportation Safety Board should cause improved reporting of the toxicological effects on pilots by requiring investigation and re-submission of future reports where this data category is improperly completed. The Department of Commerce should expand its annual reporting requirements. Information should be collected from manufacturers and distributors on the quantity of pesticides shipped as final sales to retailers or direct to consumers by county.

The Environmental Protection Agency should expand in-house and supported monitoring activities to identify pesticides and their metabolites in the aquatic environment (surface and ground fresh waters and estuarine). This activity should be complemented by an expanded program of development of improved pesticide concentration and analytical procedures. The elimination of the masking effect of polychlorinated biphenyls in analyses of pesticides is a specific analytical need. A coordinated surveillance system must be established to provide in-depth pesticide information on reservoirs, lakes, rivers, and estuaries. The results must relate the movement of pesticides to hydrological conditions. Quantification of the amounts and types of pesticides being transported to the estuaries relative to climatic and seasonal factors is needed. Rates of interchange between biological organisms and sediment, must be established.

The U. S. Department of Agriculture through its Extension Service, should:

- encourage growers and custom operators to use the most advanced pesticide application equipment under favorable meteorological conditions;
- encourage growers to use cultural and management practices which minimize sediment loss;
- expand its educational efforts on proper selection and judicious use of pesticides;
- increase its crop and pest surveillance services;
- discourage use of pesticides where furrow irrigation is practiced; and
- encourage incorporation of pesticides into the soil to minimize the effects of overland drainage and atmospheric contamination of the aquatic environment.

In a related activity, the Soil Conservation Service should expand its soil erosion control program to emphasize retention of pesticide-treated soils that now enter the aquatic systems.

Government and industry should engage in the development of improved pesticide formulations and equipment capable of delivering the minimum quantity of toxicant needed to control the pest. An integral need is the design and manufacture of equipment capable of generating droplets or particulates of narrow size range. Improved methods of pesticide impingement using electrostatics and other techniques should be evaluated.

The Environmental Protection Agency should:

- develop water quality standards for pesticides based upon residue tolerances of sensitive and essential members of the food web,

- develop water quality standards which establish strict limits on pesticide concentrations in effluents from point sources, industrial and municipal outfalls. State water quality control agencies should be responsible for enforcement of the standards, and

- promote development of standard methods and procedures for use in decontamination of highly concentrated pesticide spillage. Practical and efficient decontamination procedures for low level pesticide concentrations, regardless of source, should also be expanded.

The activities of the Working Group on Pesticides, an intergovernmental agency organization, should be continued. This liaison minimizes the possibility of duplication of inhouse and sponsored studies. It provides a potentially valuable forum for input to development of improved analytical techniques and water quality standards.

A set of national priorities must be established by the U. S. Department of Agriculture for developing alternative methods of pest control beginning with those situations which utilize the largest quantities of broad spectrum, persistent pesticides. The Environmental Protection Agency should reexamine the registration of pesticides which persist in the environment more than one year, are very insoluble in water, and are very soluble in animal fat. Focus of the examination should be with the view of cancelling registration if safe, effective alternative methods are available.

There are gaps in the knowledge of the effect of pesticides that can only be filled after appropriate research. Long-term (chronic) epidimeological information should be developed for the effect on life forms ranging from microflora and microfauna to man. Programs of the National Institutes of Health should be oriented to fill this need. The Environmental Protection Agency should:

- increase inhouse and supported research to develop information regarding specific pesticide degradation rates, mechanisms, products and toxicities in fresh, brackish and salt water; and

- expand inhouse and supported toxicological measurements of the effect of pesticides on aquatic flora and fauna. Emphasis must be given to dynamic rather than static test procedures. Under these conditions the simultaneous effect of multiple contaminants and environmental factors can be determined.

The Environmental Protection Agency and the U. S. Department of Agriculture should jointly support programs to develop information regarding the effect of pesticide sorption of particulate and organic matter on the subsequent chemical and biological degradation mechanism. Details are especially lacking on such processes involving soils and aquatic bottom sediments of the Southeast.

Additional gaps in the knowledge of pesticides and their effects will be filled only after field investigations produce relative, useful information.

- Field testing to improve soil incorporation techniques for pesticides and the injection equipment should be accelerated by government and industry.
- The Environmental Protection Agency Solid Waste Management Office should develop safe disposal techniques for waste pesticides, and pesticide containers, when landfill and recycling methods are employed. These techniques should provide for chemical and/or biological decontamination of these wastes.
- The Environmental Protection Agency Air Pollution Control Office should establish standards for incineration of pesticides, and their containers, designed to limit atmospheric contamination and the resultant damage to the aquatic environment. This office should also determine the contribution of pesticides to the aquatic and soil environment by atmospheric fallout and washout.
- The Agricultural Research Service of U. S. Department of Agriculture should receive greater support for large-scale field testing to determine the effectiveness of promising alternative methods of pest control. Successful programs can then be adopted regionally to eradicate, reduce or maintain pest populations below economic injury thresholds. Pest control at the farmer level should be reoriented to facilitate management programs for the entire infestated region.

- The Environmental Protection Agency and the U. S. Department of Agriculture should jointly ascertain the long-range effects of low-level concentrations of pesticides added to the aquatic environment by irrigation practices.

Certain regulatory and legislative recommendations are derived from the study.

- The Southeastern states must reduce the time required to formulate pesticide legislation, enact legislation and implement pesticide programs as technical advances elucidate the complex interaction between man and the other factors affecting the environment.
- Annual registration of pesticide products as practiced by the states should be adopted for federal registration.
- The registration procedures on pesticides should include an assessment of packaging adequacy from the viewpoint of child safety.
- An Executive Order should be issued by the President which would cause all federal agencies introducing pesticide substances into public waters and onto public lands to file with state water pollution agencies the chemicals used, the amount, the time of use and the purpose.
- The federal government should encourage state water pollution control agencies to issue regulations requiring all state government agencies using pesticides in state waters and on public lands to file similar statements.
- The focus of the federal pesticide program should be shifted to provide incentives for the states to enact and enforce a high quality state pesticide program. Federal standards on registration, inspection, and enforcement should be established. States should be provided with federal grant assistance to operate and administer their pesticide programs which satisfy the federal standards.
- The Federal Insecticide, Fungicide and Rodenticide Act should be amended to provide for a joint, comprehensive, federal-state pesticide program and to grant federal officials authority to issue "stop-sale" and "stop-use" orders.
- The investigative function performed by the Accident Investigation Section in the Pesticides Office of the Environmental Protection Agency should be expanded.

PESTICIDE USAGE IN THE SOUTHEASTERN UNITED STATES AND ITS EFFECT ON THE AQUATIC ENVIRONMENT

Volume II

A. PESTICIDE USAGE

1. Introduction

The southeastern United States has traditionally grown crops, such as cotton, tobacco, citrus, peaches and peanuts, which require application of large quantities of pesticides for profitable production. In the past, the Southeast has accounted for the largest share of organochlorines used in the United States.[1] Control of pests in cotton, alone consumes 70% of the total DDT used nationally.[2] The use of pesticides is an almost inevitable consequence of the development of modern intensive agriculture. High production characteristics of new hybrid varieties, monoculturing of crops and minimum tillage practices have increased the need for pesticides.[3]

The national rate of increase in total pesticide usage has averaged more than 7% a year. For herbicides the increase is substantially higher and their usage has more than doubled over a 4 year period (1962-66).[3] The sales of pesticides in the USA for the 8 year period, 1962-1969, are shown in Table A-1.

Table A-1. Pesticide Usage in the U.S.A.[3]

Year	Sales in millions of pounds			
	Fungicides	Herbicides	Insecticides	Total
1962	97	95	442	634
1963	93	123	435	651
1964	95	152	445	692
1965	106	184	473	762
1966	118	221	502	841
1967	120	288	489	897
1968	124	318	498	940
1969	127	348	502	983

Source: Metcalf, R. L.

Information on principal usage, types and volumes of pesticides is important in this era of national concern for the environment. This is particularly vital with respect to the persistent pesticides, to determine the extent and trends of environmental pollution.

2. Major Crops and Soils of the Southeast

A variety of climatic gradations from temperate to subtropical and diverse soil types makes the southeastern United States suitable for profitable production of many crops.

a. Crops

The most commonly grown crops are tobacco, cotton, peanuts, soybeans, corn, pecans, peaches, citrus fruit and vegetables. Of the total national production of tobacco, citrus, peanuts, pecans, cotton and vegetables in 1969 approximately 85%, 68%, 65%, 61%, 28% and 12%, respectively, were produced in the Southeast.[4] (Table A-2).

North Carolina and Kentucky lead in production of tobacco; Florida in citrus production; Alabama and Georgia in production of peanuts; and Georgia, Alabama and Mississippi in production of pecans.

For many years, the southeastern United States was the leading producer of cotton, however, the region presently accounts for only 28% of the total U. S. production (Table A-2).

b. Soils

The soils of the southeastern United States are generally acid in reaction and low in organic matter, and fall either entirely or partially into 13 physiographic regions.[5] These are as follows:

Table A-2: Production of Various Crops in the Southeastern States, 1969[4]

State	Tobacco 1000 lbs.	Cotton 1000 bales	Peanuts 1000 lbs.	Soybeans 1000 bu.	Rice 1000 cwt	Corn 1000 bu.	Pecans 1000 lbs.	Apples mil. lbs.	Peaches mil. lbs.	Citrus * 1000 boxes	Vegetables tons
	Crops										
Alabama	800	461	285,175	14,743		17,332	36,000		50.0		109,830
Florida	26,028	9.4	85,065	4,563		13,962	4,600			180,000	1,687,680
Georgia	97,890	282	946,270	11,208		47,058	83,000		175.2		200,380
Kentucky	436,802	5.8		13,580		76,846		20.9	16.5		15,480
Mississippi		1,328	1,200	50,380	2,520	9,858	14,000		17.5		63,580
North Carolina	715,968	100	337,840	24,258		89,828	3,000	204.0	56.0		242,120
South Carolina	136,658	205	20,150	21,578		18,894	3,500	8.0	338.0		166,730
Tennessee	120,796	422		28,632		27,830		10.4	9.4		52,990
Total for the Southeast	1,534,942	2,813.2	1,675,700	168,942	2,520	301,608	144,100	243.3	662.6	180,000	2,538,790
U. S. Total	1,806,656	10,015	2,523,399	1,116,876	91,303	4,577,864	235,600	6,721.8	3,665.4	265,070	20,441,230
% of U. S. Total in the Southeast	85	28.1	66.4	15.1	2.7	6.6	61.2	3.6	18.1	67.9	12.4

* Production of Crop for the growing season of 1968-69

Source: Agricultural Statistics - USDA (modified)

- The Coastal Plain soils - extend from South-Central Texas to North Central North Carolina. Cotton production is centered in this area and much of it is rolling or hilly. Control of excessive soil loss by water erosion is a major management problem.

- The Southern Appalachia Plateau - comprises a series of relatively flat-topped ridges in Northeastern Alabama and Northwestern Georgia. The soils are developed from sandstones and shales. Soils developed from shale tend to be finer and shallower and present a problem of water infiltration and erosion.

- The Southern Piedmont - extends from North Carolina Southwest through South Carolina and Georgia into Alabama. Most of the Piedmont is hilly. Because of the steep slopes and the erosive nature of the soils, erosion has been severe. The surface soil has been removed in many places and subsoils are now frequently farmed.

- The Limestone Valleys - contain soils of limestone origin and are mainly found in the Tennessee and Coosa River Valleys in Alabama. Small areas are found in Northwestern Georgia. The topography is level to undulating.

- The Brown Loam Area - forms a belt east of the Mississippi River flood plain which extends from Northwestern Tennessee South across the Mississsippi to the lowlands of the Gulf Coast. The topography ranges from level to hilly. Row cropping has resulted in extensive erosion over the entire area.

- The Black Prairie Area or Black Belt - extends from the eastern part of Alabama to the northeastern corner of Mississippi. The land is gently rolling and the soils are poorly drained.

- The Piedmont Subregion - includes all of North Carolina except the nothern one-third. The land is gently rolling and rough. Soils erode easily and the fine-textured subsoil, which is very difficult to cultivate, is exposed. Practices such as contour farming and terracing should be extensively used because of the relatively high erodibility of the many sandy soils in this area.

- The Blue Ridge Subregion - lies mostly in Western North Carolina, but it also includes parts of, Tennessee, Georgia and South Carolina. Sheet erosion is a severe problem.

- The Appalachian Valley Subregion - extends eastward across Tennessee and several adjoining states. Surface erosion on many slopes is severe.

- The Allegheny-Cumberland Highlands - include the Cumberland Plateau of Tennessee and the eastern mountainous region of Kentucky. The soils are relatively shallow and moderate erosion in cultivated fields is a serious problem.

- The Bluegrass Subregion - consists of two separate sections one in Kentucky and the other in Tennessee. Soil erosion is not a problem in this area.

- The Florida Peninsula adjacent Flatwoods - include parts of South Carolina and Georgia and almost all of Florida. Runoff and erosion are of minor importance in this region. Natural drainage of the soils varies from excessive to very poor.

- The Mississippi Delta Region - is an alluvial plain of the Mississippi Valley. At least 30 states have contributed, through erosion, to the soils of this valley. Soil types reflect the action of floodwater and soils vary from clay to sand and have poor to excessive internal drainage. Most of the land is gently rolling and erosion is a problem.

The soil types of the United States have also been classified according to 7th Approximation which is a new system.[6] Most of the soils of the Southeastern states, except those in Florida and Kentucky, belong to the order ultisols and suborder udults.

3. Historical Development of Pesticide Usage

Historical development of pesticide usage in southeastern United States closely parallels the development for the entire country.

Plant protection by the use of chemical sprays or dusts or seed treatment did not originate in the 20th century but has been practiced on a small scale for a long time. However, large scale farming practices of the twentieth century have hastened the evolution of pesticides.

The first insecticidal materials used for insect control included the arsenicals, lime-sulphur, petroleum oils and nicotine. During the intervals between World Wars I and II , flourine compounds, Pyrethrum, Rotenone, synthetic organic materials, (e.g. dinitro compounds) and thiocyanates came into use. Discovery of insecticidal activity of DDT in 1942 led to concerted efforts by chemists and entomologists to find other potentially effective insecticides. These efforts led to discovery of such compounds as Benzene hexachloride, Toxaphene, Chlordane, Aldrin, Dieldrin and several organic phosphates.[7]

The history of weed control in crops began with the use of salt, ashes, and smelter wastes. From 1887-1900, copper salt was used to selectively kill broad leaf weeds in cereals. In the year 1900, calcium cyanide was added to the list of selective herbicides. Ferrous sulfate, copper salt and sodium arsenate were used before World War II. Auxin activity and selectivity of 2, 4-D were discovered in 1942 and 1944, followed by 2,4,5-T in 1948 and phthalamic acid in 1952. Many other herbicides belonging to the groups such as substituted ureas, carbamates, triazines and substituted phenols have been developed and are presently being used.[8]

The history of fungicides use can be divided into three distinct eras. These are the Sulfur Era (from ancient times to 1882) the Copper Era (1882 to 1934) and the Organic Fungicide Era (began in 1934). During the 19th century, however, two classes of inorganic fungicides, first sulfur, either alone or as lime sulfur, and then copper, principally a mixture of copper sulfate and lime in water called Bordeaux mixture, were being applied to foliage to protect plants from disease fungi. These developments continued and by the 1930's many of the important foliar diseases were being controlled by spraying or dusting with some form of either copper or sulfur. In spite of the subsequent development of organic fungicides, sulfur and copper fungicides are still being used. However, the quantities of each being applied are decreasing.[9]

Concurrently with the early development of foliage fungicides development of chemicals for the control of seed-borne bunt or smut fungi of cereals occurred. The use of copper sulfate soaks was for a time popular, followed by the introduction of formaldehyde and copper carbonate. In the early part of this century the development of organic mercury compounds for seed treatment was initiated, the first being a chlorophenol mercury. The nonmercury organic fungicides began in 1934 with the issuance of a patent covering a variety of derivatives of dithiocarbamic acid. Development was slow but in the early 1940's Thiram was introduced as a seed treatment. Thiram is also effective on foliage but other dithiocarbamates such as Ferbam, Ziram, Zineb, and Maneb were more fully developed as foliage protectants. The latter two compounds are in particular being widely used for control of a great variety of foliar diseases. They are effective and safe at economic rates of application and have contributed greatly to the production of quality vegetables and other crops.[9]

4. Major Pests and Their Control

There are several dozen destructive pests of crops in the southeastern United States that cause heavy losses virtually every year and are responsible for the use of most of the pesticides. These major pests and the pesticides recommended and widely used are presented in Tables A-3, A-4, A-5. This information was compiled from the State Agricultural Extension Service Bulletins.

TABLE A-3 Economic Weeds of Major Southeastern Crops and Herbicides Recommended for Their Control.

CROPS	WEEDS	HERBICIDES RECOMMENDED
Tobacco	Annual grasses, broad leaf weeds, white clover	Pebulate, Benefin Mylone, Vampam, Tillam, Enide
Citrus	Broad leaf weeds and grasses	Bromacil, Fenuron, methyl bromide, 2-4-D, Dalapon
Peanuts	Broad leaf weeds, grasses Texas millet, nut grass	Vernolate, Benefin Naptalam, DCP, Nitralin, Lasso, Dynanap,Balan
Cotton	Annual grasses, broad leaf weeds, crabgrass green and yellow foxtails, gooseweed	Trifluralin, EPTC, Nitralin, DEPA, MSMA, CIPC, Planavin, Cotoran, Diuron
Peaches	Annual grasses and broad leaf weeds	Simazine, Dalapon, Dichlo-benil
Vegetables	Annual grasses, broad leaf weeds, crab grass, johnson grass	Vapam, Bromacil, Trifluralin, Linuron, Benefin, Diphenamid, Randox, Vegedex EPTC, DCPA
Soybeans	Annual grasses, borad leaf weeds, ragweed, johnson grass, barn yard grass	Amiben, Vernolate, Dalapon, Lasso, Trifluralin, 2, 4-DB, Tenoran, Dyanap
Corn	Annual grasses, ragweed, johnson grass, crab grass, velvet leaf	Atrazine. 2, 4-D, So,azome, Dalapon Diuron, Paraquet, Linuron, Sutan, Lasso
Apples	Annual grasses, broad leaf weeds woody perennials, poison ivy	Methyl bromide, Simazine, Dalapon

Table A-4 Economic Insects of Major Southeastern Crops and Insecticides Recommended for Their Control

CROP	INSECTS	INSECTICIDES USED
Tobacco	budworm, hornworm, cabbage looper, bollworm, aphids	Carbaryl, Malathion, Parathion
Citrus	Scale insects, mealy bugs, White flies, aphids	Azinphosmethyl, Parathion, Systox
Peanuts	Southern corn rootworm, corn earworm, southern armyworm	Diazinon, Malathion, Carbaryl
Cotton	Bollweevil, bollworm, pink bollworm, tobacco budworm, cabbage looper	Methyl parathion, DDT Toxaphene
Peaches	Scales, oriental fruit moth	Azinphosmethyl, Parathion
Vegetables	Tomato and tobacco hornworm, tomato fruitworm, cabbage looper, aphids, imported cabbageworm, root maggots	Diazinon, Demeton, Phosdrin, Carbaryl, Methoxychlor
Soybeans	Corn earworm, bean leaf beetle, stink bugs, green cloverworm.	Carbaryl, Methoxychlor
Corn	Armyworm, corn earworm, cutworm, common stalk borer, corn leaf aphid	Malathion, Methoxychlor
Apples	Codling moth, leaf roller, curculio, aphids	Azinphosmethyl, Parathion

Table A-5 Economic diseases of Major Southeastern Crops and Fungicides Recommended for Their Control

CROP	DISEASES	FUNGICIDES RECOMMENDED
Tobacco	Wild fire, anthracnose Blue Mold	Zineb, Ferbam, Maneb, Meltiram, Streptomycin Sulfate
Citrus	Citrus canker, anthracnose, melanose, scab, dieback	Neutral Copper Compounds, Metallic Copper, Zineb
Peanuts	leafspot, seed rot, seedling blight, pod rot	Thiram, Captan, Terraclor, Zineb, Methylisothiocyanate
Cotton	Dampling off, seed decay angular leafspot, anthracnose, wild fire	Captan, Maneb, Terraclor, Terrazole
Peaches	leaf curl, blossom flight, scab, rhizopus rot	Dichlone, Captan, Ferbam
Vegetables	Downy mildew, anthracnose, scab, leafspot, fusarium wilt, southern blight	Maneb, Zineb, Tri-basic Copper, Terraclor
Soybeans	leaf spots, wild fire, downy mil-dew, sclerotial blight, seed decay	Thiram, Captan
Corn	Seed decay, seedling blight, seed-ling root rot	Thiram, Captan, Maneb
Apples	scab, rust, mildew, fire, blight, leaf spot	Maneb, Zineb, Captan, Cyprex

5. Regional and State Usage of Pesticide

Early realization of the potential acute danger to the public posed by use of synthetic chemicals to control agricultural and other pests led to the establishment of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). This act provided for registration of pesticidal chemicals shipped in interstate commerce as well as imported pesticides.

Concern for the total quantities of pesticides applied for control of agricultural pests, and the associated chronic health hazard to the public and the environment, is of recent origin. Consequently, no laws exist which require pesticide manufactuers, distributors, or users (growers) to report actual quantities of pesticides sold or applied in the different states to any state or Federal Agency. The absence of such regulations prohibits an accurate inventory of pesticide usage by states.

The Economic Research Service of the USDA published information on pesticide usage by regions for two years. This publication was terminated after 1966. The information published was based on random sampling techniques and not on actual quantities of pesticide applied by growers.

The existence and availability of inventory material and information varies widely from state to state within Region IV. Several states (e. g. Tennessee and Kentucky) have conducted special surveys to obtain quantitative information on pesticide usage. Generally these surveys provide information on pesticide usage for one year. Other states such as, North Carolina, have very little or no information on pesticide usage.

A brief discussion of available inventory information for the Southeastern states, other than North Carolina, follows.

a. Regional

Much of the information on pesticide usage compiled by the Economic Research Service was published on a combined state basis. In one case the information is combined for four states in Region IV (Alabama, Georgia, South Carolina, Florida) and in another, for all eight states. A discussion of this combined information is contained in this section. Additionally, control of fire ants, which is a regional problem, is also discussed.

(1) Combined States Information

In 1964 herbicide use was less than insecticides and fungicides. Out of approximately 84 million pounds of herbicides used in the country, the Southeast (Alabama, Georgia, South Carolina and Florida-four state area) accounted for only 3.4 million pounds. Herbicides used in large quantities were 2, 4-D, Dinitro, Atrazine, Trifluralin and Benefin.[10]

Thirty-five million pounds of insecticides were used in the Southeast in 1964. The Delta area (Mississippi, Louisiana and Arkansas) utilized 27 million pounds. The insecticides most frequently used were DDT, Toxaphene, Carbaryl, and Methyl parathion. More acres were treated with DDT in the Southeast than in any other region, 3.5 million acres or 31 percent of the total of 48 states.[10]

During the same year fungicides were applied in greater quantities than any other pesticidal group. This amounted to 73 million pounds or 44% of the total used nationally. Sulfur was the leading fungicidal material applied (64.5 million pounds).[10]

In 1966 insecticides applied to cotton exceeded the combined total for all other major crops.[11,12] A similar situation was observed for fungicides applied to citrus (Table A-6).

(2) The Fire Ant Problem

Some fifty years ago the imported fire ant Solenopsis saevissima richteri Forel entered the United States from Latin America, probably at the port of Mobile, Alabama.[13] These ants construct large mounds, have fiery stings and exhibit aggressive mobilization upon disturbance.

At least two species of native fire ants in the southeastern United States so closely resemble the imported ant that it is difficult and at times impossible for an expert to separate them in the field.[13]

There have been three periods in the history of the ant's spread. An initial period of a decade or two (1918-1932) when the ant became established on about two or three hundred thousand acres within a few miles of the Mobile Bay area; and natural spread peripherally was less than one mile per year. A second period of perhaps two decades (1932-1950) when the ant became established on about two to three million acres within 50 miles of Mobile Bay area, and natural spread was moving peripherally at a rate of one to three miles per year. A third, seemingly explosive, period was during the last two decades.[13,14] By 1957, these ants had spread over large land areas in Alabama, Mississippi, Louisiana, and Florida, as well as small areas in Texas and Georgia.

There is very little conclusive evidence that the ant actually harms other insects, plants, or birds and wildlife. But it inhabits open areas such as fields, where its large mounds inhibit use of farm

Table A-6 Pesticides Used on Major Crops of the Southeastern United States, Federal Region IV, 1966 [11,12]

	Pounds active ingredients				
	Herbicides	Insecticides	Fungicides	Other	Total pesticides
	1,000 pounds				
Citrus	288	2,355	1,502	411	4,536
Cotton	2,542	32,786	50	1,294	36,672
Tobacco	15	3,330	20	12,134	15,499
Peanuts	2,892	5,529	55	6,150	14,626
Corn	3,643	428	2	44	4,117
Soybeans	1,395	2,712	4	49	4,160

Source: Eichers, T. R. (modified)

equipment. Its wasplike sting causes a great deal of pain and inconvenience to livestock, farmers, laborers, picnickers, and schoolchildren.[15]

Results of research begun in 1949 on control of the insect in Alabama indicated good control with 2 pounds of Heptachlor or Dieldrin or 4 pounds of Chlordane per acre, when broadcast as granules, for a period of 3 to 5 years.[16, 17] Aerial application of 5% or 10% Heptachlor at a rate of 2 pounds of technical material per acre was equally effective for control of this insect. Bait containing 0.075, 0.15, or 0.3% Mirex applied at rates of 3, 5 or 10 lbs. per acre respectively, all gave excellent control of ants in Mississippi.[18]

Mirex was hailed on its introduction as "the perfect pesticide" because it is quite precise in killing its target organism.

Mirex is a delayed-action bait. A first spraying is almost entirely picked up by worker ants who take it back to their nests. There it then kills the queens and ultimately destroys most of the colonies. Two more sprayings aimed at killing off the remaining ants were included in prior practice but this carries the risk that the bait, left untouched by the now-sparse fire ant population, will be ingested by other insects or birds or will flow into neighboring streams.[15]

The use of Mirex has been critized because, in some field tests, it has been toxic to shrimp, crabs, and other species of ants, such as the carpenter ants. A final question arises because, like DDT and mercury Mirex is highly persistent in the natural environment. It could pass along the food chain to become concentrated in higher organisms. Current methods of Mirex bait application attempt to limit these hazards. Mirex is aerially sprayed at 1.7 grams of Mirex chemical and 1 1/4 pounds of corncob grits and soybean oil per acre. This is equivalent to about two thimblefuls of Mirex chemical per acre.[15]

Despite the minute quantities applied, Mirex ranks as the fourth most abundantly found pesticide in Southeastern water.[19]

b. Alabama

Cotton, peanuts, soybeans, corn, pecans, peaches and vegetables are the most important crops produced in Alabama.

The most commonly used herbicides, in the state in 1970, were 2, 4-D, Atrazine, Treflan, Planavin, Cotoran, DSMA, MSMA, Dinitro, Balan, and Lorox (Table A-7).[20-24]

Cotton receives applications of both pre-and post-emergence herbicides. The most commonly used herbicides are Treflan and Planavin (preemergence) and DSMA and MSMA (postemergence). Since much of the total cotton acreage receives application of both pre-and post-emergence herbicides, the figures for acres of cotton treated exceed the total acres planted.[21] Approximately one-half of the corn acreage receives applications of preemergence (Atrazine and 2, 4-D) and post-emergence herbicides (2, 4-D).[22]

The dollar value of insecticides used shows an increase from 1965 to 1969 but declines slightly in 1970 (Table A-8). Of all the crops, cotton and peanuts were the major users of insecticides. Mirex has been used extensively in attemps to control the fire ant.[25-30]

Quantitative information on fungicide usage in the state is presently not available.

Table A-7: Herbicide Usage (acres treated with various herbicides) for the Major Crops Grown in Alabama, 1970 [20-24]

Crop	Acres Planted	Acres Treated	Preemergence Treatment		Postemergence Treatment		
			Herbicide	Acreage Treated	Herbicide	Acreage Treated	Remarks
Cotton	550,000	846,068	Treflan alone or Planavin alone	165,328	DSMA or MSMA	118,530	Acres treated "over the top" 58,679
			Treflan and Cotoran	95,107	MSMA and Cotoran	50,260	Layby - acres-89,089 treated with Karmex, Cotoran, Lorox
			Planavin and Cotoran	35,627	MSMA and Karmex	20,050	
			Cotoran alone	58,780	MSMA and Herban	17,415	
			Others	-	Others	-	
			Total Pre-emergence	475,362	Total Post-emergence	222,938	
Corn	694,000	306,923	Atrazine	189,429	2, 4-D	46,837	Acres treated preplant with butylate - 12,912
			Lasso	16,659	Atrazine	39,478	
			Others	-	Others	-	
			Total Pre-emergence	215,124	Total Post-emergence	91,799	

Table A-7 (Continued)

Herbicide Usage (acres treated with various herbicides) for the Major Crops Grown in Alabama, 1970

Soybeans	609,000	242,000	-	24,200	-	9,680	Acres - 58,080 treated preplant with some planavin, some vernan
Sorghum		7,218	Propazine	3,788	Atrazine 2, 4-D	4,300 2,918	
Sorghum Sudan		2,870 2, 4-D					
Coastal Bermuda		8,546 Simazine					
Peanuts	190,000	253,486	-	37,750	Cracking time Dinitro alone	14,850	Acres treated preplant 78,370 with Balan, 29,800 with Balan-Vernan, others - Total 114,861
					Dinitro and Falone	18,175	
					Dinitro and Diphenamid	16,775	
					Total Cracking Time	58,025	

Source: Burns, E. (modified)

Table A-8: Insecticide Usage on Crops, and Beef and Dairy Cattle in Alabama (1965-1970) [25-30]

A. Cotton	1965	1966	1967	1968	1969	1970
1. Total acres planted	816,604	559,733				
2. Acres dusted		113,645	89,209	90,220	79,951	47,075
3. Acres sprayed		319,268	273,884	336,262	354,802	310,953
4. Non-treated acres			10,430	113,304		206,797
5. Systemic insecticides treated as:						
a. seed treatment		96,995	91,950	115,866	139,827	170,125
b. furrow treatment			47,176	59,781	742,752	121,336
B. Peanuts						
1. Total acres planted	201,792	194,099				
2. Acres treated with systemic insecticides		50,045	59,975	67,090	77,865	84,690
3. Estimated cost of control programs	$455,400	$352,074	$312,643.50	$281,941	$270,293	$12 per acre
4. Estimated value	$1,918,200	$2,100,110	$1,510,804	$934,359	$1,013,509	
C. Soybeans						
1. Total acres planted	280,987	316,195				
2. No. of acres requiring insect control		194,262	177,815	191,305	273,370	245,102
3. Estimated cost of control program						
4. Estimated value				506,050	$2,899,250	$1,462,160

Table A-8 (Continued)

Insecticide Usage on Crops, and Beef and Dairy Cattle in Alabama (1965-1970)

	1965	1966	1967	1968	1969	1970
D. Stored Grains	2,907,500	2,065,100	2,692,200	2,523,500	2,360,000	1,527,800
No. of bushels of all grain in form storage fumigated and/or treated with a protectant						
E. Other crops (acres treated)						
1. Commerical crops		91,822	81,106	72,344		74,795
2. Peacan trees			444			19,540
3. Peaches		8,026	2,777			
4. Apples		1,779	1,807			
5. Cloves		17,430	20,349	14,540	12,485	5,645
6. Alfalfa		2,840	1,575	1,523	1,455	660
7. Corn		170	1,248	1,820	4,055	21,550
8. Grain Sorghum		9,950				
9. Temporary grazing crops			74,415	42,275	45,060	61,825
F. Beef Cattle						
1. Beef cattle treated for all insects	1,221,300	746,170	787,060	750,680	761,150	786,600
2. Estimated value of control program	$3,098,850	$3,760,500	$4,032,500	$4,027,750	$4,411,500	$4,352,300
G. Dairy Cattle						
1. Dairy cattle treated for all insects	161,741	122,415	115,395	114,023	113,657	401,940
2. Estimated value of control program	$1,499,185	$1,343,656	$1,339,295	$1,293,450	$2,233,400	$1,840,625
3. Dairy barns in which an effective fly control program was conducted	1,402	1,134	967	925	856	804

Table A-8 (Continued)

Insecticide Usage on Crops, and Beef and Dairy Cattle in Alabama (1965-1970)

	1965	1966	1967	1968	1969	1970
Acres treated with mirex fire ants control	226,397	578,711	585,716	278,681	180,205	273,890
Amount of insecticides used in all aspects of insect control (dollar value)	$12,854,500	$16,737,500	$17,717,500	$17,289,723	$21,473,500	$19,355,700

Source: Ledbetter, R. J. (modified)

c. Florida

A wide variety of field crops, fruits and vegetables are grown in Florida. Control of pests in these crops requires extensive use of pesticides.

Available information on herbicide usage indicates that Treflan, Lasso, 2, 4-D, Hyvar X, Atrazine and Randox are the most commonly used herbicides (Table A-9).[31] Herbicides are also employed for aquatic weed control (primarily water hyacinth) which is a serious problem in Florida. It has been estimated that aquatic weed control measures are needed on 2.8 million acres of inland water. Presently only 10% of this area is treated with herbicides.

Quantitative information on pesticide usage is lacking, particularly with respect to insecticides and fungicides.

Projections on future use of pesticides in Florida indicate the following:[32]

- Herbicide usage will reach approximately 5.5 million pounds by 1975 and about 6 million pounds by 1980. Increased acreage under treatment as well as use of more than one chemical or application per crop will be responsible for these increases.

- Fungicide usage will also increase considerably. Over 32 million pounds of fungicidal chemicals will be utilized annually by 1975 and 40 million pounds by 1980. These projections were based on chemicals which were available in 1969. Should new fungicides with improved efficiency become available the figures for projected usage will probably be lower.

- Projected usage of insecticides and miticides, other than oil and sulfur, will be approximately 17 million pounds in 1975, and will reach approximately 19 million by 1980.

- The projected usage of fumigants and non-fumigant nematicides for 1975 are about 6.2 and 5.2 million pounds, respectively.

TABLE A-9 Herbicides Usage on Various Crops in Florida, 1971[31]

Crop	Acres Planted	% of acreage treated	Herbicides used in decreasing order
Corn	357,000	20	Atrazine, 2,4-D, Sutan, Lasso
Soybeans	204,000	40	Treflan, Lasso, Dyanap Tenoran
Peanuts	53,000	80	Balan, Lasso, Premerge, Dyanap, Vernan
Tobacco	11,000	20	Tillam or Enide
Cotton	12,000	90	Treflan, Organic Arsenicals (MSMA, DSMA), Lorox
Vegetables			Randox, Vegedex, Diphenamid, Treflan, Eptam
Citrus	800,000	70	Hyvar X, Casoron, Sinbar, Paraquat
Woody ornamentals	10,000	40	Paraquat, Herbicide Oils, Simazine, Treflan

Source: Currey, W. L. (modified)

d. Tennessee

Some of the most important crops grown in Tennessee are cotton, tobacco, soybeans, corn, fruits, and vegetables.

The pesticide market in Tennessee is relatively large. A survey conducted in 1965 by the Tennessee Agricultural Experiment Station indicated that over 17.3 million pounds of pesticide materials valued at more than $16.6 million, at the manufacturer's level, were utilized. This represented 4.6% of the total U.'S. sales for that year. Of total pesticide sales, 56% were for insecticides, 28% for herbicides, 7% for fungicides, and 9% for rodenticides and other pesticides.[33]

Another survey was conducted by the Tennessee State Department of Agriculture in 1970. In this survey, acreage figures for various crops were taken from the reports of the cooperative Federal-State statistics on agriculture. Crops represented in the survey are, for the most part, the major crops of the State's agriculture. Total acreage of crops surveyed in the state represented more than 90% of the cultivated acreage. Information obtained by the survey on acreage and pesticide usage by crops were projected against the total acreage in the State to arrive at a prediction of total pesticide usage by crops. The information indicated that herbicides were used more widely and in greater amounts (67% of total) than all other pesticides combined. Insecticides accounted for 30% of total usage and fungicides only 3%.[34]

Use of preemergence herbicides for weed control in corn, cotton and soybeans increased from 1966 to 1970. (Tables A-10, A-11, A-12). A similar situation existed for use of post-emergence herbicides on cotton and soybeans. However, a slight decrease was observed for post-emergence treatment in corn.[35]

Table A-10 Acreage of Corn Crop Treated with Various Herbicides, in Tennessee, 1966-1970[35]

	1966	1968	1970
Total acres planted	1,018,000	783,000	722,000
Preemergence Herbicides			
Alachlor (Lasso)			12,205
Atrazine (AAtrex)	234,278	294,350	353,452
Atrazine (AAtrex) + butylate (Sutan)			20,870
Diuron (Karmex)	11,930	6,130	2,375
2, 4-D	40,382	31,841	20,507
Others (Paraquat, and Simazine	9,002	26,749	3,960
Total acres treated with preemergence herbicides	295,592	359,070	413,369
% of acreage treated	29	53	65
Postemergence Herbicides			
Atrazine	12,691	20,790	10,452
Linuron	6,305	4,905	1,625
2, 4-D	80,469	53,811	35,595
Other (Evik)			250
Total acres treated with postemergence herbicides	99,465	79,506	47,922
% of acreage treated	10	12	8

Source: Hadden, C. (modified)

Table A-11 Acreage of Cotton Crop Treated with various Herbicides, in Tennessee, 199-1970 [35]

	1966	1968	1970
Total acres planted	410,000	392,462	425,000
Preemergence Herbicides			
Diuron (Karmax)	158,382	70,440	63,520
Fluometuron (Cotoran)	45,914	115,815	144,811
Nitralin (Planavin)		34,710	48,414
Prometryne (Caparol)			8,000
Trifluralin (Treflan)	104,985	92,262	129,669
Others (DCPA, and Norea)	11,345	19,840	3,834
Total acres treated with preemergence herbicides	320,626	333,067	398,248
% acreage treated 4	78	94	96
Postemergence Herbicides			
Herbicidal Oil	3,755	6,600	750
DSMA or MSMA + Surfactant	74,275	93,640	155,051
DSMA or MSMS + Karmex	23,800	28,300	63,182
DSMA or MSMA + Caparol	2,100	3,000	45,700
DSMA or MSMA + Cotoran	6,750	17,515	32,010
DSMA or MSMA + Herban		6,750	2,100
Total acres treated with postemergence herbicides	110,680	155,805	298,793
% of acreage treated	22	44	72
Lay-By Herbicides			
Diuron (Karmex)		15,500	6,496
Fluometuron (Cotoran)		6,275	5,750
Linuron (Lorox)		5,050	2,100
Total acres treated		26,825	14,346
% of acreage treated		8	4

Source: Hadden, C. (modified)

Table A-12 Acreage of Soybeans Treated with Various Herbicides, in Tennessee 1966-1970[35]

	1966	1968	1970
Total acres planted	933,000	1,268,000	1,293,000
Preemergence Herbicides			
Alachlor (Lasso)			27,395
Amiben	33,275	70,985	67,870
DCPA (Dacthal)			1,007
DNBP (Dinitro)			12,585
DNBP + Napatalam (Dyanap)			72,893
Linuron (lorox)	14,345	115,840	161,756
Naptalan + Chlorpropham (Solo)	24,470	58,025	11,700
Nitralin (Planavin)		65,155	94,681
Trifluralin (Treflan)	85,850	109,808	186,777
Others (Paraquat, Naptalam + Chloropham (Alanap)	223	29,495	1,250
Total acres treated with preemergence herbicides	158,163	449,308	637,914
% of acreage treated	17	41	50
Postemergence Herbicides			
Chloroxuron (Tenoran)	6,740	87,399	131,950
Herbicidal Oil	9,484	8,530	50
DNBP (Dinitro)			6,750
Linuron (Lorox)			5,275
2, 4-DB	95,858	85,098	159,154
Other (2, 4-D)			10,050
Total acres treated with postemergence herbicides	112,082	181,027	313,229
% of acreage treated	12	17	25

Source: Hadden, C. (modified)

e. Kentucky

The major crops grown in Kentucky are corn, tobacco, soybeans, hay and small grains. The overall agricultural gross product increased approximately 350 million dollars during an eight year period (1960-1968).[36] Much of this increase is attributable to pesticide usage.

A survey of pesticide usage and sales was conducted in 1968 by the Division of Environmental Services of the State Department of Health.[36] Information obtained by this survey indicated that a total of 2, 850, 734 pounds of pesticides were sold during that year. (Table A-13). Of the total, herbicides accounted for 56. 1%, insecticides 31. 4%, and fungicides 12%. The remainder (. 5%) was rodenticides.

Of the total sales of insecticides, chlorinated hydrocarbons accounted for 69. 4%, organophosphates 16. 8%, carbamates 9. 0% and miscellaneous 4. 7%.

The use of DDT on tobacco in Kentucky has been banned as is the case for other states. Additionally, the state has banned the use of Aldrin-fertilizer mixture on tobacco.

f. South Carolina

The major crops grown in South Carolina are cotton, peaches, peanuts, soybeans, corn and vegetables.

Estimates on herbicide usage on cotton, corn, soybeans, small grains and pastures are given in Table A-14. This information is based on herbicide usage surveys conducted in various counties and districts in 1968 by the State Extension Service.[37]

A majority of the cotton crop and approximately one-half of the corn was treated with pre emergence herbicides. (Table A-14).

Table A-13 Amounts of Various Pesticides Sold in Kentucky in 1968[36]

Pesticides	Amount used in pounds
INSECTICIDES	
CHLORINATED HYDROCARBONS	
Product	
DDT	151,015
Chlordane	127,778
Aldrin	101,079
Rothane (TDE)	94,449
Methoxychlor	46,967
Toxaphene	29,881
Dieldrin	26,979
Endosulfan (Thiodan)	21,393
Kelthane	8,898
Lindane	4,025
BHC	3,456
Heptachlor	2,347
Tedion	1,407
Endrin	500
Total	620,174
ORGANO-PHOSPHATE	
Product	
Malathion	51,467
Diazinon	20,728
Parathion	19,799
Di-syston	18,858
Dibrom (Naled)	14,800
Guthion	11,899
Systox (Demeton)	6,000
Ethion	1,975
Ciodrin	1,347
Korlan (Ronnel)	984
Cygon (Dimethoate)	871
Phosdrin	720
DDVP (Vapona)	536
Miscellaneous Organo-Phosphates (5)	394
Total	150,378

* Pesticides of less than 500 pounds are grouped under miscellaneous.

Table A-13
(continued)

RODENTICIDES

Product		
Warfarin		9,482
Arsenic Trioxide		2,916
Zinc Phosphide		1,270
Prolin		699
Miscellaneous Rodenticides (4)		232
	Total	14,599

HERBICIDES

Product	
Methyl Bromide	431,788
MH (Maleic Hydrazide)	352,956
Atrizine	200,679
2, 4-D Amine & 2, 4-D LV	142,248
Sodium Chlorate	99,047
Diphenamide (Enide)	49,359
2, 4, 5-T	38,356
Dalapon	30,079
Trifluralin (Treflan)	22,001
Alanap (NPA)	22,794
Eptam	19,373
Amiben	18,224
Calcium Methanearsonate	16,670
Vernolate (Vernam)	15,845
Sodium Arsenite	14,580
Linuron (lorox)	14,376
DCPA (Dacthal)	13,513
CIPC	10,420
Simazine	11,498
Solan	9,090
DSMA	8,294
Paraquat	7,184
Sutan	6,387
Sodium Metaborate	4,711
Picloram (Tordon)	4,030
Dinitrocresol	3,532
Chloroxuron (Tenoran)	3,369
Planavin	2,500
Casoron	2,454
Vorlex	2,440
Hyvar (Isocil)	2,400

Table A-13
(continued)

CARBAMATES

Product		
Carbaryl (Sevin)		80,704
	Total	80,704

MISCELLANEOUS

Lead Arsenate		31,467
Pyrethrims		3,076
Piperonyl Butoxide		3,025
Rotenone		2,254
Other Miscellaneous (9)		1,952
	Total	41,774

FUNGICIDES

Product		
Sulfur		126,180
Copper Sulphate		107,772
Captan		38,590
Zineb		20,620
Maneb		20,527
Ferbam		8,010
Lime Sulphur		6,062
Phaltan		5,905
Cyprex		3,210
Dithane (Nabam)		1,168
Polyram (Metiram)		1,168
Botran		1,200
Thiram		760
Miscellaneous Fungicides (4)		1,523
	Total	342,695

Table A-13
(continued)

(Herbicides Continued)

Metham (Vapam)		2,118
Balan		1,614
Banvel-D		1,600
Dazomet (Mylone)		1,600
Silvex		1,240
Diuron (Karmex)		1,200
Monuron (Telvar)		1,200
Aminotriazole		1,006
CDAA (Randox)		890
Endothall		600
Miscellaneous Herbicides (21)		7,145
	Total	1,600,410
	Grand Total	2,850,734

Source: Moore, E. E. (modified)

Table A-14 Herbicides Usage (acres treated) on Important Crops in South Carolina (1968)[37]

Crop & Treatment	Total Acres Planted	Acres Treated	% Treated
Cotton	326,585		
Preplant (incorporated)		295,141	90
Preplant (incorporated plus premergence)			
Treflan or Planavin		48,380	15
Postemergence (early and mid season)		158,690	47
Lay-by		73,900	23
Total Acres Treated		576,111	
Corn	378,200		
Preemergence-Atrazine		168,508	45
Postemergence		126,333	33
		294,841	
Total Acres Treated			
Soybeans	1,001,000		
Preplant (incorporated)		409,234	41
Treflan or Planavin			
Preemergence		56,588	6
Postemergence-Tenoran		160,485	16
2,4,D-B		193,426	19
Total Acreas Treated		819,733	
Small Grains	252,250		
Postemergence		108,840	43
Permanent Pastures	749,880		
Postemergence		217,465	29
Coastal Bermuda			
Simazine		13,234	5

Source: Nolan, C. N. (modified)

Additionally, most of the soybeans and much of the acreage planted to small grains also received application of herbicides.[37]

The herbicides used in large quantities during 1968-70 were Treflan, Atrazine, 2,4-D, DSMA, MSMA and Tenoran (Table A-15).[38]

Quantitative information on pesticide usage, particularly with respect to insecticides and fungicides, is lacking.

g. Georgia

The important crops of Georgia which are extensively treated with herbicides are cotton, corn, peanuts, soybeans and pastures. The most commonly used herbicides for weed control in these crops were Treflan, Planavin, Cotoran, Karmex, CIPC, DSMA, MSMA, Lorox, Caparol, Sutan, Atrazine, Lasso, 2,4-D, Banvel D, Vernam, Balan, Sesone, DNBP, Amiben, 2,4-DB, Dyanap, Tenoran and 2,4,5-T.[39,40]

Herbicide usage survey data indicated that the acreages of all crops treated with herbicides increased considerably from 1965-1971. (Table A-16). Prior to 1971, information on acreage of corn and soybeans which received herbicidal treatment but no tillage, was not reported.[39,40]

Presently, no information is available on the quantities of insecticides and fungicides used in the state.

h. Mississippi

The most important crops grown in Mississippi are cotton, soybeans and corn. Some of the commonly used herbicides for weed control in cotton and soybeans were Treflan, Planavin, Cotoran, Karmex, Telvar, Lorox, herbicidal oil, MSMA + Karmex, MSMA, Amiben, Dyanap,

Table A-15 Amounts of Major Herbicides Used in South Carolina During 1968-1970[38]

Herbicide	Pounds of Active Ingredient 1968	1969	1970
Treflan	245,000	265,000	295,000
Planavin	15,000	35,000	50,000
Atrazine	190,000	195,000	260,000
Simazine	10,000	15,000	20,000
Karmex	30,000	30,000	25,000
Cotoran	25,000	35,000	40,000
Herban	15,000	25,000	30,000
Tenoran	115,000	135,000	140,000
Lorox	80,000	85,000	100,000
2,4-D	240,000	250,000	250,000
2,4-DB	20,000	30,000	40,000
Banvel, 2,4,5-T etc.	15,000	15,000	20,000
Dyanap & Dinitro	20,000	45,000	55,000
MSMA & DSMA	160,000	175,000	185,000
Lasso & Amiben and others	10,000	10,000	20,000
Total	1,190,000	1,345,000	1,530,000

Source: Nolan, C. N. (modified)

Table A-16 Acreage of Various Crops Treated with Herbicides in Georgia (1965-1969)[39,40]

Crop and Treatment	Acres treated with herbicides					
	1965	1966	1967	1968	1969	1971
Cotton						
Preplant and preemergence	403,117	347,625	292,875	356,247	372,460	483,415
Postemergence		62,883	67,402	180,829	168,732	263,614
Total	403,117	410,508	360,277	537,076	541,192	747,029
Corn						
Preplant and preemergence	164,332	162,831	272,482	309,847	412,309	536,514
Postemergence	2,389	199,754	347,971	380,489	373,655	478,916
Total of preplant, preemergence & Postemergence	166,721	362,585	620,453	690,336	785,964	1,015,430
No Tillage (Atrazine + paraquat)						6,962
Peanuts						
Preplant	66,797	151,514	273,652	387,039	430,503	515,359
Pre or post emergence	229,575	259,862	180,369	107,007	173,667	319,012
Total	296,372	411,376	454,021	494,046	604,170	834,371
Soybeans						
Preplant and preemergence	17,832	95,395	191,020	190,065	236,858	333,655
Postemergence		11,495	45,467	42,696	49,583	142,855
Total	17,832	106,890	236,487	232,761	286,441	476,510
No Tillage (Paraquat)						10,980
Pastures						
Postemergence		252,216	311,324	342,515	350,816	325,465
Fence rows or noncrop land						29,010

*1970 data not available
Source: Swann, C. W. (modified)

Lasso, Solan, Dinitro, Tenoran, 2,4-DB, and Wax bar.[41]

Cotton and soybeans acreages treated with herbicides increased each year from 1968-1970 (Table A-17). This trend in herbicide usage is similar to that observed for most of the other Southeastern states.

Information on insecticide usage for 1970 indicated that 1,371,000 acres of cotton were treated for control of cotton bollworms and boll weevil.[42] The major types and quantities of insecticides applied were as follows:

- Toxaphene - 8.5 million pounds at an average rate of 2 lbs. per acre.
- Methyl parathion - 5.5 million pounds at an average rate of 0.5 lb./acre
- DDT - 3 million pounds at the rate of 1 lb. per acre.

Presently, no information on insecticides and fungicides is available.

6. Conclusions

Most pesticides used in the Southeastern United State are directed towards the following major pests:

- Insects: Cotton boll weevil, cotton bollworm, tobacco budworm, tobacco hornworm, scale insects of citrus, cabbage lopper, pink bollworm, codling moth and mealy bugs.
- Weeds: Broad leaf weeds, rag weed, johnson grass, pigweed, crab grass, barn-yard grass, green and yellow foxtails, water hyacinth and goose weed.
- Disease: Citrus melanose, citrus and apple scab, leaf spot disease of peanuts, wild fire of tobacco and cotton, anthracnose of tobacco and cotton, root rots of corn, fire blight of apple, downy mildew of beans, leaf spot of apples, beans and cotton.

Table A-17 Cotton and Soybeans Acreage Planted, and Treated with Herbicides in Mississippi (1968-1970)[41]

Crop & Treatment	1968	1969	1970
Cotton			
Total acres planted		1,120,079	1,151,552
Total acres treated (preemergence)	1,232,036	1,548,084	1,335,432
Total acres treated (postemergence)	1,359,215	1,857,323	2,127,899
Soybeans			
Total acres planted		2,214,360	2,292,425
Total acres treated (preemergence)	964,050	1,866,550	1,637,795
Total acres treated (postemergence)	683,625	1,374,135	1,539,288

Source: Anderson, K. L. (modified)

An accurate inventory of pesticide usage is needed to determine present trends and provide a basis for making future projections on pesticide usage. Additionally, inventory information is required to determine the extent and trends of environmental pollution by pesticide usage. This is particularly important with respect to the usage of persistent pesticides.

Information on pesticide usage (quantities used and acreage treated) is presently not available mainly because distributors, sellers and users of pesticides are not required to report specific information regarding pesticides sold or applied, to any responsible agency.

The most recent information available from U. S. Department of Agriculture concerning quantities of pesticides used by farmers on a regional level is five years old (1966). Certain information is availabe for pesticide usage in a few states (e. g. Kentucky and Tennessee) where special surveys were conducted. These surveys only represent a one year compilation. In most of the Southeastern states herbicide usage surveys have been conducted more regularly than for any other group of pesticides. Herbicide usage, on various importnat crops of the Southeast, has increased considerably during the past few years.

In the southeastern United States, the most widely used herbicides are Treflan, Dalapon, 2, 4-D, Atrazine, Planavin, Cotoran, DSMA, MSMA, EPTC, Dinitro, Balan, Lorax, Simazine, Methyl bromide and Maleic hydrazide.

Most commonly recommended and used insecticides in the Southeast are Toxaphene, BHC, Parathion, Malathion, Disyston, Systox, Carbaryl, Methyl arathion, Diazinon, DDT and Chlordane. DDT has been used extensively to control insects in cotton, tobacco and other crops. However, its use is decreasing, while that of Toxaphene, Parathion, Malathion and Methyl parathion is increasing. Mirex has been very extensively applied to control fire ants in the Southeast.

Insecticide applications to cotton in the Southeast exceed the combined total for all other major crops. A similar situation exists with fungicides applied to citrus.

The most commonly recommended fungicides in the Southeast are Sulfur, copper sulfate, Captan, Zineb, Maneb, Cyprex, Dithane, Botran, Thiram and Ziram.

Practically all Southeastern soils used for agricultural purposes are subject to moderate or severe runoff and erosion. Soils in a large portion of Florida are an exception because lack of adequate drainage is a severe problem. Soil erosion and runoff problems could be reduced by proper management practices.

7. Recommendations

1. A national and state reporting mechanism for documenting, as accurately as possible, the total quantities of pesticides used should be established. Initially, the reporting procedure should be established at primary and secondary levels to provide a cross reference. Pesticide manufacturers would represent the primary level while state or county pesticide distributors could represent secondary level.

2. The Economic Research Service of the U. S. Department of Agriculture should reestablish its program of compilation and publication of information on use of pesticides. However, the information should be published on a state as well as regional basis.

3. Growers should be encouraged to use less persistent pesticides as they become available.

4. The U S. Department of Agriculture through its Extension Service should encourage growers to use cultural and management practices which minimze loss of sediment. Special emphasis should be placed on areas in which most pesticides are applied.

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B. APPLICATION TECHNIQUES AND TYPES OF PESTICIDE

1. Introduction

Economic control and safety have been twin objectives of pest control for many years; however, both goals have been elusive. The failure of the pest control profession to establish reasonable economic thresholds and reticence of farmers to accept those available have led to many problems associated with the use and misuse of insecticides. The problems relative to resistance, disruption of natural control, and pollution have proven much more difficult to evaluate. The price of ignoring ecosystem contamination has been high.[1] It appears clear that steps must be taken to reduce the contamination by pesticides of soil, water, and air as well as on non-target organisms and man.

Efficient pest control using pesticides depends upon selection of proper pesticides, application at the proper time and the use of equipment that can efficiently place the toxicant in the microenvironment of the pest. Of the total pesticides applied, no more than 2% is effective.[2] The remainder is indicative of the inefficiency of the existing application techniques.

Careful selection of existing methods would considerably reduce the amount of pesticide required for effective pest control; with a concomitant decrease in contamination of the ecosystem. Major benefits would accrue from improved pesticide delivery systems. The answer to the past problem, therefore, does not lie in increasing still further the use of pesticides. It lies in increasing the use of safe pesticides and in increasing the efficiency of application techniques.

2. Pesticide Application Methods and Equipment

Pesticide formulation is an important factor in selecting the most appropriate method of application. Pesticide formulations can be grouped on the basis of physical state as solid materials, liquids (common "spray" materials) and gases. Dust, granules, baits and seed dressings are the most common forms of solids. Sprays are formulated as solutions, wettable powders and emulsions. Gases are generally used in confined spaces such as greenhouses, seed storage areas, or for soil fumigation. A fumigation effect is also created by foggers which produce effects similar to gaseous forms of pesticides.

Pesticides may be applied as a broadcast, in narrow bands, individual spot treatments, or directed to a particular part of the plant.

a. Sprays

A major portion of pesticides (herbicides, fungicides and insecticides) are applied as sprays. In 1964, 46% of the farmers in the southeastern U. S. owned power-driven sprayers compared to 23% who owned dusters.[3] Since then custom spraying, primarily by aircraft, has increased.

Sprayers are classified as high volume sprayers, low volume (LV) sprayers and ultra low volume (ULV) sprayers. High volume sprayers apply from 30 to 500 gallons of spray per acre; low volume sprayers from one to 30 gallons per acre; and ULV concentrated formulations in amounts less than two quarts per acre.[4] Most spray equipment utilize pumps, nozzles and booms to produce the different types of spray. Some examples of ground-operated sprayers are the following:

- Hydraulic sprayers in which the liquid mixture is forced through a spraying system and released onto the target area,

- Multipurpose sprayers which are designed to operate over a range of pressures varying from very high to very low and are primarily used for orchard spraying,

- Conventional low pressure, low volume sprayers which are equipped with a boom and with nozzles that are suitable for LV and ULV sprays,

- High pressure, high volume sprayers which are employed for thorough coverage of plants having dense foliage (e.g. bushes, vines, and truck crops), and

- Air blast sprayers which utilize a blast of air to propel sprays in LV. Small droplets are created.

Improvements have been in ground equipment used to apply ULV sprays. The major problem was the inability to adequately regulate the flow rate of the pesticide. This problem was solved by using drilled discs or small metering valves mounted in the insecticide lines. Stainless steel or plastic tanks were used to hold the insecticide and, in some models, filters were installed to help eliminate nozzle stoppage.

Aerial application of pesticides, either from fixed-winged planes or helicopters, utilizes a modification of conventional low-volume, low-pressure hydraulic spray, dust, or granular application techniques. The most common dispersal apparatus used on aircraft is the pump, boom, and nozzle spray system. Spray-deposit patterns are adjusted by shifting nozzle locations on the boom. Droplet size can be varied by changing the pump pressure, the orifice size in each nozzle, or the nozzle direction in the slipstream of the aircraft. The application rate is changed by increasing or decreasing nozzle size or number of nozzles in the boom.[5] Some types of aerial spraying equipment are:

- Fixed wing aircraft of single or multiengine types, equipped with boom and nozzles used mostly to apply spray in LV or ULV range,[5] and

- Helicopters which utilize air blast of the rotors for increased droplet impingement.

One of the more serious shortcomings of fixed-wing aircraft as a pesticide applicator is that the underleaf coverage may be less than with ground application or helicopter applications. Rotor downwash of the helicopter ensures that there is a minimal drift of materials to adjoining fields.[6] Helicopters have the advantage over fixed-wing aircraft in maneuverability and landing and consequently less time is lost in ferrying. They are better suited in small fields. Helicopter operators cannot increase their speed of application without sacrificing, uniformity in coverage. The necessary low speed coupled with the low capacity is a disadvantage from the cost standpoint where large areas are involved.[7] These advantages and disadvantages must be weighed in determining the most effective, economical system.

Improvements in nozzles and booms are directed toward reducing the volume of spray required for effective pest control. Recently developed microfoil booms produce droplets of nearly uniform size and reduce drift. Spinning-disc or screen-cage nozzles, such as the Mini-Spin and Micronair nozzles, have a similar capability.[8,9] Hydraulic nozzles with flat fan tips, also produce droplets of acceptable sizes, and are relatively inexpensive.[10] However, problems exist with the degradation of the diaphragms and erosion of the tip orifices. Another type of nozzle, the hollow-cone, produces droplets larger than those produced by nozzles previously discussed.[10] Air curtain nozzles have been developed to be used in conjunction with the techniques of electrostatic charging of the spray droplets.[11]

b. Dusts

The development of dusting equipment is less advanced than that of spray equipment. Dusting appliances operate on the principle of emitting a blast of air in which the dust particles are airborne. Rotary-type dusters, in which dust is fed onto fan blades, are used for ground application. Aerial dusting, which was extensively employed for many years in the Southeast, is decreasing.[12] Aerial dusters are categorized as follows:[7]

- Standard dusters which consist of hopper, wind-driven agitator, a feed control gate and a spreader suspended below the fuselage,
- Breeches-type duster in which the lower part of the hopper leads to the shutters and the dust is emitted into emission tubes located on either side of the corner of the fuselage, and
- Suspended tank-type dusters in which the dust is stirred by a windmill type of agitator and emitted through gates consisting of crosswise matching slots operated from the cockpit.

Many problems inherent in the use of dusting as a method of pesticide application restrict its use. Drift hazards, inefficient deposition of active ingredient on the target, agglomeration and poor settling are a few examples of the problems.

c. Granules

Granule applicators are designed to place in the target area pesticides impregnated on a suitable carrier, such as corncob, clay minerals, or walnut shells.[5] Although variations in design occur, basic granular applicators consist of a hopper for the pesticide, a mechanical-type agitator at the base of the hopper, and a metering device, usually a slit-type gate, to regulate the flow of the granules. Granules may be applied as a broadcast or band treatment, before, or at a planting time, and worked into the soil; as a postplant, side-dress application through drop tubes and fertilizer shoes; or from the air, to penetrate foliage. The last procedure is used to apply Mirex, a slow-release pesticide used for fire ant control in the Southeast.[13]

d. Foams

Foam delivery is one of the recent additions to pesticide application methodology.[14] The system which produces the foam varies with the application. Land-based equipment generally consists of a water pump, an air compressor, foam generator and regulation module. Various chemicals are utilized to improve wettability and penetration of the spray. Aerial foam application equipment has also been developed. This may be mounted on fixed-wing aircraft or helicopters. Depending upon the need, foams can be generated in a pattern varying from 1/16" droplet size to continuous cover similar to that dispersed by an aerosol shaving cream dispenser. Foam application is still in the experimental and trial stage but the properties of the foam makes this, a desirable technique. Foams have larger volume, higher viscosity, better structural strength (cohesiveness) and greater clinging ability against runoff than conventional sprays. Additionally, foams have reduced evaporation characteristic and drift hazard. Weeds, insect and disease control by foam application shows considerable potential.

e. Soil Incorporation

Many preemergence herbicides, some insecticides, and fungicides, are applied to the soil. For improved efficiency they may be incorporated or injected into the soil. Conventional tillage equipment (discs, harrows, rotary tillers, etc.) are used to incorporate surface-applied pesticides to varying depths.[15] Spray sweeps are used to pressure inject many volatile herbicides, either in bands or in uniform swaths. Limited developmental effort has been vested in improvement of soil incorporation equipment.

3. Efficiency of Pesticide Application

The ecological impact of widespread use and dissemination of pesticides warrants renewed consideration of the efficiency of spray application methods.

The efficiency of pesticide application equipment lies in its ability to deliver a dose capable of killing or damaging the maximum number of pests with the minimum amount of material. It is possible to reduce pesticide usage significantly and still provide an effective pest control program by generating critical droplet size and uniformly distributing these so that the major portion of the pesticide reaches its target.

An increase in the efficiency of application equipment with commensurate reduction in the quantity of pesticide required would reduce environmental contamination.

The following factors are considered in determining the efficiency of pesticide application methods:

- Optimization of the pesticide droplet size for a target,
- Uniformity of coverage and impingement characteristics,
- Persistence of residue in the microenvironment of the pest, and
- Reduced drift, runoff and ecosystem contamination.

Methods of application, droplet sizes, and volumes of spray are examined in an attempt to define these factors which might serve to improve the efficiency of applied pesticides.

a. Spraying and Dusting

Highly toxic pesticides make effective pest control possible with minute quantities of toxicants provided the application method delivers a continuous film of minimum thickness. The manifestations of inefficiency in pesticide application are deposition of thick deposits, the existence of gaps between zones of deposit, or in some cases, both. If the gaps are of sufficient size, the pest will escape contact and/or ingestion will not occur. For example, stomach insecticides intended to control white pine weevil must be aimed to cover feeding areas which are only 0.8 mm in diameter.

Foliar applied dusts have the advantage that formulations emitted from the machine do not evaporate. Water-based sprays evaporate quickly before reaching the target and are inefficient in dry, hot climates.[7] This shortcoming may be corrected by using oil as a carrier.[16] In such climates soil incorporated dust applications are better than wettable powders.[17] However, some disadvantages are also associated with dust applications:[7, 18, 19]

- Insecticidal dusts, when emitted from a blower, consist of a mixture of discrete particles, with agglomerates, which may consist of as many as 20 to 300 coalesced particles. This factor of agglomeration leads to wide variation of settling characteristics even in a dust of uniform fineness of grind.[18]

- In addition to size, the shape and specific gravity of dusts are important in deciding their settling characteristics. Particles of high density such as barite or lead arsenate show good deposition on foliage, whereas Derris and Pyrethrum dusts, whose particles are light and angular, give poor deposits. Cryolite dusts deposit poorly because they show little agglomeration. The fractionation of dusts during the settling process may also separate the insecticide from its diluent. Dusts are deposited better on foliage nearer the blower than at greater distances, and more permanent deposits are produced with a strong air blast.

- Comparatively dust formulations drift more than the sprays.

- The dust particles do not adhere to the plant as long as spray deposits. The efficiency of pesticidal sprays is superior to dusts.

Improved efficiency of spraying over dusting is attributed to:[18]

- Less drift and better deposition. Consequently a spray achieves equal results with two-thirds as much pesticide and a single spraying may produce the control equivalent to as many as four dust applications.

- The capability of adjusting dosage rate, droplet size, and formulation at any time which is not possible with dusting.

Generally the efficiency of pesticidal spray exceeds that of dusting. However, a potential still exists for major improvement in spray methodology.

Spray conditions have been determined empirically because no technically-based alternative has been available. In spite of years of investigations, the physical factors critical in pesticide spray delivery a1e still largely undefined. Measurement has posed one problem. There has been no way to monitor pesticide spray droplets delivered to the target until the recent development of the fluoresent particle tracer method.[20] Results from the application of pesticide sprays were difficult to correlate with the conditions existing at the time of application. Such results are based mainly on the biological evaluation of pest levels over intervals of days, weeks, or even months after the pesticide application.

Despite these problems, progress has been made in pesticide application technology. This has involved primarily ULV application techniques, optimum droplet size and improved impingement.

b. Ultra Low Volume Spray

The development of the ULV method ranks as one of the most significant improvements in spray methodology. Application of an undiluted pesticide in volumes of 1/2 gallon or less per acre is referred to as ULV. A pesticide is considered undiluted if nothing is added after it leaves the manufacturer.[4] Actually, ULV is a relative term reflecting the progress primarily of aerial spraying since its initiation during World War II. At that time, the generally accepted application rates varied from 30 to 40 gallons per acre. Eventually, as pesticide formulations improved, the application rates were reduced to as little as one gallon per acre. Each incremental reduction in the total gallonage was referred to as "low volume" spraying.

For many years, pest control officials contended that at least one gallon of spray per acre was the absolute minimum that could be applied by aircraft and still adequately cover the area regardless of the vegetation involved. Thus, when the one gallon per acre barrier was broken, it was logical to refer to this as ULV spraying.

Advantages of ULV application of pesticides over higher spray volumes are that:

- It makes possible spray application with most droplets in the 5-50 μ diameter range. These were once considered to be beyond the range of commercial reality.[2, 4, 10, 21]

- To some extent, ULV spray reduces the amount of toxicant applied, and the potential hazard to the total environment.[10, 16, 22, 23]

- ULV-applied insecticides have more residual toxicity than water-diluted sprays and are more resistant to washoff by rainfall.[24, 25]

- Savings result from the reduction or elimination of diluents. This is a major factor in reduced aerial application costs.[10, 23, 26]

- Relatively nonevaporative quality of the undiluted ULV pesticides has permitted aircraft to fly higher, making it possible to double and triple effective swath widths.[27, 28]

Weather conditions are especially important in ULV applications because the slightest wind carries minute amounts beyond the intended area.[10,29] A hazard exists to the applicator who is handling concentrated pesticides under these conditions because of the increased degree of exposure. Sufficient research has not been conducted to fully exploit the ULV technique. Aircraft spray dispersal and pesticide formulations must be improved. Hazards to nontarget organisms from pesticides applied by ULV also need considerable delineation.

c. Droplet Size

The optimum size for pesticide spray droplets that must be generated is one of the most elusive of all the factors which affect the efficiency of insecticide sprays. The optimum size for pesticide droplets is that which gives maximum control of the target pests with minimum pesticide and minimum ecosystem contamination.[2] It has been hypothesized by one investigator that the ratio of recommended dose to that needed for insect control would be the order of 1,000:1 if droplets of the optimum size were used.[16] Current practice requires much lower ratios.

It is generally believed that spray droplets of 50 μ diameter or smaller are the most effective for the control of insects.[30] Such small droplets are subject to atmospheric transport and diffusion but they effectively penetrate the microenvironment of the pest. Spray droplets of 50-100 μ have marginal efficiency. Droplets larger than 100 μ are the least effective in insect control programs because they do not become airborne and are simply deposited on the ground or on peripheral foliage. These are critical locations for potential entry into the ecosystem and are of little use in pest control.[2] Table B-1

TABLE B-1 Spray Droplet Size as a Factor in Ecosystem Contamination.[2]

Range of droplet diam (μ)	Range of % by mass in an avg commercial spray	Point of deposition in ecosystem	Potential for Major ecosystem contamination
220-340	29	Ground, ground forage, peripheral foliage, target area crops	Extremely high by ingestion and washing processes into watershed
100-220	63	Ground, ground forage, peripheral foliage, drift to adjacent areas, crops	Extremely high by ingestion and washing processs into watershed
41-100	7	Throughout most foliage, smaller size range effective in deep foliage penetration drift to adjacent areas	Wide distribution of minimum volume of deposit minimizes major entry into arthropod and vertebrate ecosystems
10-40	0.14 (usually less than 1-5%)	Maximum contact with target insects distributed widely by atmospheric transport and diffusion	Minor component of most insecticide sprays. Represents minimum amount of insecticide

Source: Himel, C. M.

TABLE B-2 The Effect of Atomization on Coverage.[19]

Droplet Diameter, (μ)	Droplet Volume, (cu μ)	Number of droplets per sq in.[a]
10	525	1,148,100
20	4,200	143,190
50	65,520	9,224
100	525,000	1,164
200	4,200,000	142
300	14,175,000	43
500	....	9

Source: Brown, A. W. A.

[a]Number of droplets per unit area for an application of 1 gal/acre.

gives ecosystem contamination as a function of spray droplet size.

The number of spray droplets available from a given volume of liquid spray is an inverse function of diameter cubed. A better understanding of the discussion of small droplet compared to large droplets can be obtained from Table B-2. The number of droplets falling on a unit area decreases from about 10,000 per square inch when their diameter is 50 μ to only 40 when their diameter is 300 μ. Proportionally, the volume of pesticide (Table B-2) carried in a droplet increases considerably as the size of the droplet increases. This is the major reason for the undesirability of large droplets.

The optimum droplet sizes for insecticides used to control many major pests in the Southeast have not determined.[31] Only a few pests (house flies, mosquitoes, boll weevil, cotton bollworm, cabbage looper and spruce budworm, etc.) have been studied in this regard. For house flies, it has been determined that the optimum droplet diameter for maximum economy of the insecticide is 22 μ. Smaller droplet sizes are required for mosquitoes.[32]

The droplet deposition on the cotton insects studied in Georgia provides an interesting analysis (Table B-3). The maximum-sized droplet of 4331 measured on 139 boll weevils was one of 63 μ diameter. These boll weevils were in a highly protected environment during spraying (9 a.m. Aug. 1, 1967 at Tifton, Ga.).[33] A free-flying insect like the boll weevil should have been subjected to a significantly higher probability of contracting droplets of the larger size ranges existing in the distribution.[18]

Regardless of the initial droplet size distribution, an examination of target species reveals that only a critical droplet size range has been effective. This is exemplified by two case studies from different parts of the country and on different target species.[2]

In a complex mountain-forest biophysical system relatively fewer spray droplets were found on spruce budworms than on cotton insects (Table B-3). The diameters of the maximum-size spray droplet in the spray droplet spectrum, $D_{max.}$ of the spruce budworm and cotton insect sprays were 350 μ and 950 μ, respectively. In each of these foliage systems, droplets greater than 120μ diameter were found on peripheral and ground level foliage, or on artificial targets placed in open areas. Large droplets did not reach the target insects. The question raised is whether large droplets (> 100μ diameter) play any essential part in the control of insects which live in a foliage environment? Yet these larger droplets constitute 90-95% or more of many insecticide sprays. The answer is the key to devising more efficient insecticide application techniques, to reducing the amount of spray drift, and to reduce contamination of the ecosystem. The data, summarized in Table B-3, demonstrate that the limiting maximum diameter for efficient insecticide spray droplets for diverse types of insects is less than 50μ. There is no evidence that 100μ droplets have any substantial effect because the majority are unlikely to reach the target.

Droplets smaller than 100μ mass median diamter (MMD) of all herbicidal formations tested were markedly more inhibitory to all weeds than were droplets larger than 300 MMD.[34] The greater effectivness of small droplets may be ascribed to more efficient absorption and translocation of herbicide. Large droplets of high concentration probably become physiologically isolated. Their profound effects on the leaf cells occur only at the point of direct contact. A larger number of contact points are produced on the plants for the same application rate by the more numerous smaller droplets. This means that more susceptible tissue (e.g; the stem growing point) comes in contact with the herbicide

TABLE B-3 Effect of Environment and Application Variables.[34]

Insect	Nominal gal/acre	Nominal height of applica-tion (ft)	Max diam spray (μ)	Max size droplets on insects (μ)	Avg no. droplets/ insect	% of droplets of indicated diam(μ)		
						20-50[a]	50-100	100
Spruce budworm	1	300-400	350	100	3[b]	98.0	2.0	0
Boll weevil	1	30	950	63	31	99.8	0.2	0
Bollworm	1	30	950	114	122	99.8	.2	0
Cabbage looper	1	30	950	114	96	99.4	.6	0

[a] Under the conditions used, the (Fluorescent Particle) FP method does not identify droplets smaller than the range of 20 μ.

[b] Of a total of 1113 spruce budworm larvae killed by the spray and collected from random sampling areas, 23% had no FP's, indicating that they had been killed by a lethal dose of insecticide delivered by spray droplets smaller than 20 μ diam.

Source: Himel, C. H. and Moore, A. D.

than in the case of the large droplets.

Components of a fungitoxic material must be closely spaced over the leaf surface and deposited during weather periods suitable for spore germination, if infection by causal fungus is to be prevented. Continuity of the foliage deposition pattern and close spacing of the particles of the fungicidal ingredients are considered essential to good disease control. Toxicity to fungicide increases as particle size of the active ingredient decreases.[19] Exceptions to this general rule have been reported. For example, droplets as large as 400 μ were claimed to produce essentially as good a disease and insect control as did others of 100 to 150μ MMD when applied to a number of row crops.[35]

d. Impingement and Uniformity of Coverage

The first problem in applying pesticide sprays is that of distributing a small quantity of active material over a large target area. The uniformity and extent of the distribution required depends on the type of pest to be controlled and the mode of action of the toxicant. A patchy distribution may be satisfactory for control of mobile insects or to apply systemic pesticides to foliage. For static pests and contact pesticides, a more uniform spray deposit is required. The degree of distribution attained depends on:[36]

- The effective area of the target surface,
- The shape of the target,
- The method of spray application,
- The volume of spray applied to the target surface,
- The droplet size distribution of the spray,

- The extent to which the spray is capable of spreading over the target surface, and
- The extent to which the deposit is subsequently redistributed by rain or dew

The first two factors are invariable, while the next three can be varied by the spray operator. The formulator can manipulate the last three on this list. The size of the droplet can be controlled to some extent by both the applicator and the formulator. In the latter instance this is determined by modification of the physical properties of the formulation.[36] For improved distribution, understanding of the effect of operating parameters on the droplet size is essential. It is unlikely that such comprehension exists with most applicators.

Pesticide impingement and uniform coverage are closely related to droplet size and to drift. Small droplets of 100μ diameter or less tend to become airborne. They have a higher probability of impinging on the target during low to mild conditions. For example, with a droplet of 70 μ and a wind of three miles per hour, the probablity is 10 times greater of its landing on a vertical surface than on a horizontal surface.[16] Since most crops grow vertically, this drift phenomenon is utilized to achieve better impingement or coverage. However, as wind velocity increases (approximately, above 5 miles per hour) the probability of the droplet striking non-target areas is increased. In addition, the very small droplets are subject to undersirable upward movement via convective currents (Table B-4). Under certain meteorological conditions, the ideal droplet size for effective insect control may need to be adjusted if the pesticide is to be delivered into the microenvironment of the pest. There is another control on the application system. This is a lower

TABLE B-4 Drift Pattern in Relation to Particle Size.[5]

Drop Diameter (μ)	Particle Type	Distance in ft. Particle Would be Carried by a 3-mph Wind While Falling 10ft.
400	Coarse aircraft spray	8 1/2
150	Medium aircraft spray	22
100	Fine aircraft spray	48
50	Air carrier sprays	178
20	Fine sprays and dusts	1,109
10	Usual dusts and aerosols	4,436
2	Aerosols	110,880

Source: National Academy of Sciences.

limit to the size of droplets for deposition on vegetation, weeds or the food of the pests. If the droplets are too small they do not have enough momentum to impinge upon the target surface.

For an aerosol to kill mosquitoes, in forested areas, the droplets must be smaller than 30μ in diameter; this prevents excessive filtering by the foliage.[18] For penetration through thick jungle, it has been determined that the droplet size should be below 10μ . If, however, the aerosol is applied to forest from aircraft with the aid of downdraft of the wing airfoil, it will penetrate and impinge so long as the droplet diameters do not exceed 50μ When emitted from generators on the ground, droplets of more than 40 μ diameter do not remain airborne for a sufficient distance to be useful. An increase in wind speed enables the larger droplets to make better contact with the target. When penetration into coniferous forest is required, the wind speed in the open should not be less than five miles per hours.[19]

It is apparent that the proportion of the spray occurring as small droplets (50μ or less) is of paramount importance in pest control. Knowledge of the in-flight behaviour of small droplets and of the mircrometerological factors affecting them would allow delivery of small droplets to the target and reduce drift potential from agricultural spray operations. The overall plant coverage and deposition of small dust particles and spray droplets can be improved. Two approaches have been advanced. Surface-active agents are commonly used and the charging of aerosol particles has also been considered for improvement in plant coverage. Adjuvants and surface-active agents added to pesticides improve their deposition, activity and disperal. This is particularly useful for herbicide application.

Examples are:[37,38]

- Wetting agents. These reduce interfacial tension and bring the liquid into intimate contact with an object. The addition of wetting agents to a pesticide, therefore, increases its adherence to the pest.

- Emulsifiers. These tend to prevent tiny droplets from coalescing.

- Penetrating agents. These may solublize the waxy cuticle or membrane of the pest so that penetration of pesticides is more readily achieved.

- Dispersing agents. These reduce cohesion between like particles which aids in pesticide dispersal.

- Spreaders. These increase the spread of the droplets and thus form a uniform coverage on the plant surface, and

- Stickers. These prevent runoff of pesticides.

A number of studies concerning the efficiencies of the charging and deposition process of the electrostatic pesticide application method have been conducted over the past two decades.[11,39-42] These field and laboratory studies reported indicate that the electrostatic processes are effective. The equipment is reliable under all weather conditions under which pesticide application might be considered, provided properly designed equipment is used and satisfactory operational procedures are followed. Dielectric nozzles were superior for inductive spraying.[39] Inductive spray charging significantly increased the spray coverage of the bottom side of cotton leaves. An average increase of 3.8 times the quantity of pesticide per unit area for the same application rate was achieved over uncharged sprays. This difference was measured on the leaf bottoms which is the critical area. The bottom area hosts the majority of pests. In another test electrostatic charging enhanced deposition 2.7 times that of uncharged spray.[40]

Direct application of electrostatic charging to agricultural sprays using high applied voltages similar to those for charging paint sprays has not been tried. This is because safety, portability, and reasonable size are difficult to achieve for equipment requiring high voltages, such as 50-100 KV, under field conditions.

Electrostatic deposition of dust requires a different nozzle than those previously described for spray applications. The nozzle found most efficient for electrostatic dusting is of the air curtain type.[11]

Air curtain nozzles give higher deposits per unit area of a more uniform distribution than any of the commercial nozzles evaluated. The average deposition efficiency of charged dust is more than double that of the uncharged dust. However, this efficiency varies with the properties of material and the operating conditions. The major variation in performance of the electrostatic dusting equipment has been attributed to variations in the electrical resistivities of the dust formulation, and to the relative humidity at the time of dusting.[41]

The efficiency of any pesticide spray and the degree of control obtained is a function of the ultimate point of deposition of each of the pesticide spray droplet produced. Although the initial justification for electrostatic charging of pesticides was primarily a matter of economics, the need to reduce environment pollution has become an increasingly important additional consideration.

e. Soil Incorporation

Soil application of pesticide is an essential agricultural practice. It is required to control weeds prior to their emergence, to reduce injury to crops from soil-borne diseases (root rot, seedling diseases) and by insects active in the soil environment (corn borers, cut worms.) Improvements in methods of application have been made to increase the effectiveness of soil-applied pesticides. Soil incorporation is one of the most prominent of these methods. Injection (subsurface spraying) is used to a lesser degree.

In a study conducted in Georgia, incorporation of pesticides into the soil surface by rototilling caused a tenfold reduction of Lindane and Dieldrin losses in run-off water.[43] Greater loss occurred from soils where the Aldrin was left on the soil surface following an emulsion application. Increased persistence occurred after granules had been incorporated into the upper 4 to 5 inches of soil layer.[44] This suggests that where high levels of pesticides are present on a soil surface, the possibility of harmful water pollution from the area could be greatly minimized by incorporating the pesticides into the soil.

From the standpoint of agronomic practices and environmental considerations, the following advantages can be obtained by soil incorporation methods rather than surface applications of pesticides:

- Increased herbicidal effectiveness by dispersal in the root and emerging shoot zone, increasing the possibility of contact with weeds and other pests.[45-49]

- Reduced loss of herbicide through incorporation to appropriate depths and maintainance of a lethal concentration in the surface soil for increased residual action. Incorporation decreases runoff and drift and increases residual action for prolonged weed control.[47, 50-52]

- Decreased variability in the results from area to area and from season to season have been clearly demonstrated. Results with most surface applied chemicals are highly dependent upon soil and climatic conditions. Several investigators have shown that exposure to sunlight or ultraviolet light plays a major role in decomposition of herbicides on the soil surface, and the chemical volatility and high temperature greatly affects the break down of certain chemicals. Reduced variability in the performance of a herbicide under varying soil and climatic conditions,[53] and

- Decreased volatilization, runoff and drift.[51]

The efficiency of weed control with soil-incroporated herbicides is affected by many factors. These include soil conditions (moisture, temperature, texture and structure), physiochemical properties of herbicides and environmental conditions (sunlight, temperature and rainfall). Depth of incorporation and the tools utilized have been shown to affect the herbicidal efficiency.[15,46,54-58]

The development of herbicides requiring soil incorporation created the need for a device capable of uniform incorporation. However, incorporation tools presently available do not provide the desired soil placement. Development requires methods of evaluating these devices with respect to uniform distribution of the chemical in the soil and depth of mixing. Several investigations have used a traceable material as a substitute for the herbicide. These included radioisotopes, granules, magnetic particles and dyes.[59] A fast and efficient method of evaluating soil incorporators utilizes a fluorescent dye.

Because of the strong sorption of many pesticide residues to soil particles, pollution by pesticide occurs through the transport of pesticides-laden soil particles to the aquatic environment. Erosion control combined with soil incorporation provides a means of drastically reducing surface runoff and volatilization losses.

4. Conclusions

Presently, 63 percent of all pesticides are applied by aircraft. The remainder is applied with ground equipment. Most pesticides are applied as sprays, either to the plant foliage or to the soil surface. Some pesticides are incorporated in the soil. Consequently, any research program designed to minimize contamination of the ecosystem by pesticides must include improvement in spray application and soil incorporation equipment.

Pesticide usage could be significantly reduced and still provide an effective pest control program if it is uniformly distributed and the major portion reached its target. The initial problem is to atomize relatively non-volatile pesticides formulations into uniform-size droplets which are sufficiently numerous that the pest cannot avoid contacting a lethal dose. The second problem involves deposition of small particles or droplets on the target. One of the methods that could improve deposition of pesticides is electrostatics. The third problem involves incorporation and injection of soil-applied pesticides. These processes involve optimum depth considerations. All of these problems merit intensive research and development.

Spray efficiency is related to optimum droplet size, uniformity in spray coverage produced, and degree to which drift and runoff is minimized. Ninety percent or more of spray droplets produced by existing aerial and ground equipment are not of the optimum size. This portion of the spray constitutes the major source of pesticidal pollution.

5. Recommendations

1. The program of the Agricultural Research Service of the U. S. Department of Agriculture (USDA) to determine the optimum droplet size range for major pests should be expanded. Research on improved methods of pesticide impingement through the use of electrostatics and other techniques should also be increased.

2. Government and industry should jointly engage in the development of improved pesticide formulations and the design of equipment capable of producing the desired droplet size.

3. Government and industry should expand research to improve soil incorporation and injection equipment.

4. The Environmental Protection Agency and USDA should jointly sponsor studies on the comparative efficiency of methods of pesticide application to minimize contamination of the environment.

5. *The Department of Agriculture, through its Extension Service,* should encourage growers and custom operators to use the most advanced pesticide application equipment under proper meterological conditions.

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C. THE ROUTE OF PESTICIDES INTO AQUATIC ENVIRONMENT

1. Introduction

Pesticides may enter surface waters as a result of agricultural, commercial, and domestic applications. They are used for diverse purposes such as control of pests in agricultural products, stored food and fabrics, structural material, parks, golf courses, home lawns and gardens, etc. Other sources of pesticidal entry into the aquatic environment are industrial waste discharges; pesticidal applications directly onto water surfaces; drift from aerial applications; overland drainage; intentional dumping; cleaning of contaminated materials and equipment; incinerator and open burning gaseous and particulate discharges; wind-blown, treated materials; and accidental spills.

Agriculture is the chief consumer of pesticides in the Southeast. Their fate after application is complex. It may involve biological and photo-degradation, chemical oxidation and hydrolysis, direct volatilization, and migration into adjacent areas, translocation into plants, and sorption onto airborne particulates and soil materials. It is difficult to accurately determine the quantity of pesticides transported into the aquatic environment from time and place of such applications. A more thorough understanding of the physicochemical nature of the pesticide, as well as the associated ecological system, will be necessary to comprehend their route into the aquatic environment.

Soil is an important terrestrial sink for pesticides. It controls the movement of the chemical through leaching and/or vaporization. Transport into and within the water media is likely to involve particulate matter and sediments via processes as yet not been well defined.

Information is not available to describe the role of natural hydrologic dynamics in controlling the movement of pesticides through the aquatic environment. There is well-documented evidence that certain chlorinated organic pesticides are rather widely distributed and persistent in the environment and are accumulated in the aquatic food chain. Intensive systemic research is required to provide a more complete understanding of the interaction between pesticides and the water environment.

2. Properties of Pesticides

The nature of pesticides is one of the most important factors that governs their movement into water courses. Like other chemicals, they obey physical and chemical laws. By defining their behavior and properties, a better understanding of their effects in the environment will be realized. The relevant physicochemical properties of pesticides include the dissociation constant, molecular structure, size and configuration of molecules, water solubility, and dipole moment. These and other properties appear to influence the movement and retention of pesticides in, through, and from soil surfaces. The dissociation constant indicates the degree of acidity or basicity. This is an important factor in the sorption and desorption of the pesticide in soils. The electronic distribution within the molecule establishes its properties and will be affected by the nature of aliphatic and aromatic substitutions onto the parent molecule. In turn, these affect the ease of hydrogen bonding. Van der Waals forces increase with increasing molecular size and especially with increase of the number of double and triple bonds. The nature of functional groups further influences inter-and intra-molecular hydrogen bonding and affects the affinity of the molecule for the sorbing surfaces. Sorption may be precluded through steric hindrance as a result of molecular configuration. Water solubility will influence the partition of the pesticide among the liquid, solid, and vapor phases. This affects transport of the compound from the area of initial application. The degree of polarity of the pesticide affects its solubility in water and its affinity for sorbing surfaces. Thus, the dipole moment may correlate with the retention and movement of pesticides in soils and in aquatic environment. Molecular chemical properties are closely related to the functional groups and strucuture of the pesticide molecule. It is known that the sulfur atom in the alkyl chain of an organic compound can be easily oxidized in the atmosphere to sulfoxide or sulfone. Thimet and Temik, organic phosphorus and organic carbamate pesticides, respectively, are examples. They become more toxic when they are oxidized. Purely chemical reactions taking place between pesticides and soils have been reported[2]. A detailed analysis of the chemical properties of pesticides is beyond the scope of this report.

Organic phosphorus pesticides hydrolyze with comparative rapidity. Although Parathion is long-lived (50 percent hydrolyzed in water in 120 days), most of this class are hydrolyzed over intervals of hours to a few days[3]. An unusual case of persistence of Parathion has been reported[4]. About 0.1 percent of the total Parathion applied to soil remained 16 years after application. Parathion may have dissolved into lipids of the soil organic matter and thus have been protected from bacterial degradation and hydrolysis. Degradation of Parathion occurs either via hydrolysis or by reduction to its amino form. The latter alternative depends upon the population of soil microorganisms. In soils of low moisture content and low microorganism activity, Parathion persists over longer periods[5]. Carbamate compounds are less persistent and disappear in rivers within 8 weeks of application[6].

Chlorinated hydrocarbon pesticides exhibit a very high photo- and biological-resistance. Technical Aldrin, Chlordane, Endrin, Heptachlor, Dilan, Isodrin, BHC, and Toxaphene remained in Congaree sandy loam soil up to 14 years and were measured at 40, 40, 41, 16, 23, 15, 10, and 45 percent of initial application, respectively,[7] Thirty-nine percent of the DDT remained in three types of soil up to 17 years. No measurable degradation nor chemical change was observed for BHC, DDE, DDT, DDD, Dieldrin, Endrin, and Heptachlor epoxide after 8 weeks in river water[6]. The high stability and long persistence of certain organochlorine pesticides in soil have been reported[8-12]. Persistence of these compounds is influenced by soil type, moisture, temperature, and mode of application. DDT, Aldrin, and Lindane persist longer in muck soil than in Miami silt loam[10]. The persistence of Aldrin is affected by soil moisture. Water, apparently, causes a displacement of the Aldrin from the soil particles and enhances evaporization of the compound[9]. Aldrin and Heptachlor persist longer in soils of low temperature than in soils of high temperature[10]. Incorporation of Aldrin and Heptachlor into the soil increased the persistence of these compounds by a factor of ten[12].

Interaction between herbicides and soil microorganisms has been studied[13, 14]. It was demonstrated that various phenoxyacetic acid herbicides are more inhibitory to microorganisms under acid conditions than under neutral or alkaline conditions and they disappear more rapidly from soils under conditions favorable for microbial development[14]. Photo-and biological-stability are inherent properties of individual pesticides and important in determining their persistence in the environment. Organic herbicides in water may be completely destroyed by exposure to intensive high energy radiation[15].

Picloram could not be detected in a solution which originally contained an initial concentration of 1 milligram per liter (mg/l) after 30 minutes or less exposure to high intensity ultraviolet irradiation. Enzymatic conversion of chloromaleylacetic acid to succinic acid has also been reported[16]. In order to understand the route of pesticides and their by-products into the aquatic system, these and other processes must be considered. For example, *photo-and biological-detoxification of* pesticides determine over what distance and time they effect the aquatic environment. There is also an urgent need to develop effective pesticidal decontamination methods suitable for use in various aquatic environments. Activated carbon treatment of potable supplies is the only established process[3]. No comparable treatment of natural systems exist.

3. Sorption-Desorption Phenomena

The principal source of water pollution by pesticides today is runoff from the land. To ascertain directly the transport mechanism of pesticides by overland flow, it is necessary to understand fully the sorption and desorption of chemicals on soil and aquatic sediments. Clay minerals are the major components of Southeastern soils and complexation onto their surfaces is an important factor. Sorption and desorption of organic pesticides by soils are closely related to soil type and constituents, moisture, temperature, cation exchange capacity and surface area, and the physiochemical properties of the pesticide itself. Organic components of the soil appear to possess the greatest sorption potential for cationic and molecular pesticides[1, 17, 18]. The clays, especially montmorillonite and vermiculite, play an important role in sorption because of their high cation exchange capacity and relatively large surface area. The oxide and hydroxide components of the soil may also contribute to the total sorption capacity through high anion exchange capacity and large surface area.

The forces involved in sorption may be coulombic (chemical sorption), Van der Waals (physical sorption), or hydrogen bonding. Isotherms have been measured for a series of herbicides sorbed onto clays and found to be highly dependent on pH and electrolyte concentration[17]. The organic content is usually very low in many of the coarse-textured soils of the Southern United States. In this situation the clay fraction assumes a greater importance as sorption sites for pesticides.

Biodegradation markedly affects the stability of dilute organic clay complexes in solution. If this is not recognized then misleading information can result from sorption studies[19]. Clay particulates are usually negatively charged in aqueous solutions. Sorption is attributed to the charge attractive forces between the negatively charged clay surface and the positively charged organic ions[20]. Unionized organic molecules and organic anions are either not sorbed or are very weakly sorbed because of competitive sorption of the more polar water molecule and the repulsive force between the organic anions and clay surface[20]. Sorption by organically treated clay indicates that the solubility of the organic sorbate mainly governs the extent of sorption[21]. This organo-clay is often hydrophobic in nature.

Pyridine sorption onto kaolinite and montmorillonite is described by the empirical Freundlich relationship (amount sorbed per unit weight is an exponential function of the equilibrium concentration of the sorbate)[22]. Significant sorption occurs in less than 17 minutes and is attributed to a cationic exchange process. The amount sorbed depends on the aqueous solution pH and temperature. Maximum sorption occurs at pH 4.0 and

5.5 for sodium montmorillonite and sodium kaolinite, respectively. In the case of desorption, pyridine desorption is directly related to the number of stages and/or the volume of solution, with maximum desorption occurring at pH 1 and 11. Desorption is much slower than sorption at a comparable pH and clay to organic ratio[23]. These carefully-controlled studies must be repeated with many of the pesticides if the processes affecting persistence are to be understood. Many of the published results are suspect because adequate experimental controls were not maintained.

Huang, et. al. reported that the sorption of DDT, Heptachlor, and Dieldrin by kaolinite, illite, and montmorillonite is very rapid and exhibits Freundlich type isotherms[24,25]. These investigators concluded that the primary mechanism of the sorption of these pesticides by clays is through the formation of hydrogen bonding and other strong forces of interaction. Only Van der Waals forces contribute significantly to the sorption of Dieldrin. These findings may be in error. Because of the nonpolar nature of the chlorinated hydrocarbon, it is very unlikely that they are retained by the pure clay particle via any of the aforementioned sorption forces. In fact, these pesticides tend to associate with or accumulate in the organic fraction of the crude clay. The clays used in many studies are not properly characterized or prepared to assure that they are not organo-clays at the outset. In nature, they may be converted to organo-clays but the nature of these converted materials is not known.

It has been reported that the sorption and desorption of Dieldrin by montmorillonite sediment are not significantly affected by either temperature (10°C to 30°C) or salt concentration (0.03 to 3.0 percent)[26]. The investigator also stated that soluble organic matter, such as glucose, alanine, and stearic acid, did not exert an effect on the rates and equilibria of the sorption of Dieldrin, DDT, and Heptachlor by montmorillonite and illite. These investigations are not scientifically acceptable as reported. There is no specific description of the physicochemical characterization of the clay or the experimental techniques[27,28]. The nature of saturating cation, source and purity of the clay minerals employed, clay particle size and surface area, and the pH of the aqueous system are important factors which will affect the sorption properties of the clay. These must be reported if the results are to be meaningful.

The sorption of dithio-carbamates (fungicides) by clays is reported to be the result of coulombic forces because of the ionic nature of the compound in solution[17]. The ethylene dibromide (a fumigant) and organic phosphorus insecticides may be retained at the clay surface through external hydrogen bonding. This is because of the noncharge nature and unequal distribution of charge of the respective molecules[17].

The sorption of 2, 4-D by Bentone 24 (an organo-bentonite) is rapid and considerable but sorption of the chemical by untreated bentonite was below detectable limits[29]. Greater sorption was found in more concentrated sorbate solutions or under more acidic conditions. Sorption is directly proportional to the organic fraction of the clay. Thus, reports that clays sorb negatively charged molecules (such as 2, 4-D) may be attributed to a mechanism not readily appreciated by those making the studies. The clays complex organic molecules, such as amines, cationic detergent, etc., from aqueous solution and the resulting organic clay surface then sorbs the 2, 4-D. The physical and chemical nature of the organo-clay surface determines the extent of subsequent sorption of other organics such as pesticides.

It has been reported that clay minerals (illite, kaolinite, and montmorillonite) sorb very little 2, 4-D or Isopropyl N- (-3 Chlorophenyl) carbamate (CIPC)[18, 30]. Hamaker, et. al. found that organic matter and hydrated metal oxides are principally responsible for the sorption of 4-Amino-3, 5, 6-trichloropicolinic acid on soil[3]. The poor sorption of this compound's anionic species by clay minerals and the strong sorption by hydrated metal oxides would appear to be consistent with a process of replacing the hydroxyl ions from the metal oxide surface. The greatest sorption of the acids, 2, 4-D, and 2, 4, 5-T was observed onto soils containing a high percentage of organic matter and for red and acidic soils[31].

Freundlich type isotherms were measured for sorption of a number of herbicides onto montmorillonite[32]. Regardless of the chemical character of the sorbent, sorption occurs to the greatest extent on highly acidic H-montmorillonite (a homoionic clay) as compared to the near neutral Na-montmorillonite. The degree of sorption of organic compounds with widely differing chemical characteristics is governed by the degree of water solubility, the dissociation constant of the sorbate and the pH of the clay system. The surface acidity affects the sorption of basic organic compounds by the clay.

The organic content of the soil is the major factor influencing retention of chlorinated hydrocarbon pesticides in soil. For example, dieldrin retention is related to the organic content of the soil[33] and the immobilized residues of herbicides-derived chloroanilines are chemically bonded to humic substances of the soil[34]. However, as stated earlier, the organic content of many of the coarse textured soils in the Southern United States is very low. In these states, the clay fraction of the soil is likely to be the principal factor involved in sorption of pesticide.

Within the aquatic environment, it has been established that bottom sediments exhibit higher pesticide concentrations than surface water[35, 36]. For example, 0.02 to 3.58 parts per million (ppm) of DDT and its metabolites and 0 to 2.47 ppm of Toxaphene were found in the bottom sediment of selected Delta Lakes in Mississippi[35]. Lake waters are generally low in pesticide residues. It has been found that the sorption of both Endrin and Dieldrin by bottom sediment is time-dependent and pH sensitive[36]. The sorption of Dieldrin occurs only at a low pH. If the pH is adjusted above 7, Endrin will not remain associated with the bottom sediments for an extended period of time. Similarly at pH greater than 8, the sorption of Dieldrin is negligible. The sorption of Endrin is salinity-dependent, but not so, in the case of Dieldrin. Because the pesticidal concentration is maintained by a dynamic equilibrium, the desorption of pesticides from bottom sediment may occur as a function of changes in physical, chemical and biological stresses. This provides a potentially continuous supply of these chemicals to the aqueous solution. This tends to extend the potential contact time of the pesticides to aquatic organisms and affects the aquatic food chain.

The aquatic organism can magnify many-fold the pesticide doses originally introduced into the ecosystem. The dose is passed along and concentrated in the aquatic food chain. Eventually it may reach man or recycle in the aquatic environment. It has been determined that flora and fauna contain DDT and its metabolites nearly 1,000 times as great as the concentration present in the water[37]. Residues of DDT and its metabolites, and Toxaphene in the flesh of fish from selected Mississippi Delta Lakes have been found to be 0.15 to 10.60 ppm and 0 to 20 ppm, respectively[35]. The median concentrations of Endrin and Dieldrin in oyster samples were determined to be less than 10 ppm in the lower Mississippi River[36]. It was found that DDT accumulated in lake trout[38] and in marine phytoplankton[39]. Toxaphene concentrates in aquatic plants and fish[40]. The biological magnification capability of aquatic life significantly increases the hazardous and destructive potential of pesticides originally present in the water. It also serves to localize these materials and modify their transport within the aqueous system.

Pesticidal contamination is found on plants and agricultural products grown on pesticide-treated soils. These pesticides are apparently first sorbed by the root system and then translocated into the plant. Aldrin and Heptachlor residues have been found in cucumbers and alfalfa grown on pesticide-treated soils[41]. Similarly, residues of Endrin or DDT have been detected in turnips[42], soybeans[43,44], and peanuts and tobacco leaves[44,45] grown in soil treated with these pesticides. Cotton plant leaves accumulate different amounts of Dimethoate under different light and humidity conditions. Both high humidity and darkness greatly reduce Dimethoate accumulation in the leaves[46]. Five kinds of carrots were found contaminated with various amounts of Aldrin or Heptachlor. This was a result of considerable difference in rates of sorption[47]. DDT, BHC, and Parathion are translocated to root crops and cause decreased yields[48].

It can be concluded that sorption and desorption processes are the major factors influencing pesticide movement into aquatic environment after application. Sorption is affected by soil type, clay and organic content of the soil, soil temperature, physicochemical nature of the pesticide, the degree of the saturating cations on the colloid exchange site, and pH of the ecosystem. Bottom sediments, aquatic organisms and plants grown in pesticide-contaminated areas accumulate large amounts of pesticides. Sorption capacity and desorption processes for various types of soil need investigation under varying field conditions, such as rainfall intensity, pH, temperature, etc. Less persistent pesticides may be necessary at certain times. Appropriate concentration and application techniques must be evolved.

4. Movement into Water

Water solubility, although important in the physical transport of the pesticide from the area of application, is not considered to be the major factor in leachability. A very water-soluble compound will not leach if it is irreversibly sorbed and an insoluble compound will leach readily if it is not sorbed[49]. The moisture content of the soil as well as the intensity and frequency of rainfall affect the overall movement of pesticides in the soil. A low moisture content favors retention of the pesticide in soil because it lowers total solubility and enhances the competition of the pesticide for an adsorption site. Bailey reported that a lower rainfall intensity resulted in greater removal of a herbicide from the upper surface horizons than did less frequent rainfall[1]. Certain pesticides are leached in greater amounts and to greater depths under lower rainfall intensities. Weather patterns may be as important as total rainfall in determining the movement of herbicides in soil[17].

With readily available soil moisture, phytoactivity may be enhanced. This action likely results from increased susceptibility of a plant to the herbicide, increased transpiration, and/or increased availability of the herbicide[49]. Laboratory data showed that penetration of Dieldrin into the soil is dependent on both soil type and moisture level at the time of application. Thus, distribution in the soil may vary from a thin layer of concentrated insecticide to a relatively thick layer of less concentrated insecticide. Field penetration of Dieldrin was found lowest in arid soils and highest in wet soils[50].

The movement of water into the soil from the surface is known as infiltration while the movement of water through the soil is known as percolation. The infiltration of water into the soil depends on the soil's initial moisture content[51]. The forces of gravity, capillarity and hydrodynamic factors cause the movement of water soluble pesticides down through the soil. Soil texture will affect the movement of pesticides[1, 18] *Pesticides leaching is greater in soils of light texture.*

The three major means of pesticide transport[1] within soil are:

- Diffusion in the voids of the soil
- *Diffusion in the soil water*
- Downward flowing water

The first and third are important in the movement of volatile and nonvolatile pesticides, respectively. Pore size and pore size distribution affect the rate of water passing through the soil as well as the extent of downward spreading motion of the pesticide.

If no appreciable attenuation occurred, a pesticide could pass through the following parts of the environment in sequence[52]

- Soil Surface
- Zone of aeration or the zone between the soil surface and the water table
- Zone of saturation or the zone of groundwater
- Stream course
- The sea.

In some cases, pesticides extend through the zone of aeration into the zone of saturation where they tend to spread laterally.

The depth of the zone of aeration varies from near zero in swampland to several hundred feet in arid regions. The zone of saturation may extend to a considerable depth, but as the depth increases, the accompanying weight of the overlying soil and material tends to close pore spaces and, thus, relatively little potable water is found at depths of more than 2,000 feet.[53] In the zone of aeration the moisture may be present as gravity water in transit to large pore spaces, as capillary water in small pores, as hydroscopic moisture adhering to a thin film on the grains of soil, and as water vapor.

The movement of water vapor in the soil is related to temperature, i.e., vapor movement is from high to low temperatures. However, for the most part temperature gradients are usually small and the quantity of moisture moved is negligible.

Groundwater, in its natural state, is constantly moving and this movement is controlled by established hydraulic principles. Darcy's law is used to express the movement through aquifers, most of which are natural porous media. The measure of the ease of flow through the porous media is known as permeability.

Sorption and retention of cations on the surfaces of aquifers are dependent upon the fine silt, clay, and organic fractions of the aquifer. The principal cations involved are sodium, calcium, and magnesium. The soluble products of soil weathering and erosion add salts to the groundwater during its passage through soils. Irrigation water, percolating to the water table, contributes large quantities of salt. This is primarily the result of the drainage water salts being concentrated by the evapotranspiration process.[54]

Generally, the chlorinated hydrocarbons, such as DDT, persist in the soils and do not move in appreciable concentrations through the soils and into the drainage effluent as groundwater.[55] Pesticide residues do not penetrate deeply enough into the soil to obviate a biological hazard. Downward movement is aided by cultivation. The preponderance of residue accumulations appears to be confined chiefly to the top one foot of soil, and within this depth most residues are found within the cultivation layer (4 to 6 inches). In the fire ant control program, most Heptachlor residues have been found within the top inch of soil. Humus layers fall within the zone in which most residues occur.[56]

The movement and distribution of DDT in a heavy clay soil has been studied by several investigators. For example, Swoboda, et. al. found that most of the DDT remained in the top 12 inches of soil but that some DDT was found at the lower profiles probably as the result of leaching.[57] Breidenbach, et. al. reported that percolate water, intercepted below the rooting depth at 2.44 meters (8 feet) contained no Methoxychlor and only trace amounts of 2, 4, 5-T fourteen months after application. The total amount of 2, 4, 5-T found in the percolate was so small that it did not indicate significant contribution to groundwater contamination.[58] A major portion of the applied pesticide was removed from the soil by overland drainage.[58]

The movement of micron-size particles through a sand bed has been investigated using radiochemical tracers.[59] The transport rate of the finer particles was essentially the same as that of the cations in solution, while the rate of the coarser particles appeared to be significantly slower. Sodium humate, a common soil constituent, can solubilize insoluble pesticides such as DDT in water, thereby, facilitating the transport of the pesticide. Swoboda, et. al. suggest that the movement of pesticides in soil in the Southern states is primarily caused by leaching, movement with soil particles, and volatilization (because of high soil temperatures).[57]

A mathematical model has been developed to describe the movement of DDT and its decomposition product, DDE, in an ecosystem. Some predictions of the consequence of adding DDT to the environment are possible and are based on its transport, accumulation, and concentration, within ecosystems.[60]

It can be concluded that a major portion of the applied pesticide is removed from the soil by overland drainage. Movement of pesticide through the soil by infiltration and percolation is small and it contributes in only a minor way to groundwater contamination.

a. Direct Application

Many organic pesticides are added directly to water to control aquatic insects, trash fish, and aquatic plants. Examples include: Dieldrin for control of sand fly larvae; Toxaphene and Rotenone for control of various species of fish; and phenoxy acetic and propionic acid for aquatic plant control.[61] In these cases, direct water contamination results.

It has been found that Fintsol can be used more effectively than Rotenone under a wider variety of conditions for controlling sunfish in catfish pounds.[62] Aquatic weeds (Parrots Feather, Needlerush, *Pithophora sp.*, *Potamogeton sp.*, and *Microcystis sp.*) have been controlled by the application of herbicides (2, 4-D, Aquion, Karmex, copper sulfate and Kuron) in conjunction with fish production.[63] High rates of 2, 4-D application for water milfoil control in Tennessee Valley Authority reservoirs have not produced adverse effects on aquatic fauna or water quality.[64]

In a sand fly eradication program, it was reported that during 1955, 2,000 acres of salt marsh in St. Lucie County, Florida, were treated with 1 lb/acre of Dieldrin.[3,65] Twenty to thirty tons of fish, an estimated 1,117,000, representing some 30 species, were killed and reproduction was not observed for four weeks. Crustaceans were virtually eliminated; however, fiddler crabs survived in areas missed by the spray treatment.

The presence of tree roots in sewer lines creates a major problem in urban areas. Control has been achieved by the flooding technique for addition of herbicides such as Metham and Dichlobenil.[66] However, this practice does not take into account that these herbicides will be introduced into the sewage system and may then present a major contamination problem.

To eliminate harmful side effects on non-target species, direct application of pesticide to waters should be minimized and alternative controls devised wherever possible.

b. Overland Drainage

Not all of the pesticides applied to land end up in a waterway, but it is likely that almost all pesticides in streams result from storm runoff or overland flow.[1, 52, 55, 67, 68] The pesticides are initially sorbed onto particulate matter and then transported as complexes to the water course.[1] Chlorinated hydrocarbon pesticides have been found in bottom sediments in 126 locations of the Mississippi River. These deposits are attributed to agricultural sources.[69, 70] Since chlorinated hydrocarbon pesticides are only slightly soluble in water, they may be transported as a film, emulsion, or in association with particulate matter. Chlorinated hydrocarbons are found in surface waters of the Southeast.[71, 72] The number of occurrences reached a peak in 1966. Their presence has declined sharply since 1967. This trend is consistent with the decrease of production and usage of chlorinated hydrocarbons and the increase in the use of organophosphorus and carbamate compounds.

Instances of surface water contamination with chlorinated hydrocarbon pesticides have occurred in certain areas of Georgia[73], in major river basins of the United States, in the Mississippi River and Delta area[72, 75, 76], in sugar cane farming areas of Louisiana[77], and in farm ponds.[78, 79] Surface runoff from fields was the main source of these pesticidal contaminations. For example, Toxaphene and BHC were detected in all samples taken from a stream in northern Alabama from the summer of 1959 through the winter of 1963. Analyses of treated and untreated drinking water showed that purification processes failed to completely remove these two compounds.[80]

(1). Soil Erosion

The transport of pesticides into the aquatic environment and their persistence presents a complex problem.[81] It has been established that there is a relatively long persistence of certain chemicals which have been in use since 1945. Eroded soils previously treated or incorporated with pesticides are major sources of surface water contamination. It has been estimated that the gross sediment eroded each year in the United States is around 4 billion tons. This loss occurs by the processes of sheet erosion, gullying, and a stream channel erosion.[82] Entrainment, transportation, and deposition of sediments depend on the properties of the sediment and the hydraulic characteristics of the waterway. The seven principal sources of streamborne sediment are:[83]

- Sheet erosion, the removal of surface soils by overland flow without the formation of channels of sufficient depth to prevent cultivation or crossing farm machinery;
- Gullying, or the cutting of channels in soil caused by concentrated runoff;
- Erosion of stream banks and channels;
- Mass soil movements, such as landslides;
- Flood erosion; and
- Erosion associated with development, such as roadway construction.

The modes of sediment transport may be classified as:[82]

- Bed load, rolling or sliding of sediment along the stream bed;
- Suspended load, suspension of sediment in the moving water; and
- Wash load, fine particles carried into and through the channel with no relation to the stream bed material.

An investigation of Atrazine associated with runoff and erosion was made using simulated rainfall and surface applications to soil. It was found that greater losses resulted when the rain was applied immediately after the herbicide application. The Atrazine content was highest during the early stages of runoff as might be expected. Concentrations in the soil fraction of the washoff (water-soil mixture) were higher then in the water fraction.[84] Simulated rainfall intensities and storm duration were used to investigate 2, 4-D contained in washoff from cultivated fallow Cecil sandy loam soil.[85] Concentrations of 2, 4-D in the washoff were positively correlated with the application rate and were greatest at the beginning of each storm. The *iso-octyl and butyl ether ester formulations* of 2, 4-D were far more susceptible to removal in washoff than the amine salt.[85] For Dieldrin-incorporated soils, losses were appreciable when erosion occurred and reached 2.2 percent of the amount applied.[86]

Effects of soil cultivation on the persistence and vertical distribution of pesticides were investigated over a ten-year period.[11] After treatment, DDT and Aldrin were rototilled into the soil. First one-half of each plot was disked to a depth of approximately 5 inches for 5 consecutive days each week for a 3-month period. The other half served as a nondisked control. While only 26 percent of the applied DDT was lost in a 4-month period from the nondisked portion, 44 percent was lost from the disked portion. For Aldrin, 53 percent was lost in the nondisked and 70 percent in the disked plot. No difference in the distribution of the residue in the soil layers was found between disked and nondisked soils.

Chlorinated hydrocarbon insecticides applied to the soil to control subterranean termites have moved through the soil very slightly after 10 to 20 years of weathering in open fields in southern Mississippi. There was only about 1 foot of vertical movement and only about 20 inches of horizontal movement of DDT under the soil surface in 2 decades.[87]

Aldrin and Heptachlor were applied either to the soil surface or incorporated into the soil by rototilling to approximately 5 inches.[12] Recoveries of these pesticidal residues ranged from 2.7 to 5.3 percent of the applied dosages. Measurement was made 4 months after a soil-surface application. However, incorporation of the pesticides into the upper soil layers increased the persistence of the residues by a factor of 10. One year after treatment of the upper soil layers, 90 percent of the recovered residues were located within the upper 3 inches of the soil. The highest concentration of the insecticides was found within the second inch of the soil layer. A deeper penetration and a more equal distribution of the residues was noticed 3 years after the soil treatment.

A field study examined losses of Dieldrin that had been disked into a silt loam soil to a depth of 7.5 centimeters. In general, the amount lost in the runoff water was a very small fraction of the quantity applied. At most, this amounted to 0.07 percent of the original dosage in the first season, with the largest losses occurring in the first 2 months after application. Highest Dieldrin concentration in the water was 20 micrograms per liter (μg/l) soon after application. Concentration was always less than 2 μg/l in the second year.[86]

Soil cultivation is one of many factors that affects the disappearance of insecticides from soil. It must be cautioned that the disappearance of the pesticides from soil does not mean its removal from the environment. After the application of the pesticide to a soil, a partitioning among soil, water, and air takes place. Distribution of the pesticide in the environment is controlled by many variables including temperature, soil properties, soil water content, and the nature of the pesticide. The increased loss of pesticides from cultivated soils can be partially explained by the continued exposure of new surfaces. However, other factors such as soil moisture, organic content, and temperatures will affect the loss rate.[88]

The possibility of DDT accumulation in soils from spraying is more likely in orchards and with crops where the green plants are turned under and incorporated into the soil after each harvest. Pesticide movement downward is aided by cultivation and rainfall and other natural

In some newly developed irrigation fields it was found that after irrigation began, use of organophosphates and carbamates increased greatly.[94] The results indicate that irrigation water carries away some of the applied pesticides which results in the need to increase pesticide applications to compensate for the loss. Results also showed that there was little vertical penetration of pesticides from surface applications (penetration did not exceed 12 inches).

It is concluded that pesticides removed by irrigation runoff in either the liquid form or settleable silt were only a small percentage of the amount applied. Ground water contamination by pesticides percolating through the soil from irrigation can be considered very slight. Irrigation practices do not constitute major problems for the aquatic environment with respect to contamination by pesticides. However, factual assessment of this situation will only be obtained after thorough investigation. Information is needed regarding pesticidal residue distribution, magnitude, and persistence in the ecosystem resulting from irrigation practices. Such information will permit long-range evaluation of the effect of these chemicals and anticipate harmful environmental effects before they occur. No such problem has been identified in the Southeast.

c. Atmospheric Processes

Pesticidal compounds may enter the atmosphere in several ways and in various physical states and then be redeposited directly or indirectly in the aquatic environment. Direct drift from spraying operations contributes particulate or globular matter at concentrations which are likely to vary inversely with the distrance from the site of application. Such effects are usually local but the possibility exists for a more extensive influence. Several organochlorine insecticides volatilize from treated soils, thus adding a slow but long-term contribution to the atmosphere.[95] Effluents and vapors from industrial processes, such as pesticide manufacturing or moth-proofing of garments, also contribute. Quantities may accrue from the use of domestic aerosol insecticides and thermal vaporizers and the dust from treated soil, clothing, and carpets. The concentration of these compounds in air is lower by a factor of 10 to 100 times that in rainwater.[95]

Pesticides can be transported by wind and deposited in water far from an area of application. Even a trace of precipitation may deposit unusually large amounts of pesticides on sites far from the source of the contamination if it falls through windblown dust clouds. Pesticides are now considered to be universally present in the air. Their distribution to sites remote from application areas depends on prevailing patterns of wind circulation and deposition rates. The potential for atmospheric contamination and subsequent transport during field application of pesticides is high.

Since many variables are involved in aerial applications of pesticides, no limited study will elucidate all factors or permit accurate prediction of this mode of pesticide contamination.[96] Atmospheric degradation is enhanced by a highly dispersed particulate or droplet state. Moisture, light and oxygen are factors in determining the rate of hydrolysis, photodegradation and oxidation, respectively. The danger of inhalation is greater with stable pesticides. To minimize atmospheric contamination, the development of less persistent and less volatile pesticides is needed. Pesticide application techniques must be improved to effect maximum delivery efficiency of minimum quantities close to the target under metereorologically suitable conditions.

(1) Volatilization

Pesticide residues may enter the atmosphere by codistillation from water surfaces[26, 97, 98], by vaporization from plants and soils[99], and by aerial drift during application. The DDT residues in precipitation in south Florida averaged 1,000 parts per trillion at four sites between June, 1968 and May, 1969.[100] Based on precipitation content (80 parts per trillion), some have estimated that one quarter of the total annual production of DDT could eventually be transported to the ocean. Volatilization can be a significant factor contributing to the net loss of a pesticide applied to a crop or to a soil surface.[12, 86, 101] Field experiments involving Endrin application to sugar cane showed that atmospheric concentration reached a maximum of 540 nanograms per cubic meter (ng/m^3) during the next three days. This concentration decreased rapidly to 30 ng/m^3, 77 days later.

A water budget for Birmingham, Alabama indicates that during the months of July, August, and September a deficit in soil moisture will usually occur with the rates of actual evapotranspiration being very high.[88] Thus, the top soil layers will tend to be dry. It has been reported that the rate of volatilization from a soil decreases with a reduction of moisture content in the soil. As would be expected, the volatilization of pure pesticides increases with temperature.[102] One would expect to find a much higher pesticide vapor pressure at the elevated ground temperatures found in the Southeast. However, there is experimental evidence that increasing the temperature results in a decrease in the relative vapor pressure.[78] This may be attributed to the formation of a stronger sorption force soil for pesticides in dry and less competition from water molecules for the sorption sites of the dry soil.

Experimental evidence, in conjunction with known meteorological date for the Southeast, suggests that during those months when the temperatures are high and soil moisture is depleted, the amounts of pesticide volatilization is reduced.[78]

The major source of DDT residues in soybean plants was found to occur through vapor movement from contaminated soil surfaces. In contrast the presence of Dieldrin, Endrin, and Heptachlor resulted primarily from root uptake and translocation through stems to leaves and seeds.[103] The amount of DDT sorbed after vaporization from surface-treated soil was found to be 6.8 times greater than that obtained through root uptake. DDT losses were at the rate of about 2 pounds per acre per year in summer and about 0.3 pound per acre per year in winter.[104] The implication is that about half the DDT applied to field crops may enter the atmosphere. The soil moisture content and its influence on volatility was not considered in the study.

A direct relationship between the initial DDT concentration (below 100 μg/l) and the DDT codistillation rate has been reported.[98] At the highest concentration tested (1,000 μg/l), the codistillation rate was as much as six times greater than anticipated by theoretical dissemination equations. This finding is in agreement with DDT's great affinity for the air-water interfaces, which facilitates the high codistillation rate. However, the results of this study are subject to criticism since DDT solubility is in the order of 1 μg/l. A non-homogeneous solution results when greater pesticide concentrations are attempted at room temperature.[27]

Experimental studies of the volatilization of soil-applied DDT and DDD (incorporated into commerce silt loam) from flooded and nonflooded plots showed that within the first two days, the atmospheric concentration of DDT at 10 centimeters dropped from a maximum value of 1977 to 58 ng/m^3 above the flooded plot and from 2041 to 100 ng/m^3 above the nonflooded plot. Corresponding levels of DDD decreased from 405 to 30 ng/m^3 and from 575 to 92 ng/m^3, respectively. It is evident that the flooding treatment effectively retarded the volatilization of both pesticides. Major changes in the atmospheric concentrations of both pesticides above the nonflooded plot, apparently, are related to certain climatological factors.[105]

An investigation of the volatilization of Lindane and DDT from four types of soils shows that neither pesticide was volatilized at 30° and 55°C when the soils contained less than a monolayer coverage of water. The rate of pesticide loss was constant for each soil in the moisture range of 1/3 to 15 bars and the pesticides volatilized over a longer period of time from the finer textured soil than from the coarser textured soils. For

Lindane and DDT at 30° C, the rate of volatilization from soil was in descending order: Valentine loamy sand, Hand loam, Raber silty clay loam, Promise clay.[106] It was assumed that an equilibrium existed between the vapor phase and nonvapor phase of the pesticides. The vapor density was independent of water content until the water content in the soil approached a monolayer. Vapor density increased with increases in pesticide concentration and increases in temperature, but decreased with increases in surface area. In order to explain the different vapor densities between moist soils, one must consider factors regulating the equilibrium between solid and solution phases as well as diffusion in both the vapor and nonvapor phases. Neutral pesticides probably are held to the mineral fraction of the soil by weak physical forces. One would expect more retention of the pesticide by the organic fraction of the soil than the mineral surfaces. Both types of pesticide sorption increase as surface area and organic matter content increases.

Aldrin and Dieldrin disappeared rather rapidly from agar in glass-covered petri dishes.[107] In most instances, this disappearance was considerably retarded by inoculation with either fungi or bacteria. Thus, volatile compounds which are low in water solubility may be lost to the atmosphere under sterile conditions but this loss may be reduced by the presence of microorganisms which consume, react with or physically cover the compounds.

Vapors are given off from Aldrin-, Heptachlorphorate-, Lindane-, Heptachlor epoxide-, and Dieldrin-treated soils.[108] An increase in the rate of Aldrin volatilization from the soil resulted from increases in insecticide concentration in the soil, soil moisture, relative humidity of air passing over the soil, soil temperature, and the rate of air movement over the surface of the soil. A decrease in the rate of Aldrin volatilization was noted in dry soils containing increased amounts of clay and organic matter and in wet soils containing increasing amounts of organic matter. Vapor loss of Trifluralin from water was found to be proportional to concentration, with losses being greater during a 12-hour period than during an 8-hour period.[109] Placement of the herbicide below the soil surface (0.5-inch) resulted in a very low vapor loss for both moisture regimes.

(2) Dusting and Spraying

Fallout from aerial pesticide application is a principal source of water contamination.[68,100,110,111] High levels of the atmospheric contamination by pesticides (DDT, Toxaphene, Parathion, and organophosphate) have been measured in the agricultural areas of the Southeast including Dothan, Alabama; Orlando, Florida; and Stoneville, Mississippi. Higher pesticide levels were found when pesticide spraying was reported than when no spraying was in progress.[112]

Aerial pesticidal sprays usually reach the target in amounts equal to or less than 50 percent of the quantity distributed.[111] During practically every spray operation, many nontarget organisms are killed. Many of these may be predators of the organism that the spray attempts to control. DDT residues may travel great distances once in the atmosphere, and eventually enter the aquatic environment through precipitation or dry fallout processes. Pesticidal drift from Mississippi cotton field applications has killed a large number of fish, snakes, frogs, turtles, and some egrets.[111] Aerial spraying of organophosphate pesticides on farm land has caused severe poisoning of a farm worker and the death of a 16 year old boy.[113]

Spray drift from agricultural sprays is influenced by many factors such as sprayer design, spray pressure, fluid properties, and meteorological conditions. Spray drift potential has been evaluated.[114]

Spray techniques and droplet size are closely related to the overall control of pesticide residue passage to the waterways. An account has been presented describing methods used, estimation of the spray coverage, and the size of spray particles.[115] Experimental results showed that 150 microns mass median diameter spray drops provided the most efficient swath pattern for forest spraying.[116] A review of findings between 1954 and and 1961 showed that larger mass median diameter drops (500 micron) required lower pressure, and usually lower dosages, than smaller drops (100 micron mass median diameter) with essentially equivalent results.[117]

It is necessary to further explore the significance of droplet size on the effectiveness of pesticide spray applications. There is a need to define the significance of droplet size on potential contamination of the water resources. Spraying must be based on using the proper chemical on a given crop in the right amount at the right time. Applications should be terminated prior to harvest to prevent excessive residues on food and fiber.

(3) Windblown Materials

Wind can sweep away surface soil to which pesticides are sorbed. These particles can be deposited into the aquatic environment by rain or by settling processes.[55] High winds have created dust clouds from which precipitation has deposited an unusually large amount of contaminated soil. In this case, selected samples showed 1.3 parts per million of total chlorinated hydrocarbon. Pesticides detected were Chlordane, Heptachlor epoxide, DDE, DDT, Ronnel, Dieldrin, and 2,4, 5-T.[118] Deposits of Malathion and Azinphosmethyl following aerial application were measured at various wind speeds and flight altitudes. These pesticides were detected as far as 800 meters (1/2 mile) downwind of application. Estimated recoveries from the adjacent areas, into which the spray drifted, ranged from 18 to 96 percent of the amount applied.[96]

DDT residues have been found in the Antarctic.[119] The analytical results and the estimated snow volume ($2.4\text{-}3.0 \times 10^{16}$ cubic meters) were used to project total DDT accumulation at 2.4×10^{9} grams. Concentrations of chlorinated hydrocarbons in airborne dust, carried by the trade winds from the European-African land areas to Barbados, range from less than 1 to 164 part per billion. The lower limit of the average concentration in 1 cubic meter of air is 7.8×10^{-14} gram.[120]

Analysis of rainwater and dust have revealed the presence of chloroorganic substances in all samples examined. Proof that pesticides can be transported to earth by rainfall was obtained from a deposit of dust on the Cincinnati, Ohio area on January 26, 1965.[121] It is reasonably certain that soil is constantly being picked up by winds, transported at high altitudes over long distances, and deposited elsewhere either by sedimentation or by rain. In order to minimize pesticidal losses from the application area and possible inhalation hazard due to wind-blown treated soil, less persistent pesticides are preferable and applications should be avoided on windy days. Soil conservation practices are also quite important.

d. Disposal Processes

The problem of the final disposition of pesticides falls into two categories:

- Disposal of pesticide residues and wastes and
- Disposal of pesticide containers.

Mississippi State University has conducted studies with an over-all view of the pesticide disposal problem.[122, 123] The waste problem is classfied into three general catagories:

- Disposal by land burial,
- Disposal by chemical and thermal methods, and
- Recycling of waste and containers.

Mixtures or formulations were more biodegradable than single pesticides, provided that at least one or two of the pesticides in a mixture were relatively easy to biodegrade.[122] However, biodegradation in soil may result in the suppression of soil bacteria and favor growth of Streptomycetes and fungi. If the bacterial population is suppressed for an extended period of time, important processes such as nitrification, nitrogen fixation, sulfur transformation, and others are endangered. Thus, the burial of pesticides presents problems beyond the contamination of water.

Chemical and thermal disposal methods were compared and it was shown that incineration was superior to chemical methods.[123] Incineration at 800 to 1, 200° C for five minutes is the most effective method for the disposal of pesticide wastes. However, the process in itself is not entirely satisfactory. Incineration without the entrapment of pesticides in the resulting gases represents an environmental threat through air pollution. Volatile pesticides and their degradation products could conceivably endanger the surrounding countryside. Another serious problem arises from the residue that remains after incineration. The quantity of residues can be considerable and the residues may retain other toxic elements, such as arsenic. If pesticide residues are to be disposed by burning, it is possible that further chemical treatment will be needed.

Little is known about pesticides released from incineration municipal and industrial wastes and treatment plant sludges. Because of the large atmospheric releases could be significant and widely dispersed.

Disposal of pesticide containers presents a particular problem. These containers retain substantial residue. If the container, such as a metal drum, is recycled, this problem is lessened. However, if these containers should be disposed by dumping, the buildup of toxic material could be significant and the material could subsequently be transported to other areas by water movement.

The magnitude of the problem can be illustrated by an example. The number of containers reportedly used in the state of Mississippi in 1969 were:[124]

- 55-gallon drums------------------------------65, 750

- 30-gallon drums -------------------------------- 16,000
- 5-gallon drums -------------------------------240,000
- 1-gallon cans ---------------------------------401,000
- 0.5-gallon (glass, metal, and plastic containers) -- 35,000
- 0.25-gallon (glass, metal and plastic containers)-- 80,000

A 1970 survey of 75 counties in Tennessee indicated that 3,332 empty pesticide containers were discarded as trash.[124]

Much remains to be accomplished with respect to the safe disposition of used containers with pesticide residues although industry is developing guidelines.[125] A nationwide disposal system should be initiated as soon as possible. Open burning should be prohibited, even in rural areas, because of air contamination. Research is needed specifically in the following areas:

- Recycling techniques for pesticide containers,
- Chemical and biological decontamination methods, and
- Thermal degradation with special emphasis on incineration research.

5. Case Studies

A number of documented cases reported in the Southeast of either intentional or accidental nature have been reviewed.

a. Intentional

A Parathion and Methyl arathion manufacturing plant in Alabama dumped its effluent into a creek when its treatment plant failed in 1961.[67] Fish, turtles, and snakes died along 28 miles of the stream. Traces of Parathion residues were recovered from the Coosa River into which the creek entered. Lesser fish kills were reported 90 miles down the Coosa River.

Five pesticide-formulating companies dumped waste materials into city sewers; channels and sloughs near their plants; and onto city and private dumps where they could be washed away by rainfall.[70] Pesticides residues (Dieldrin, Aldrin, Endrin, Isodrin, Chlordane, Lindance, and DDT analogs and metabolites) varied in concentration from less than 0.5 ppm in river bottom muds to thousands of ppm in the vicinity of the industrial plants in the lower Mississippi River basin.

Dieldrin is used as a fungicide in an Augusta, Georgia, wool scouring plant. This plant discharges the chemical into the Savannah River. A similar plant previously used and discharged Dieldrin into the Ogeechee River near Statesboro, Georgia, but an alternative is now used.[126]

Drums containing chemical wastes have been found in and along the North Sea. The wastes were analyzed and found to contain lower chlorinated aliphatic compounds, vinyl esters, chlorinated aromatic amines and nitro-compounds, and the insecticide Endosulfan.[127] This could occur in the Southeast where pesticidal wastes and containers require disposition.

A fish kill took place in Indian Swamp, North Carolina, on or about June 10, 1971. This occurred when a person deliberately discharged about two gallons of Chlordane solution into the surface waters. On June 14 and 15, 1971, Indian Swamp waters exceeded from 2 to 10 times the recognized toxic limits of Chlordane.[128] Another fish kill occurred on July 6, 1971 in Bear Swamp Creek at S. R. 1301 and was caused by spent pesticide jugs.[129] The jugs, containing Endosulfan, were thrown onto the bank and allowed Endosulfan to enter the creek.

Over-aged Parathion bags (15 percent dust) were dumped into the Peace River near a bridge one mile upstream from the municipal water intake of Arcadia, Alabama, a town of 6,000 people.[67] All but 8 to 12 bags were eventually recovered. Subsequent analysis showed less than 1μg/l concentrations in the local water distribution system.

Disposal of waste containers and discharge of pesticides into the aquatic environment endangers the aquatic life and results in damage to fishing operations. Measures must be taken to stop this practice. Proper methods for disposal of un-used pesticides, pesticide wastes, and pesticide containers have been described.[122, 130] Joint federal, state, local, and industrial regulatory effort is requisite as it concerns safe disposal of empty pesticide containers, wastes, over-aged and unwanted pesticides.

b. Accidental

Accidents, caused by spills of pesticides in the Southeast, have been reported. Studies of Parathion and Azinphosmethyl residues from accidental and deliberate (research) spills showed that these compounds do not break down as rapidly as expected.[81] The soils studied were silt loam with high organic content and pH of about 5.0. The plots were exposed to weathering and routine sprinkler irrigation. In the top one inch of soil, Parathion and Azinphosmethyl concentrations were reduced by 46 and 10 percent, respectively, over a two-year period.

A comprehensive examination has been performed on a shallow farm well contaminated with persistent pesticides.[131] The well was located less than 25 feet from a site previously used for flushing an insecticide sprayer. Pesticide levels in the water have been monitored for more than 4 years, during which time a gradual decline in concentration has occurred. Soil core samples indicate a relatively high surface contamination but very little downward percolation. Sediment samples from the bottom of the well exhibit the highest concentration of all samples.

Surveys of the chlorinated pesticide levels in South Atlantic and Gulf of Mexico oysters, occasionally exhibit high concentrations of chlorinated pesticides.[132] This indicates a possible future problem i.e., contamination of shellfish-growing waters. These waters should be kept under surveillance.

The fire ant control areas of the Southeast, whether treated with Heptachlor or Dieldrin, reported disastrous effects on aquatic life. In Wilcox County, Alabama, most adult fish were killed within a few days after treatment. Fish from ponds in a treated area of Florida were found to contain residues of Heptachlor and a derived chemical, Heptachlor expoxide.[133]

Mirex has been used extensively since 1962 in the Southeast to combat the fire ant. The United States Department of Agriculture contemplated a full eradication program. Mirex was to be applied aerially over 126 million acres. The project was to require twelve years and cost an estimated 200 million dollars.[126] Mirex is highly persistent in the natural environment and has been shown to be moderately carcinogenic in laboratory mice.[134, 135] In short-term field tests, Mirex has been shown to exhibit a relatively low acute toxicity to marine crustaceans. However, subsequent long-term studies have demonstrated delayed toxic effects on crabs and shrimp. Eighty percent mortality in shrimp and 60 percent mortality in crabs occurred when they were exposed to only 0.1 mg/l of mirex in water for 15 days.[136] Because it is very insoluble in water and very soluble in animal fat, the chemical moves rapidly from water into aquatic species and up the aquatic food chain. Current spraying techniques involve Mirex impregnated corn cobs. This is a risky practice because the untouched bait may eventually be carried into waterways by runoff. Incorporation of the bait into the soil may solve this problem. A national survey of 5, 000 oysters and other shellfish has demonstrated that Mirex is the fourth most commonly found pesticide residue.[136] It was also reported that Mirex contaminates shellfish in estuarine drainage areas of the Southern states.

During the summer of 1950, insect infestation was unusally great in northern Alabama and some 80 to 95 percent of the cotton farmers began heavy applications of Toxaphene.[3, 61, 133] An acre of cotton was sprayed with 63 pounds of Toxaphene. Frequent and heavy rains washed the pesticide into nearby streams and caused extensive fish kills in 15 tributaries of the Tennessee River. Two of these streams are municipal water supplies but no harmful effects to humans were reported.

Fish kills occurred in Choccolocco Creek and in the Coosa River near Anniston, Alabama, during May, 1961.[137] Parathion and/or related organic phosphorus compounds were accidentally released by a local chemical company. The pesticides entered Choccolocco Creek via the Anniston city wastewater treatment plant.

In March, 1965, 2,500 to 3,000 pounds of 5 percent Chlordane wettable powder were spilled from a truck passing through Orlando, Florida. As much as possible was salvaged from the street. From 1,300 to 1,700 pounds were lost into the street's storm drainage system from which it passed into a dry creek bed near one of the city's lakes. When the potential danger to the lake was realized, the concentrated water and soil were disposed.[67] The study did not cite the means of disposal.

On September 4, 1967, a truck lost a drum of Malathion in Cordele, Georgia.[126] The Malathion spilled in the street. The local fire department was called to clean up the street as a traffic safety precaution. The Malathion was washed into the storm sewer system which discharges into Gum Creek, a tributary to the Flint River impoundment, known as Lake Blackshear. A 0.32 inch rainfall occurred that night. The next day a massive fish kill was reported in Gum Creek. On November 2, 1969 another fish kill was reported on Gum Creek.[138] By November 4, fish were dying over a three mile reach of the stream below the Cordele wastewater treatment plant. Approximately 1,500 fish were killed. The fish kill was likely the result of Malathion entering Gum Creek through the city wastewater treatment plant. In August, 1971, a minor fish kill at a state fish hatchery near Cordele was evidence of indiscriminate spraying by a local duster.[139] Two fungicides, Benlate and Isobac 20, were being sprayed on an adjacent 90-acre peanut field.

Three fish kills are reported for the state of North Carolina. The first and third were caused by pesticides that washed into the stream by heavy rainfall from cultivated fields. The first occurred in Symonds Creek beginning in May of 1970. The water was found to contain less than 0.001 mg/l of Preforam. Significant concentrations of insecticides such as Toxaphene were measured in the bottom samples and in the flesh of the fish samples.[140] The second occurred in Hyde County between August 27, 1970 and September 2, 1970, and was caused by aerial overflights of crop-spraying aircraft applying DDT, DDD, DDE, Parathion, Thiodan, Toxaphene, and Sevin to soybean fields in the area. These aircraft were observed to be discharging pesticides into the surface waters.[141] The third occurred in Lake Junaluska on November 21, 1970. It was caused by Endrin and the kill continued until the latter part of March, 1971.[142]

On June 20, 1971, a fire of about ten hours duration occured at an agricultural chemical warehouse in Farmville, North Carolina.[143] The warehouse contained a wide assortment of hazardous chemicals including pesticides. Water was used to extinguish the fire. Dikes were constructed to retain these waters until they could be pumped to polyethylene-lined pits. This particular incident points out the need for a rapid response program for unusually hazardous situations.

An aerial application of 30 pounds per acre of 10 percent Dieldrin was made near Spring Creek, Hardeman County, Tennessee on March 24, 1961. Approximately 3,400 acres were treated. Various species of terrestrial animals, fish, reptiles, and crustaceans were found dead as a result of this treatment.[144] On February 2, 1962, 1,500 acres in and near the north end of Bradley County, Tennessee, were treated with 10 percent Dieldrin at the rate of 30 pounds per acre by airplane dusting to combat an infestation of white fringe beetle. Various kinds of fish and animals were found dead as a result of this treatment.[145]

On May 22, 1962, approximately 800 acres in the Crandull area of Johnson County, Tennessee, were sprayed with 10 percent Dieldrin at 2 pounds per acre. Fish mortality began downstream from the treated area on the first day after application and continued to be heavy for the next four days. As a result of the nearly complete decimation of the resident fish population and the possible public health hazard, Beaver Dam Creek was closed to public fishing for the remainder of the 1962 season.[145]

A heavy fish kill was reported on or about August 21, 1969 in the lower 11.4 miles of Beans Creek near Elora, Tennessee. The cause was Endrin and Methyl parathion associated with runoff from cotton fields. An estimated 73,712 fish were killed.[146]

Although awareness of safety in handling pesticides is increasing, the task gets more complex as new chemicals are developed. Educational efforts must reach the entire population including scientists, regulatory officials, educators, industralists, and the users of pesticides. The reasons for accidents are preoccupation, clumsiness, forgetfulness, disregard, inattention, unpreparedness, distraction, and in general, a common denominator-lack of awareness.[130] The goal must be complete protection of the food supply from pesticide residues, protection of the aquatic environment from pesticide contamination and total elimination of pesticide accidents.[147] Safe handling procedures in pesticidal application must be followed by all users to prevent future accidental spills.[125,147,151]

6. Conclusions

After two decades of intensive use, pesticides are found throughout the world. They are present in the aquatic environment and in the atmosphere, even in places far from any spraying sites. The persistent nature of certain pesticides permits them to be carried from the air and soil into the aquatic environment. There they can move from one organism to another via the food web or be cycled in the aquatic environment.

Physical and chemical properties of pesticides govern their movement from one system to another. Sorption and desorption are the processes which limit the rate of movement of pesticides from the soil into the aquatic environment. Specific sorption and desorption mechanisms for each pesticde under environmental conditions are not known. These mechanisms are influenced by the clay and organic content, temperature degree of cation saturation within the soil, and by climatic conditions. These factors also influence pesticide sorption-desorption at the benthic level of the aquatic environment.

Pesticide movement into the soil environment is influenced by sorption, thermal and biomass characteristics, and general chemical composition. Knowledge of the chemical and physical nature of pesticides facilitates a prediction of their fate. Common fates in the soil environment are sorption and desorption, photo- and oxidative decomposition, hydrolytic and biochemical degradation, leaching, and phyto-assimilation. Organic matter favors sorption of both non-ionic and ionic pesticides. The soils of the Southeast have a high clay content and sorption of mostly ionic pesticides is anticipated. Many of the pesticides applied to the soil are strongly sorbed and do not percolate through the soil. Pesticides normally are confined to the top few inches of the soil.

Pesticides in the soil are generally in contact with water. The quantity of water may significantly alter their reactions. For example, phytoactivity is greatly enhanced in moist soil. Solubilities; partitioning (soil, water, and air); and interaction of these properties alter the reactions of individual pesticides.

The sorption process and its binding power must be examined relative to leaching. Leaching of pesticides deserves greater attention because this is the process of most rapid movement from the soil into the aquatic environment.

The direct movement of pesticides from the soil surface to a waterway requires consideration of climatic conditions before, during and after application. Principal consideration should be given to volatilization losses, movements into the soil, persistence at the site of application, and movement of the remaining fraction to uncontaminated areas.

Pesticides move into the aquatic environment from the land even though universally present in the air. Movement from land may take several forms but overland drainage is the most significant. Good conservation practices reduce overland drainage. The occurrence of pesticides in waterways is primarily attributed to their sorption by runoff particles. Deposition and subsequent desorption of the sorbed particles will provide a continuous source of pesticide to the aquatic environment.

Considerations should be given to rainfall as a climatic factor influencing pesticide movement into water. Pesticides movement into and over the soil is of a uniform nature during periods of low rainfall intensity. This also occurs during overhead and flood irrigation practices. High rainfall intensity and furrow irrigation, however, produce disproportionate pesticide movements. This movement can result in waterway contamination.

Pesticides enter the soil environment through mechanical incorporation or infiltration processes. Incorporation (or induced turnover) is favored since it reduces atmospheric and runoff contamination. However, plant uptake and persistence of pesticides is increased.

Information on pesticide decontamination is needed. Sorption by activated carbon is the only method presently available for removing pesticides from water. However, suitable methods for disposal of the sorbed materials has not been developed. Thermal, photochemical and biological degradation are considered as possible decontamination methods in instances where concentrated pesticides occur. Photochemical, biological and sorption processes offer potential for removal of low-level concentrations in waterways.

Current agricultural application practices result in contamination of the aquatic environment through atmospheric processes. Those processes which contribute to contamination include volatilized fallout and washout, drift from dusting and spraying operations, and wind-blown, pesticide-treated soils. Other aerial or atmospheric routes include incineration of pesticide contaminated materials and direct application of pesticides into the aquatic environment.

Case studies have documented that runoff, accidental spills, and intentional pesticide dumping are prevalent means of entry into the aquatic environment. Non-selective toxicity and subtle long-term effects can create ecological imbalances. Therefore, there is an urgent need to use existing and safer pesticide alternatives, to better educate pesticide users regarding potential hazards, and to limit usage of persistent pesticides.

7. Recommendations

1. Federal and state pesticide control programs should be expanded to promote the development of more selective, less persistent, less volatile pesticides, and more efficient application methods.

2. The Environmental Protection Agency should coordinate with other governmental agencies, e.g. USDA, U. S. Army Corps of Engineers, and state environmental agencies, to:

   - Strengthen the present air, soil, and water monitoring programs. Specifically, improvements in planning, sampling, analytical testing and reporting are needed and additional intergovernmented cooperation is required; and

   - Upgrade the educational training programs for the general public to increase the awareness of the hazards of pesticides to the aquatic environment.

3. The Environmental Protection Agency Pesticides Office should sponsor research to:

   - Reexamine the registration of pesticides which persist in the environment more than one year and those that are soluble in animal fat. Registration should be cancelled if safe, effective alternative methods are available;

   - Define the details of persistent pesticide sorption and desorption processes in relation to the specific soils and aquatic bottom sediments of the Southeast. The competitive relationship of water and pesticides for the sorptive sites on organic and inorganic substrates should be determined. Other dynamic forces contributing to physical movement of pesticides should be elucidated under natural environmental conditions;

- Ascertain the concentrations of pesticides added to the aquatic environment through current irrigation practices; and

- Determine the contribution of pesticides to the aquatic soil environment by atmospheric fallout and washout.

4. The Environmental Protection Agency Water Quality Office should:

- Promote development of standard methods and procedures for use in decontamination of highly concentrated pesticide spillage. Practical and efficient decontamination procedures for low-level pesticide concentrations, regardless of source, should also be expanded.

- Develop water quality standards which establish strict limits on pesticide concentrations in effluents from point sources, industrial and municipal outfalls. State water quality control offices should be responsible for enforcement of the standards.

- Undertake an educational and training program through state agencies to train selected local government personnel in emergency procedures to protect the aquatic environment from pesticide spills.

5. The Environmental Protection Agency Air Pollution Control Office should:

- Establish standards for incineration of pesticides and their containers.

- Promote investigations into thermal degradation of pesticides.

6. The Environmental Protection Agency Solid Waste Management Office should develop safe disposal techniques for waste pesticides and pesticide containers when landfill and recycling

methods are employed. These techniques should provide for chemical and/or biological decontamination of the wastes.

7. The Department of Agriculture should:

- Encourage the incorporation of pesticides into the soil to minimize the effects of overland drainage and atmospheric contamination of the aquatic environment; and

- Examine the use of pesticides where furrow irrigation is practiced.

8. The Soil Conservation Service should expand its soil erosion program to emphasize soil retention on pesticide-treated fields.

9. Federal and state governments, in collaboration with industry, should expand their research programs to improve application techniques. The studies should determine optimal droplet size and area coverage relationships, while considering vaporization and drift effects.

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D. THE IMPACT OF PESTICIDES ON THE AQUATIC ENVIRONMENT

1. Introduction

The use of pesticides affects a great variety and number of organisms. Benefits derived from pesticides are measured by their effectiveness in reducing populations of pest species. Conversely, detriment is equated to adverse effects on nontarget species.[1] Because pesticides are rarely applied in such a manner that only the target species are exposed, nontarget species mortality will continue to be expected. Long-and short-term effects on nontarget organisms, occurring through specific pesticidal usage in the Southeastern region, are discussed. The movement of pesticide residues through the aquatic food chain is considered. Physical, chemical and biological synergisms associated with pesticides in the natural environment are examined. Finally, the occurrence of low-level concentrations of pesticides in drinking water is evaluated relative to human health.

2. Movement of Pesticides by Aquatic Organisms

An aquatic organism may be exposed to pesticides through several mechanisms: direct entry of pesticides into the habitat, movement of an organism into areas previously contaminated by and retaining pesticides, transportation of pesticides from contaminated habitats via suspended material or other organism "carriers", or a combination of these. Uptake of pesticides by aquatic organisms may be direct or indirect. Direct uptake refers to ingestion or absorption either from direct contact with the pesticide or from various abiotic, pesticide-contaminated attributes of the aquatic environment.[1] Indirect or secondary exposure results from oral ingestion of organisms previously contaminated by pesticides. For example, such exposure occurs as pesticides and their metabolites are passed from organism to organism in a food web. The pesticides involved in this process are relatively stable.[1,2]

a. Direct Uptake

The distribution of pesticides in water influences the pathway of biological uptake. Algae, higher plants, and invertebrate and vertebrate animals sorb large amounts of pesticides from the water and the sediment. The quantity accumulated by each biological entity is dependent upon the physiology and behavior of the organism, the chemical characteristics of the pesticide, and the seasonal periodicity in the quantities of pesticide available within a given aquatic habitat.

(1) Plant

Algae are the primary producers in the aquatic environment. Grazers and higher consumer organisms depend upon algae as a food source, either directly or indirectly. Therefore, any accumulation of a toxicant by algae constitutes a potential hazard to consumer organisms.[3] Axenic algal uptake of DDT has been shown to be related to specific partitioning coefficients between a species of organism and seawater.[4] The need to view accumulation of pesticides in biological material as a partitioning mechanism has been emphasized.[5] This implies that an equilibrium is established between ambient and internal concentration of pesticides. Experimental measurement of the pesticide-absorbing ability of diatoms has been performed.[6] In doing so, unnaturally high concentrations of pesticides were employed.[4] Erroneous estimates of uptake may be obtained since it has been shown that high concentrations may affect the partitioning coefficient of an organism for DDT residues in water.[7] Axenic cultures of three species of phytoplankton, Syracosphaera carterae (a coccolithophorid), Amphidinum carteri (a dinoflagellate), and Thalassiosira fluviatilus (a centric diatom) were used to determine DDT uptake.[4] Sixteen to 54 percent of the pesticide was removed the media by the algal cells. An expected value of 30 ppm (parts per million) DDT residue was obtained. This was based on an estimate of 1.9×10^5 for a relative partitioning coefficient estimate of DDT concentration in whole seawater at 15 ppt (parts per trillion). This predicted value was found to be within the 95 percent confidence interval of analytical values obtained by electron capture detection, gas-liquid chromatography of the phytoplankton samples. This report, however, is open to criticism since it does not present the times required for each algal species to attain equilibrium uptake.

Filamentous algae are capable of accumulating very large amounts of chlorinated hydrocarbons.[8] The accumulations of Dieldrin by communities of benthic algae dominated by Stigeoclonium subsecundum in early stages and later by Synedra ulna, Epithemia sorex, Cocconeis placentula euglypta and Nitzschia sp., have been studied in laboratory streams. The influence of current velocity, light intensity and difference in algae community structure was considered.[3] Dieldrin concentrations ranging from 0.05 to 7.0 ppb (parts per billion) were maintained in the laboratory streams of natural water for periods of 2 to 4 months. Algal samples were found to contain Dieldrin concentrations ranging from 0.1 to 100 milligram per kilogram (mg/kg). Algal concentrations of Dieldrin were as much as 30,000 times those occurring in the water. The physical factors studied had little effect on Dieldrin accumulation but did, however, exert a strong influence on the species composition of the algal communities.

This indirect influence can affect accumulation. Communities dominated by filamentous algae accumulated greater amounts of Dieldrin that did those in which unicellular diatoms were dominant. Extensive pesticide sorption by select algal communities constitutes contaminated food source for animals which feed on these forms.

(2) Invertebrates

Daphnia magna is a planktonic organism and is considered to be among the first animal links in the aquatic food chain. Daphnia concentrated DDT by a factor of 16,000 to 23,000-fold during exposure to 8 ppb for 24 hours.[9] Uptake was principally through the carapace and was initially rapid. The DDT level in the living Daphnia reached 75% of its final value within one hour.

The direct uptake of pesticides from the sediment by shrimp and crabs is associated with feeding habitats. Oysters continously pump water through their valves during respiration. Simultaneously extraction of food occurs. The organisms can in this fashion accumulate pesticide-contaminated particles. These are important food chain intermediates and commercial food products.

Organic particulate matter, occurring in estuaries, is an important food source for benthic organisms. In areas where the bulk of the primary production occurs through the slow bacterial-decomposition of plant materials such as marsh grasses, rushes and mangroves, there may be a release of pesticide residues to the substrate. As this decaying plant detritus is utilized by other microorganisms it becomes an enriched food source. DDT and its metabolities in the Carmans River marsh of New York[10] were found to be most abundantly associated with particles of 250 to 1000 micron diameters. Detritus particles of this size are ingested by consumer organisms and, in this way, enter diverse food webs. The mud-dwelling fiddler crab, Uca pugnax, was shown to concentrate DDT residues in its muscle tissues after consumption of detrital food material from sediment.[10] Similarly, polychlorinated biphenyls, PCB, are biologically mobilized. Aroclor 1254-contaminated sediments from Escambia Bay, Florida, were placed in separate aquaria containing local, uncontaminated populations of the adult pink shrimp, Penaeus duorarum, and shore burrowing fiddler crabs, Uca pugilator.[11] Both species accumulated Aroclor 1254 in their tissues by ingesting contaminated-sediment particles or by absorbing the leached chemical through the gills. The amount of Aroclor 1254 in individual crabs in sandy silt sediments averaged 80.0 ± 25.0 mg/kg (wet wt.) while the hepatopancreas[12] of the shrimp averaged 60.0 mg/kg (wet wt.). These tissue concentrations were found to be directly related to the amount of Aroclor 1254 contained within the sediment (61.0 ppm, dry wt.). Greater concentrations of Aroclor 1254 residues were accumulated by shrimp exposed to sandy silt sediments than from contaminated silt sediments. This was attributed to the chemical leaching from the sediments, followed by direct absorption through the gills from the aqueous phase.

Oysters efficiently store trace amounts of pesticides. A study of uptake rates and retention by 4 different mollusc, showed that the Eastern Oyster, Crassostrea virginica contained 26 mg/kg; the hooked mussel, Brachidontes recurvus, contained 24 mg/kg; the European oyster, Ostrea edulis contained 15 mg/kg and the Crested Oyster, O. equestris, contained 23 mg/kg after exposure for 7 days to 1.0 mg/l (micrograms per liter) DDT in flowing water.[13] The European Oyster is extremely sensitive to changes in trace-level concentrations of chlorinated hydrocarbons. For several years it has been used as an estuarine monitor organism by the Bureau of Commercial Fisheries at Gulf Breeze, Florida.[14] High-river stages and seasons of maximum pesticide usage in drainage basins correlate with peak residue levels in oysters.[14] Oysters provide a sensitive indes of the initiation, duration and extent of chlorinated hydrocarbon pollution in an estuary. The ability of oysters to concentrate or eliminate residues is dependent upon the level of pollution, the water temperature and the position relative to the water flow. DDT residues of 150 mg/kg may require 3 months or longer to be eliminated while residues of less than 0.1 mg/kg may disappear in about two weeks. Fresh water mussels and crayfish are filter- and substrate-feeders, respectively, and are capable of concentrating high levels of pesticides.[15]

It can be concluded that:

- Daphnia, an important fish-food organism, concentrates DDT rapidly upon exposure to low concentrations in solution.
- DDT and its metabolites are associated with organic detritus especially in particle sizes ranging from 250 to 1000 microns.
- Detritus feeders concentrate DDT and PCB's from the sediment. PCB's biologically accumulate in concentrations approximately equal to sediment concentrations.
- Shrimp are capable of accumulating greater PCB concentrations from sandy silt sediments than sand sediments because of leaching of the compound from the sediments.
- Pesticide monitoring of certain sedentary, filter-feeding organisms is useful in assessing the degree of chlorinated hydrocarbon pollution in a given habitat.

(3) Vertebrates

Tests have been conducted on several freshwater fish native to the Southeast to determine the pathway of Endrin entry into fish. The mosquitofish, Gambusia affinis and the black bullhead, Ictalurus melas demonstrated the ability of accumulate Endrin directly from solution.[16,17] G. affinis assimilated 10.48 mg/kg during 40 minutes of exposure in a solution containing 250 μg/l Endrin. The principal mode of entry into I. melas was found to be via the gill surfaces.

The ability to accumulate and eliminate pesticide residues has been demonstrated to occur in certain freshwater and estuarine fish. Small bluegills, Lepomis macrochirus, and goldfish, Carassius auratus, were exposed to 0.03 mg/l concentrations of C^{14}-tagged DDT, Dieldrin and Lindane for 5 to 19 hours. The fish were rinsed with uncontaminated water following exposure and placed in pesticide-free aquaria. Lindane was eliminated from both species of fish within two days. More than 90 percent of the Dieldrin was eliminated in the first two weeks. Less than 50 percent of the DDT was eliminated after 32 days. The DDT and Dieldrin were shown to be readily transferred from contaminated to uncontaminated fish in the recovery aquaria.[18] Similar experiments were performed using pinfish, Lagodon rhomboides, and croakers, Micropogon undulatus, collected from an estuary near Pensacola, Florida.[19] Each species was exposed to p,p'-DDT at 1.0 mg/l for two weeks or 0.1 mg/l for five weeks under dynamic test conditions. In the latter case, the fish were placed in pesticide-free water for eight additional weeks after exposure to establish elimination rates. Pinfish and croakers exposed to 0.1 μg/l DDT accumulated a maximum DDT concentration of 10,000 to 38,000 times the aqueous concentration in two weeks. This concentration remained constant thereafter. After eight weeks in pesticide free water, pinfish lost 87 percent and the Atlantic croakers 78 percent of DDT. There was no increase or decrease in body concentrations of the metabolites DDD or DDE. However, fish from the estuary usually contained as much DDD and DDE as DDT. This indicates that fish from the estuary obtained the pesticide after it had been metabolized and passed through the food chain or that DDT was rapidly metabolized within the fish.

The uptake, retention and release of organophosphates and herbicides by fish has also been studied. Malathion can be directly absorbed by carp, Cyprinus carpio.[20] Uptake from exposure to 5 mg/l of Malathion was time dependent for a period up to four days. Subsequently, equilibrium conditions were established. The equilibrium concentration was 28 mg/l. The greatest Malathion concentrations were found in the liver. The compound degraded within a week following exposure. Uptake took place primarily through the gills.

The uptake and release of the herbicide, Simazine, by green sunfish (Lepomis cyanellus) were measured after exposure to contaminated water and food.[21] Fish absorbed Simazine in amounts directly proportional to the concentration in the water, i.e., 0.95 and 2.29 mg/kg total residue were measured after three weeks exposure to 1.0 and 3.0 mg/l, respectively. Simazine residues were eliminated from fish after seven days in freshwater. Little or no Simazine was found in the tissues of fish 72 hours after feeding. The residue which was detected, occurred in the viscera.

It can be concluded that fish can readily take up pesticides via the gills. An equilibrium is established between the body and water concentrations. Simazine can be accumulated in higher concentrations through direct absorption than through contaminated food pathways.

Chlorinated hydrocarbons and organophosphates can be absorbed and concentrated to levels much greater than that of the aqueous phase. DDT metabolites, measured in fish taken from estuaries, are at much greater concentrations than those in fish exposed to DDT within the laboratory. This indicates that substantial quantities are acquired from food chain organisms. Chlorinated hydrocarbon residues are stored, whereas, organophosphates are metabolized within a few weeks to a month. Species differences reflect varying storage ability. For example, pinfish stored 2.4 times as much DDT as croakers when both were exposed to 0.1 μg/l DDT. The elimination of stored pesticides from previously contaminated fish moving into uncontaminated waters, renders these residues available for uptake by uncontaminated fish.

b. Indirect Uptake Through Food Chain

Organisms may obtain pesticides directly from the environment or indirectly through the foods they consume. Lower members of a food chain may accumulate these compounds and, subsequently, pass them on to consumers.

(1) Plant-Animal Chain

The primary producers in aquatic food chains are bacteria, phytoplankton, periphyton and aquatic macrophytes. They can accumulate pesticide residues. They provide food for herbivorous animals. Thus, the pesticide residues become biologically transferred and are magnified as they are passed from plant to animal.

Bacteria are nutrient regenerators which serve as food for filter-feeding aquatic organisms. A common shallow-water marine bacterium, Pseudomonas piscicida, was subjected to various levels of DDT and Malathion.[2] The bacterium exhibited no alterations in growth rate or morphology when exposed to 10 mg/l labelled DDT or 100 mg/l of Malathion. DDT uptake was rapid in a medium containing 1.0 µg/l (90 percent uptake in 24 hours). The DDT was found localized in the cell wall, whereas, the metabolites DDD and DDE occurred in greater concentration inside the cell. An artificial food chain has been established using this bacterium as the primary link. In addition, filter-feeding oysters and pipefish represented higher consumers. DDT was converted to its metabolites, DDD and DDE, during progression through this chain of organisms. The parent compound is less stable than the degradation forms. Conversion of the parent compound to its metabolites is significant since may explain the high levels of DDE occurring in terminal food chain members (birds and mammals) of natural ecosystems. A similar conversion with metabolite storage could occur with other chlorinated hydrocarbons. However, such metabolites have not been identified, "in situ".

Malathion has a half-life of 55 days in water at pH 6 and four to five days at a pH of 8.[2] P. piscicida maintains a high pH (9.5) in its surrounding microenvironment. It was proposed that Malathion was rapidly hydrolyzed in this fashion. Rapid degradation was checked by allowing the bacterium to hydrolyze Malathion in phosphate-free water for 48 hours. After that period, the bacteria were removed and algal cells (Chlorella sp.) were introduced. An untreated Malathion solution served as a control. Twenty-five percent more algal cells were noted in the bacterially-degraded solution than in the solution containing Malathion alone. The increased algal growth was considered to have resulted from phosphate fertilization provided by the hydrolysis of Malathion.

Other phytoplankton organisms have shown varying responses to chlorinated hydrocarbons.[22] Four species, Dunaliella tertiolecta, Coccolithus huxleyi, Skeletonema costatum and Cyclotella nana, were subjected to short-term exposures (24 hours) of C^{14}-labelled DDT, Dieldrin, and Endrin in concentrations varying from 0.01 to 1,000 µg/l. Seven-day exposures to DDT and Endrin were performed to determine the effects on cell division. Dunaliella was not affected by any of the three insecticides in concentrations up to 1,000 µg/l. The rate of C^{14} (photosynthetic carbon) uptake by Skeletonema and Coccolithus was reduced by each insecticide in concentrations above 10 µg/l. DDT added daily at 100 µg/l stopped cell division in Skeletonema but had no effect on Coccolithus. Endrin had little effect on cell numbers of Skeletonema, although the rate of growth was slower. Cyclotella was inhibited by all three insecticides in concentrations above 1 µg/l. These pesticides could affect natural populations of food chain organisms through inhibition of cell division, photosynthesis and growth. Concomitantly, this reduced food source would be reflected in reduced consumer populations.

The gonads of the marine phytophagus fish, Mugil cephalus, or mullet, sampled in Florida, have been found to contain concentrations of DDT ranging from 3 to 10 mg/kg. The bottlenose dolphin, Tursiops truncatus, feeds extensively on mullet and might be expected to further concentrate the pesticide. Blubber samples of beached, dead dolphins were found to contain up to 800 mg/kg DDT confirming accumulation. Whether DDT was the cause of death was not determinable.[23]

The transfer of persistent pesticides from plants to animals is of importance in an ecosystem. There may be direct toxicity to the primary producers or indirect toxicity to consumers. The latter occurs as a result of feeding on producer organisms within which pesticides have accumulated. Either form of toxicity will reduce consumer populations. Eventually decomposers convert the biological material of higher trophic levels into inorganic products. These products then become available for production of organisms. Persistent pesticides could be recycled in this fashion for many years.

(2) Animal - Animal Chain

Certain aquatic organisms assimilate pesticides directly from and establish an equilibrium concentration with the environment. Oysters establish equilibrium with the water concentration and eliminate body concentrations of DDT when placed in waters free of DDT.[23] Similar observations have been recorded with freshwater fish.[24]

The body concentration does not decline in organisms continuously exposed to chlorinated hydrocarbons once equilibrium has been established. The organisms pass the stored pesticides on to their consumer. The actual quantity accumulated varies with the pesticide. *Daphnia* containing DDT or Methoxychlor were fed to guppies to complete a food chain.[24] DDT was rapidly concentrated in the fish to about 8 mg/kg in 20 days while Methoxychlor never rose above 0.17 mg/kg. Similar results were reported as a result of feeding midge larvae and tubificid worms, containing accumulated Dieldrin, to the reticulate sculphin.[25] Methoxychlor appears readily degradable in certain fish. Snails metabolize neither DDT nor Methoxychlor but accumulate both to high levels.[24]

The food chain pathways and biodegradation of persistent pesticides

(DDT, DDE, DDD, and Methoxychlor) have been studied in a model ecosystem.[26] Terrestial and aquatic components were involved. _Sorghum_ was the terrestial factor to which DDT was applied . Food chain pathways for the labelled pesticide in the system were:

Sorghum→ _Estigmene_ larva (salt marsh catepillar)
Estigmene (excreta)→Oedogonium (alga)
Oedogonium→_Physa_ (snail)
Estigmene (excreta)→_diatoms_ (4 species)
diatoms→_plankton_ (9 species)
plankton→_Culex_ (mosquito larva)
Culex→_Gambusia_ (fish)

The fate and conversion of DDT to stable and persistent DDE has been assessed. The application rate of C^{14}-labelled DDT corresponded to 1 pound per acre (1 lb/acre). One month after application to _Sorghum_, 52 percent of the radioactivity in the snail, 58 percent of the radioactivity in the mosquito larvae, and 54 percent of the radioactivity in the fish was DDE. This indicated that DDT had been metabolized to DDE. In the fish, DDE was present at a concentration of 110,000 times and DDT at 84,000 times the water concentration, respectively. These accumulations by the fish occurred in three days. Methoxychlor was rapidly degraded with very little reaching the fish. However, the snail _Physa_, stored large amounts indicating that it was unable to metabolize Methoxychlor. Biomagnification of DDT and its residues, DDE and DDD, have been substantiated in natural ecosystems, food chains and food webs.[27,28,29]

The occurrence of persistent pesticides in estuaries has been reported. During the period 1964 to 1966, a total of 133 samples of coastal oysters from South Carolina, Georgia, Florida, Mississippi, Louisana and Texas were analyzed for pesticide residues.[30] Ninety-four percent of the oysters contained one or more pesticides; 89.5 percent contained two or more; 81.2 percent contained three or more; 63.9 percent contained four or more; and 31.9 percent contained five or more. The most frequently observed pesticides were DDE (123 of 131 samples), DDT (117 of 131 samples), DDD (81 of 81 samples), BHC-lindane (55 of 133 samples) and Dieldrin (54 of 115 samples). The concentration of the individual pesticides was low. The median values ranged from 0.01 mg/kg for Aldrin, Chlordane, Endrin, Heptachlor, Heptachlor epoxide and Methoxychlor to 0.08 mg/kg for Toxaphene, when present. BHC-lindane had a median value of 0.01 mg/kg. The median values for DDD, DDE and DDT were 0.02 mg/kg. Although not stated, the total concentration of the combined pesticides could have been important. The presence of pesticides in the oysters correlated with spraying operations in areas adjacent to the estuaries.

The fate of pesticides in the estuary has been assessed.[31] Estuaries are the primary breeding ground and nursery areas of many oceanic species. Any pesticide accumulated by these species during their inshore activities will subsequently be carried to the ocean. Fish, e.g., menhaden and sardines, feed in the estuary, and then move offshore where they become subject to predation by pelagic fish and birds. In this way coastal dwellers can pass substantial concentrations of pesticides to higher trophic forms of the open ocean.

The movement and magnification of persistent pesticides (DDT, DDE, and DDD) in the food chain have been documented. These studies have involved species associated with estuarine environments. Studies involving inland water species have been limited and mainly confined to the laboratory. Quantitative information is needed on rate of transfer and accumulation of other pesticides within food chains and food webs in each aquatic environment, i.e., lakes, ponds, rivers, estuaries, and oceans.[32]

3. Impact of Pesticides on Aquatic Populations

Populations of aquatic organisms exhibit both short-and long-term effects upon exposure to pesticides. Short-term effects include: immediate kills, reduced activity, loss of equilibrium, and paralysis. Long-term effects include: population resistance, elimination of prey or predator organisms competitive ability and alteration of breeding patterns.

a. Short-Term Effects

Organomercurial fungicides in concentrations as low as 0.1 ug/l have been shown to reduce photosynthesis in lake phytoplankton isolates from Florida.[33] Merismopedia sp., Navicula sp., Crucigenia sp., Staurastrum sp. and Ankistrodesmus sp. were exposed to four different commonly used organomercurial fungicides in concentration varying from 0 to 50 µg/l. Diphenylmercury was least toxic. One µg/l of Phenylmercuric acetate; Methyl mercury dicyandiamide; and N-Methylmercuric-1, 2, 3, 6-tetrahydro-3, 6-methano-3, 4, 5, 6, 7, 7-hexachloropthalimide (MEMMI); caused a significant reduction in photosynthesis and growth of each culture. At 50 µg/l, uptake of inorganic carbon ceased. The tentative proposed drinking water quality standard for mercury is 5.0 µg/l.[34] This is considerably higher than the 0.1 µg/l effective level for phytoplankton.[33]

The green alga, Scenedesmus quadricaudata, has been treated with Diuron; Carbaryl; 2, 4-D; DDT; Dieldrin; Toxaphene; and Diazinon. Diuron and Carbaryl induced the most pronounced effects. Dramatic reduction in cell numbers and biomass occurred at concentration of 0.1 mg Cell density was reduced in four days after treatment with 0.1 mg/l of 2, 4-D. DDT, Dieldrin and Toxaphene reduced cell numbers at all treatment levels (0.1-1.0 mg/l) within two days of application. Diazinon was the only compound tested which had no effect on cell numbers, biomass or carbon uptake.[35]

Four species of coastal oceanic phytoplankton, representing four major classes of algae, were subjected to doses of DDT ranging from 1 to 500 µg/l. Photosynthetic activity of diatoms was measured by carbon uptake. All species exhibited reduced carbon uptake with exposure to less than 10 µg/l of DDT. Complete uptake inhibition occurred at approximately 100 µg/l.[36]

In South Carolina, the marine diatom, Cylindrotheca closterium, has been exposed to the polychlorinated biphenyl, Aroclor 1242. The diatom absorbed and concentrated the chemical to levels 900 to 1,000 times that of the water. This PCB inhibited growth at 0.1 mg/l. Decreased levels of RNA and chlorophyll synthesis were observed.[6]

The herbicide, 2, 4-D, reduced the cell density of the green freshwater alga, Scenedesmus.[35] The Gulf Breeze Laboratory in Florida measured no alteration of photosynthesis in 7 of 9 species of unicellular, marine algae when exposed to concentrations of 0.1 to 10 mg/l of purified 2, 4-D.[37] In 2 of the 9, photosynthetic enhancement was observed. Therefore, different algal species respond differently to specific pesticides. Information is needed to determine whether this is a result of different environmental conditions or is a basic genetic difference. Even in very small doses, the quality and the quantity of the basic food chain populations, (the phytoplankton) were adversely affected by pesticides.

Tetrahymena pyriformis cultures have been exposed to DDT from 0.1 to 10 mg/l.[38] Growth decreased with increasing concentrations of DDT. Populations were reduced by 13.8 percent at 0.1 mg/l, 20.2 percent at 1.0 mg/l, and 25.7 percent at 10 mg/l. T. pyriformis is more sensitive to DDT than Paramecium multimicronucleatum and P. bursaria.

The latter cilitates have been reported insensitive to 1 mg/l DDT over a period of seven days. During this exposure, P. multimicronucleatum accumulated DDT 264 times greater than the medium concentration and P. bursaria accumulated it 964 times the medium concentration.[38] This also demonstrates a wide range of DDT tolerance in ciliates.

Information has been compiled regarding specific pesticides and their respective lethal concentrations to marine invertebrates (crab, shrimp and oyster).[39,40] The chlorinated hydrocarbons are toxic to fish and mollusc at concentrations as low as 0.001 mg/l. Organophosphates have a pronounced effect on crustaceans at equally low levels.[7] Insecticides, as a group, are more toxic in low concentrations than are other pesticides, with two exceptions. The fungicide, Delan and an experimental antifouling arsenical, ET-546, are extremely toxic to oysters at 2.1 µg/l.

Mirex has a delayed effect on crabs and shrimp. Juvenile blue crabs and pink shrimp exhibited no adverse symptoms during a 96-hour exposure to 0.1 mg/l technical Mirex.[41] These crustaceans, however, became paralyzed and died within 18 days. Similar paralytic effects have been demonstrated in freshwater crayfish.[42] Juvenile Procambarus blandingi and P. hayi, of Louisiana and Mississippi were exposed to 1 to 5 µg/l Mirex for periods varying from 6 to 144 hours. After exposure the organisms were transferred to clean water and observed. Mortality reach 100 percent within 5 days for P. blandingi following a 144 hr. exposure to 1 µg/l of Mirex. Exposure of P. blandingi to 5 µg/l for 6, 24, and 58 hours, yielded 26, 50, and 98 percent mortality, respectively, 10 days after initial exposure. A greater sensitivity of Mirex was observed in P. hayi than P. blandingi. Delayed mortality was apparent in all tests.

The polychlorinated biphenyl, Aroclor 1254, is an industrially valuable chemical which eventually becomes a pollutant. It merits attention because it is similar to chlorinated hydrocarbons in its persistence and lethality to certain aquatic organisms once it enters waterways. Laboratory studies in Florida have demonstrated that juvenile shrimp are killed upon exposure to 5.0 ug/l of this PCB.[42] Adult shrimp taken from an estuary were found to contain a maximum of 2.5 mg/kg of the PCB. Gammarus oceanicus, exposed to 0.001 and 0.01 mg/l of the PCB for 150 hours died and were found to have severely necrosed branchiae.[44]

Acute toxicity of herbicides to aquatic crustacea is an important consideration since they are used in direct applications to control aquatic weeds and algae in lakes, ponds and waterways. Assessment of the impact of herbicidal treatment on the microfauna of natural systems has been neglected. Microcrustacea are significant in the diet of young and adult fish in the temperate regions. Daphnia magna was exposed to 16 aquatic heribicides to determine toxic levels.[45] Dichlone, Molinate and Propanil were extremely toxic to Daphnia over the concentrations range of 0.014-4.8 mg/l. Thirty-one herbicides have been bioassayed to determine toxicity levels in microcrustacea.[46] Test animals included the scud, Gammarus fasciatus; glass shrimp, Palaemonetes kadiakensis; sowbug, Asellus brevicaudus; crayfish, Orconectes nais; daphnia, Daphnia magna; and the seed shrimp, Cypridopsis vidua. Dichlone was most toxic to these six species. The 48 hour TL_{50} (the concentration in water which causes 50% of the test population to exhibit a specific response at a given time) ranged from 0.025 mg/l for D. magna to 3.2 mg/l for crayfish. The least toxic herbicide to D. magna was 2, 4-D. No adverse effects were noted at a concentration exceeding 100 mg/l. The first sign of toxicity was observed as irritability or excitability. This was followed by loss of equilibrium and coordination, immobilization, and death. Toxicity patterns (immobilization and equilibruim loss) in natural environments would make affected species more susceptible to prey-predator pressures. The amphipod, Hyalella, was found to be highly sensitive to Diquat.[47] The 96-hour mean TLm value was 4.8 ug/l. Immature stages of aquatic insects; dragonflies damselflies, tendipedids, mayflies, and caddisflies had variable 96-hour mean TLm values. They were respectively, > 100, > 100, >100, 33.0, and 16.4 mg/l.

The DDT susceptibility of Daphnia magna and the seed shrimp, Cypridopsis vidua, have been measured in terms of TL_{50}. D. magna and the seed shrimp were completely immobilized within 48 hours by 4 and 54 µg/l of DDT, respectively.[48] The TL_{50} values for the damselfy (Ischnura verticalis) and the scud (G. fasciatus) were 22.5 and 3.6 mg/l, respectively, in 48 hours. The TL_{50} for the fathead minnow, Pimephales promelas, was 24.6 mg/l in 24 hours and that of the channel catfish, Ictalurus punctatus, was 25.8 mg/l in 24 hours.

It can be concluded that certain members of the arthropods (crustacea and immature aquatic insects) are acutely susceptible to chlorinated hydrocarbons and herbicides. These organisms serve as food organisms for other invertebrates and vertebrates (amphibians and fish). Any alteration or depletion of their populations could seriously affect the entire aquatic food chain.

The most obvious short-term effect of pesticide pollution in the natural habitat is a fish kill. The Southeast Water Laboratory has documented agriculture runoff of pesticides as a pollutional source.[49] Several instances of spills associated with pesticide manufacture have resulted in fish kills. In May 1961, a plant in Alabama manufacturing Parathion and Methyl parathion accidentally diverted untreated waste into a small stream.[48] Fish, turtles, and snakes, died along a 28 mile reach of that stream with lesser kills occurring 90 miles downstream in the Coosa River. A second kill occurred in the same creek in March 1966. This was traced to the same source. Periodic fish kills since 1961 in the Ashley River in South Carolina have been traced to a plant manufacturing organophosphate pesticides.[49]

Investigations of fish kills in Alabama are made by the Water Improvements Commission and State Department of Conservation.[50] In 1967, 21 fish kills were reported in the state, 4 of these were attributed to agricultural insecticides. All occurred in the Tennessee River basin. in 1968, 48 fish kills were reported. Three were caused by agricultural insecticides; one in the Lower Tombigbee River and two in the Tennessee River. The specific insecticides and their sources were not reported.

Information on short-term, high-concentration exposures of freshwater and marine forms under dynamic test conditions is needed. Acute toxicity testing of fish under static conditions has been performed; however, the impact on microflora and microfauna have not been considered in detail. Large populations of these organisms form intermediate steps in the food chain. Higher aquatic forms, e.g., fish, can avoid large concentrations of pesticides but the sedentary or slower forms cannot. The latter are also more sensitive than fish to low-level pesticide concentrations. Therefore, short-term exposure may reduce or eliminate the food source of fish. If so, fish population reduction or elimination would follow.

b. Long-Term Effects

Chronic toxicological effects are elicited in an organism as a consequence of continuous or repeated exposure to low-level concentrations of pesticides. The time span involved may range from weeks to years. Chronic effects are dictated by the degree of exposure and by the fate of pesticide residues within the animal. If the degree of exposure is greater than the capacity of the animal to detoxify and eliminate the residues, a toxicity hazard exists. This is particularly important when pesticide effects are additive or when residues are temporarily stored in tissues.[1] If the interval between exposures are insufficient to allow for complete purging, then toxic effects become additive. If uptake rates exceed those of degradation and elimination, then excess fat-soluble residues may accumulate to high levels. Such accumulations may cause toxic effects when fatty tissues are mobilized. Stored residues of a given concentration may not produce demonstratable toxic effects in the directly exposed animal but may induce toxic effects after being passed and magnified at higher trophic levels.

(1) Population Changes

Long-term population and ecological changes are subtle and less obvious than acute effects. Causal factors may be just as subtle and difficult to identify and assess. Animal populations can be indirectly affected by pesticides through reduction in food supply. The productivity of phytoplankton (basic food organisms) can be reduced by exposure to very small amounts of pesticides. Species of estuarine phytoplankton, isolated in the Southeast, were exposed to chlorinated hydrocarbons in 4-hour controlled tests.[51] Aldrin, Chlordane, DDT, Dieldrin, Heptachlor, Methoxychlor, and Toxaphene, each at a concentration of 1.0 mg/l, reduced productivity by 70 to 94%. Endrin, Lindane and Mirex reduced productivity by 28 to 64%. Exposure of plankton to herbicides has reduced productivity to a highly variable extent according to published reports.[39] Certain DDT toxicity tests of marine plankton,[21,36] are ecologically questionable.[32] The concentrations necessary to induce significant inhibition far exceeded expected concentrations in the open ocean and exceeded by ten times the solubility of DDT (μg/l) in water.[32]

Effects of long-term, low-level concentrations of pesticides on plant populations are not known. Aquatic plants function ecologically by producing food and oxygen and by serving as spawning areas and substrates for other organisms.[52] Increased herbicide usage poses a threat to the stability of estuarine ecosystems which support shrimp, fish and shell-fish. Tests have been performed in Florida,[52] to determine an aquatic ecosystem response when rooted plants were eliminated. Two natural coastal ponds were used. One was treated with Dichlobenil and the other served as an untreated control. The ponds were without tidal effects. Physical factors such as sunlight, air temperature, wind speed and organism behavior were measured. Dissolved oxygen, pH, nitrates, dissolved carbohydrate, salinity and chlorophyll A were monitored. Gross algal primary production was determined by light- and dark-bottle techniques. Both pond basins were approximately 1 meter in depth. Bottom substrata were composed of sand and fine organic matter. Chemical and physical parameters of the two ponds were similar prior to treatment. Chara vulgaris and Potamogeton pectinatus were the dominant hydrophytes. Dichlobenil was injected beneath the water surface to achieve a concentration of 1.0 mg/l. One month after treatment, Potamogeton and 80% of the Chara were eliminated. An intense bloom, dominated by blue green algae, developed. This was attributed to the release of nutrients from decomposing vascular hydrophytes. Four genera of filamentous algae predominated during the bloom: Oedogonium, Lyngbya, Oscillatoria and Spirogyra. Three species of zooplankton; Diaptomus dorsalis (copepod), Keratella cochlearis (rotifer) and Gonyaulax sp. (dinoflagellate) also increased. Homeostatic chemical conditions were established by the algae during the period of maximal herbicide effect on vascular plants. Concentrations of phytoplankton chlorophyll rose to 29.3 mg/l after herbicide application, but fell sharply during the period of hydrophyte recovery. Phytoplankton produced over 90% of the dissolved oxygen during the period of rooted plant absence but resumed a secondary role after vascular plant recovery. The herbicide had disappeared from the water and hydrosoil 64 days after application. Residues did not persist in the organisms nor was the degradation product, 2, 6-Dichlorobenzoic acid, detected.[53] This study has shown that subtle ecological changes can occur when pesticides are introduced into the aquatic environment. Factors operating over the long-term could result in trophic population alterations. For example, a population change from carnivorous to phytophagus fish species as terminal members could result from a shift in the populations of lower food organisms. Such a change would be reflected in increased numbers of plankton-feeding mullet, in an estuarine environment.[52]

Crustacea are vital food chain organisms. Estuarine shrimp, fish and shellfish are commercially valuable species. However, pesticides and other synthetic organic contaminants, transported to estuarine basins, stress these populations.[7] Continuous exposure of white shrimp, Penaeus setiferus, and pink shrimp, P. duorarum, to low-level concentrations of DDT (0.2 µg/l) caused a 100 percent mortality in 18 days.[12] Shrimp exposed to 0.12 µg/l died within 28 days. The largest concentrations were found in the hepatopancreas. Residues found in natural populations of shrimp from Texas, Florida and South Carolina contained 0.01 mg/l of DDT and its metabolities. These field residue levels differ from those of laboratory exposed samples by a factor of 10 or 20 to 1. For example, shrimp exposed to 0.14 µg/l of DDT accumulated 0.21 mg/kg total body residue after 13 days and 0.15 mg/kg after 19 days. Shrimp that died during exposure had accumulated a minimum of 0.13 mg/kg. Concentrations of 0.03 µg/l of DDT would seriously threaten the survival of penaeid shrimp populations in estuaries.[12] Concentrations of this magnitude have been detected in certain areas of the Gulf coast.[54]

Small blue crabs, Callinectes sapidus, live in shallow estuarine waters. In these areas, they may be exposed to chronic sublethal concentrations of pesticides. Test crabs fed, molted and grew for 9 months in seawater containing 0.25 µg/l DDT. They survived only a few days at concentrations in excess of 0.5 µg/l.[55] This suggests that the threshold of toxicity is very critical. Populations that can exist in estuarine waters containing low levels of DDT may be seriously affected by a sudden, moderate increase, as might occur from runoff.

In two separate chronic exposure tests, immature oysters (Crassostrea virginica) were first exposed to 1.0 µg /l concentration of DDT, Toxaphene and Parathion for 48 weeks. In the second test, the oysters were exposed for 36 weeks to a mixture of all three of the pesticides at a total concentration of 3.0 mg/l.[56] Relatively high levels of DDT and Toxaphene were accumulated but only small amounts of Parathion. The immature oysters grew to sexual maturity in flowing seawater in both of the tests. The weights of oysters grown in the pesticide mixture were 5% lower than control oysters. There was no statistical difference in the weights of oysters grown in solutions of the individual pesticides and the controls. There were histopathological damages in the kidney, visceral ganglion, gills, digestive tubules and tissue beneath the gut in the oysters exposed to the mixture of pesticides. A mycelial fungus was also present, indicating a breakdown in the oyster's natural defense against this parasite. These changes were not observed in the oysters exposed to the individual pesticides. It can be concluded that although oysters can survive and grow in a low concentration mixture of pesticides, subtle pathological changes can be induced. Such changes reduce the ability of the organism to survive under competitive pressures. It was not established in this study whether these changes were due to a synergistic effect of all three pesticides in combination or an additive effect.

Chronic exposure to sublethal concentrations of pesticides has been shown to elicit three observably different population responses in fish: an adverse effect on population size and number, no demonstratable effect or an acquired resistance.[57-67] Adverse effects on populations have been observed as changes in mortality or growth rates. Mortality rates among populations of fish subjected to sublethal doses of chlorinated hydrocarbons have been found to be proportional to the magnitude of dose. Dichlobenil elicited numerous concentration-related responses in the bluegill, Lepomis macrochirus.[57] Dose-dependent mortality has also been observed in the freshwater sailfin molly (Poecilia latipinna) exposed to Dieldrin. More than half the experimental fish survived 1.5 and 0.75 µg/l Dieldrin but showed a 10% decrease in growth after 34 weeks. However, 0.012 mg/l Dieldrin killed all exposed fish within the first week.[58] Similar dose-dependent mortality and growth responses have been observed in goldfish and bluegills upon exposure to Mirex,[59] and in spot fish upon exposure to Endrin.[60] Offspring of a population of sheepshead minnow, Cyprinodon variegatus, which survived chronic sublethal concentrations of DDT, were found to be more sensitive to DDT and Endrin than were offspring of unexposed, control fish.[61] No observable pathological changes were reported for the continuous exposure of the spot, Leiostomus xanthurus, to sublethal Endrin concentrations (0.05 µg/l) for 8 months.[60] However, these same fish were further tested to determine whether sublethal exposure to Endrin had affected their resistance to acute toxic concentrations (0.75 and 0.56 ug/l) of Endrin. They were less tolerant than controls during the first 24 hours of exposure.[60] A similar increased sensitivity of response was observed with the same fish during chronic exposure to Toxaphene.[62] No effects on growth or mortality of the spot fish were observed when they were subjected to 10 µg/l concentrations of Malathion for 26 weeks.[63] This may be attributed to the rapid detoxification of the organophosphate in seawater. One week after the termination of the chronic exposure test, the same fish were subjected to lethal concentration of Malathion. However, differences in mortality rates between control and test fish were not significant. Fish that survived chronic toxicity testing were further stressed by placing them under reduced salinity conditions (from 26 percent salinity to 2.8 and 1.5 percent). No effects were observed between test and control fish.[63]

Development of resistance to chlorinated hydrocarbons, following long-term exposure, has been domonstrated by freshwater fish.[64] Once resistance is acquired by fish, the level remains unchanged for several generations if they are reared in insecticide-free environments.[64] Resistance to high pesticide concentrations were first noted in mosquito-fish, G. affinis, localized in heavy cotton producing areas of the Mississippi Delta. Two thousand-fold levels of resistance have been acquired by fish in this area.[65] Resistant populations of G. affinis, Notemigonus cyrsoleucas, L. cyanellus, L. macrochirus have been obtained from pond and ditch areas in the Mississippi Delta.[64, 66-68] These areas bordered large cotton plantations and are subject to contamination by run-off, spray drift, and possibly, direct application.[62, 64] Resistance was demonstrated when the fish were exposed to the 36-hour TLm concentration of DDT, Toxaphene, Aldrin, Dieldrin and Endrin. The fish from the Twin Bayou area of the Delta, as compared to control populations taken from non-agricultural areas, were resistant to all test insecticides except DDT.[64] These fish exhibited resistance to Endrin, considered to be the most toxic insecticide to freshwater fish, at levels approximately 50-fold greater than those which would affect controls. The fish communities from which these populations have been taken are represented by large numbers of a few species.[65] Top-level carnivores, such as large mouth bass or crappie were absent. Blood analysis of resistant and non-resistant strains of N. cyrsoleucas, revealed a 64-fold greater concentration of Endrin in the former than in the latter.[67]

Population resistance is not limited to fish.[69] Freshwater shrimp, P. kadiakensis, from 3 areas of the Mississippi Delta were up to 25 times more resistant to 7 chlorinated hydrocarbons, 3 organophosphates and 1 carbamate than were non-resistant control shrimp.[70]

Pesticide resistance and accumulation by non-target organisms in the aquatic environment has caused community structure imbalance.[65] Top-level carnivores, such as the largemouth bass, egrets, and gar, are absent in waters supporting pesticide-resistant populations. Resistant strains of the mosquitofish, G. affinis, can tolerate a body burden of 214.28 mg/kg after two weeks exposure to 500 μg/l Endrin. These fish released Endrin in sufficient concentration when placed in fresh tap water to kill green sunfish in 15.5 hr.[71] Adaptive physiological mechanisms that produce resistance in fish and shrimp have not been identified.[65] Resistance in a species may occur via alteration of membrane permeability, increased fat content, or altered metabolic pathways.

(2) Physiology and Reproduction

Organophosphate pesticides inhibit the enzyme, cholinesterase.[72, 73] This enzyme is functional in nerve-impulse transmission and ion transport processes. Tests have been performed on the sheepshead minnow which relate acute toxicity of Diazinon, Guthion, Parathion and Phorate to in vivo inhibition of brain cholinesterase.[72] Adult minnows were exposed to acute doses which killed 40 to 70 percent of the fish in 24 and 48 hours, respectively. The enzymatic activity of exposed fish was compared to that of control fish. The number of fish killed by each organophosphate was proportional to cholinesterase inhibition. The average level of cholinesterase inhibition in the brain of fish does not always correlate with the percentage of fish killed by a particular pesticide.[72, 74] Differences within and among populations of fish indicate that cholinesterase activity of a species fluctuates with time.[74] Some organophosphates increase in toxicity with time. For example, Parathion can be converted in the liver of certain fish to the more toxic Paraoxon, thereby increasing toxicity.[75]

Specific physiological modes of action by chlorinated hydrocarbons are not known. It has been shown that DDT impairs osmoregulation[76] and active membrane transport.[77] These mechanisms require cholinesterse (ATPase) enzymes. Chlorinated hydrocarbons, including DDE[32] and PCB,[78] induce mixed-function oxidase enzymes. These enzymes are functional in metabolizing steroid hormones, such as estrogen and testosterone. Numerous general observations on the impairment of motor and sensory systems by sublethal concentrations of chlorinated hydrocarbons have been reported.[66, 67, 79] Symptoms indicate central nervous system disorders including convulsions, loss of equilibrium, increased ventilation rate, hyperactivity and hypersensitivity to stimuli.

Although exact mechanisms of pesticide toxicity are unknown, certain structural abnormalitites in tissues and organs are associated with pesticide presence. Nimmo and Blackman,[80] of the Gulf Breeze Laboratory, have shown that exposure of pink shrimp to a sublethal concentration of DDT (0.1 μg/l) produces blood protein effects. Preliminary studies demonstrated a decrease in serum protein levels of up to 41% after 45 days of exposure. Follow-up experiments are being conducted to determine if a "threshold" concentration is reached prior to this observable gross effect. Blood changes have been reported for marine puffer fish, following chronic pesticide exposures.[81] Endrin caused an increase in serum sodium, potassium, calcium and cholesterol.

Chronic exposure to chlorinated hydrocarbons induces systemic lesions and other structural disorders. Gill changes in goldfish, characterized by swollen filaments, appeared 112 days after an initial concentration of 1.0 mg/l Mirex was applied to a pond.[59] Chronic exposure of spot fish to 0.075 µg/l Endrin for three weeks produced systemic lesions throughout the brain, spinal cord, liver, kidneys and stomach.[60] Lesions of the central nervous system, kidneys and stomach were attributed to primary effects of Endrin. It was probable that necrotic liver lesions were also attributable to Endrin. Loss of hepatic fat and glycogen was considered secondary to systemic toxicity. The appearance of lesions offers an opportunity for bacterial and fungal infections.[56, 82] Exposure of pinfish and spot fish to sublethal (5 µg/l) concentrations of the PCB, Aroclor 1254, over a maximum of 45 days produced fungus-like lesions on the body.[82] These were pronounced and hemorrhagic around the mouth. The affected spot fish usually ceased feeding, became emaciated, and developed frayed fins and lesions on the body. These exposure-associated changes could significantly reduce long-term viability of a species.

Dichlobenil caused karyolysis of hepatocytes and an increase in connective tissue stroma in the liver of bluegills.[83] Chronic exposure of bluegills to 2.4-D caused rapid shrinkage and loss of vacuolation in parenchymal cells and a depletion of stored glycogen in the liver.[57] These fish also exhibited a reduced circulation and simultaneous depletion of liver glycogen. Blood stasis resulted from congestion of larger blood vessels in the central nervous system, gills, liver and kidneys. Congestion was caused by amorphous, eosinophilic deposits of serum protein precipitates. Histopathological damage, induced by chronic pesticide exposure, may or may not be related to function of a particular tissue. There is inadequate knowledge in tissue-effect mechanisms of pesticide toxicity. Until these mechanisms are resolved, the effects of pesticide-induced histopathologies on survival of species in the natural environment cannot be understood.

Survival of a species depends on its ability to reproduce efficiently and maintain population size. Pesticides are known to interfere with this process.[57, 66, 84] However, specific factors contributing to reproductive failure and the frequency and extent of their occurrence are not known. These factors can create subtle changes in population behavior.[57] Exposure to 5 and 10 mg/l of 2, 4-D for 5 months caused L. macrochirus to spawn two weeks later than individuals in pesticide-free water.[57] Exposure to 1000 μg/l solutions of Dursban for a period of time sufficient to kill 50 percent of the test population, caused female mosquito fish, G. affinis, to prematurely terminate gestation.[66] Mosquito fish abortion has been induced by several chlorinated hydrocarbon insecticides.[66] Exposure to Dieldrin in concentration of 0. 075 and 1. 5 μg/l for 34 weeks, caused the sailfin molly, P. latipinna, to produce fewer numbers of young.[58] Populations of guppy, Poecilia reticulata, showed a change in size-class distribution after 7 months exposure to 0. 0018, 0. 0056, and 0. 01 mg/l of Dieldrin. The greatest increase was in the number of young. This was attributed to decrease in cannibalism of the young by the parent fish.[84]

The presence of pesticide in an estuary could adversely affect the breeding behavior of resident crustacea and fish populations.[85] In addition, breeding and migratory behavior of fish which spend only a portion of their life cycle in these fertile nursery grounds could be affected. For example, fish may avoid pesticide contaminated water and, thereby, be unable to reach proper spawning grounds. Some fish in Tennessee Valley Authority lakes moved out of the area when 2, 4-D was applied for the control of Eurasian water milfoil.[86] Avoidance behavior was demonstrated by the estuarine sheepshead minnow (Cyprinodon variegatus).[87] These were subjected to water containing DDT, Endrin, Dursban, 2, 4-D, Malathion and Sevin. Concentrations ranged from 0. 0001 to 0. 1 mg/l for DDT, 0. 00001 to 0. 01 mg/l for Endrin, 0. 01 to 10 mg/l for Dursban, 0. 01 to 1. 0 mg/l for Malathion, 0. 1 to 10. 0 mg/l for Seven, and 0. 01 to 10. 0 mg/l for 2, 4-D. The fish avoided four (DDT, Endrin, Dursban and 2, 4-D) of the pesticides at the concentrations tested. They avoided neither Malathion nor Sevin. The fish did not appear to differentiate between differences in lower concentration of the same pesticide but did display the ability to seek water free of pesticides. Therefore, a prerequisite for avoidance in nature would be a reasonably distinct boundary between clean and pesticide-contaminated water and free access for migration. Estuaries are often characterized by conditions that create such boundaries or interfaces.[87] There is evidence to suggest that DDT in estuaries may affect the migratory mechanism of certain fish. The greater the DDT concentration, the greater the preference for high salinity.[88] This could interfere with spawning behavior since it suggests a tendency of fish exposed to pesticide pollution to return seaward.

The reproductive organs of aquatic organisms are major storage sites for chlorinated hydrocarbons.[7, 31, 89] The gonads of the oyster, Crassostrea virginica, stored approximately twice as much DDT as the digestive tract and other organs.[89] The residues accumulated in such organs could directly affect gamete maturation and viability, cell cleavage, and vitality of the developing larvae.[89] Fish store chlorinated hydrocarbons in the gonads and in the egg yolk.[23] Pinfish and Atlantic croaker populations of Pensacola Bay lose an estimated aggregate of 1/2 lb. of DDT and metabolities during egg deposition.[31] The DDT concentration of speckled seatrout in some areas of the Gulf average about 8 mg/kg.[23] The specific mechanisms of pesticide influence on egg development and viability of young of aquatic Southeastern species have not been defined.

Chlorinated hydrocarbon residues have seriously affected reproduction of adult water fowl. Eggshell thinning and consequent population decline have been attributed to chlorinated hydrocarbon residues.[90, 91] DDE concentrations as high as 2, 500 mg/l have been found in the yoke portion of eggs with the thinnest shells.[90] Dieldrin, PCB's and Endrin were also found in lesser amounts. DDT and DDE have been included in the diets of mallard ducks in controlled experiments. Thin eggshells and reduced hatching success were abserved. A nationwide survey was conducted to determine the chlorinated hydrocarbon residue levels in the mallard and the black duck.[92] Alabama recorded the highest average level of DDE in the survey (2.17 mg/kg in wing samples). Dieldrin, Lindane, and Endrin were also found in varying amounts. Raptorial birds, such as the herring gull, Larus argentatus, the bald eagle, Haliaeetus leucocephalus, and the peregrine falcon, Falco peregrinus, feed on birds, rodents, mammals and fish. Their populations are suffering a decline in correlation with observed eggshell thinning.[93] In 1967, herring gull eggs were collected from five states including Florida.[93] The shell thickness had decreased from 1947 to 1952 values while chlorinated hydrocarbon residues had increased. Brown pelican eggshells from Florida and South Carolina[94] have shown significant thinning (16-17% decrease) as compared to pre-1947 indices and a related decline in local populations.

Transport of ionic calcium across membrances of the shell gland in birds is an energy-requiring process dependent upon ATPase.[90] Inhibition by DDE could account for certain concentration-effect correlations (DDE concentration vs. shell thickness) obtained for eggs of the brown pelican and herring gull.[90] DDE, and PCB's have been found to inhibit carbonic anhydrase.[90] The enzyme is functional in deposition of calcium carbonate in the eggshell and for maintenance of pH gradients across membranes such as those of the shell gland. Associated with eggshell thinning is the problem of increased egg eating by parents, decreased clutch size and increased embryonic mortality.[95] Unknown is the importance of PCB's to observed reproductive failures in species of birds known to accumulate high concentrations of these substances.

In summary, low level pesticide contamination of water systems produces subtle and complex changes of aquatic life as a result of chronic exposure. Physiological changes of individuals are reflected as long-term changes in biotic community structure. In nature, such changes usually go unnoticed until climatic damage occurs. For example, elimination of species considered desirable by man. Waters of the Southeast are contaminated with pesticides and the extent depends on seasonal fluctuations. Concentrations are often greatest in estuaries during the spawning season of certain crustacea and fish.[31] The level and persistence of DDT in Gulf estuarine fauna suggests that commercial species of shrimp may be endangered in certain sections.[7] Information is needed regarding ecological alterations induced by chronic stress from pesticides in fresh and estuarine waters.

4. Synergestic Effects

Synergism occurs when the simultaneous action of separate factors, operating together, produce effects greater than the sum of the effects of the separate factors. Through synergism, a pesticide may act with other pesticides or with other physical, chemical or biological factors to cause an adverse effect at concentrations far less than the toxic level of that substance acting alone. Anomalous laboratory results and field observations suggest that many interrelationships and mechanisms of synergism remain unexplained.[56, 96]

a. Physical Synergisms

Temperature and pesticides may combine in a synergistic manner to adversely affect aquatic organisms. For each 10°C increase in temperature, the metabolic rate of an organism can be expected to double. As temperature rises, dissolved oxygen concentration of the water decreases. Temperature effects may combine with pesticide action to increase toxicity. In Florida it has been demonstrated that oysters are more sensitive to DDT and Endrin at the same concentration during the summer than during the winter.[89] The reverse is true of organophosphate compounds which can be explained by the reduction in the rate of hydrolysis in colder water.[89]

Trout and bluegill have been exposed to the presence of pesticides and varying temperature.[97] Increased susceptibility was noted with most compounds as temperature increased. Exceptions were noted for bluegill susceptibility to Lindane and Azinophosmethyl. They were unaffected by

b. Biological Synergisms

Mirex has been found to affect juvenile and adult crayfish differently.[42] Mortality from treatment with 1 to 5 μg/l of Mirex for 6 to 144 hours increased with time and was inversly related to animal size. Juvenile crayfish exhibited higher mortality rates than did adult crayfish. Juveniles at a length of 1.5 cm. showed a 55 percent mortality 3 weeks after consuming one granule of Mirex bait while adults of a 3.0 cm length showed no mortality. Increased toxicity to juvenile forms over a period of time was attributed to delayed toxic effects of Mirex. Juvenile forms of other crustacean species frequently display greater mortality factors than do adult forms. This has been, and will continue to be, increasingly significant in the nursery areas of estuaries.[7] More information is needed regarding toxicity levels of specific pesticides to immature stages in the life cycle of aquatic organisms.

Amitrole, Dalapon, Endothall, Fenuron, Dichlobenil, Dimethylamine salt of 2, 4-D, isooctyl ester of 2, 4-DP, and the potassium salt of Silvex at various concentrations over varying lengths of time had no appreciable effects on hatching of fish eggs (bluegill, green sunfish, smallmouth bass, lake chub-sucker and stone-roller).[102] However, the fry were found to be more susceptible to the toxic action of some herbicides than were fertilized eggs. Concentrations greater than 5 mg/l of Silvex and 10 mg/l of Fenuron reduced the number of fry produced from fertilized eggs. Different formulations of some herbicides showed different toxicities. Endothall did not affect the fry at concentrations of 10 and 25 mg/l. Carp eggs have been exposed to DDT, Chlordane, Dieldrin, Endrin, Diazinon and Guthion at a concentration of 1.0 mg/l.[103] Embryo development was stimulated and the incubation time was reduced by one-third.

temperature increases to 23.8° C from 12.7°C in the presence of Methoxychlor. Susceptibility decreased as the temperature increased. This anomaly could be the result of decomposition of the pesticide at higher temperatures. Similar experiments have been performed in Mississippi with mosquito fish, golden shiner, bluegill and green sunfish. They were exposed to DDE, Endrin, Aldrin, Dieldrin and Toxaphene at different seasons of the year.[64] Higher tolerance levels were measured during March and April than during June and July. For example, green sunfish tolerance to Endrin over 36 hours declined from 575 to 160 μg/l. Seasonal sensitivity to lethal concentrations of DDT and Endrin has been noted in sheepshead minnows of Florida. Sensitivity to 15 mg/l of DDT decreased during colder months, March to June, and increased during warmer months, August to September.[61]

Salinity has been tested as a synergist.[98] Salinity-tolerant mosquito fish, Gambusia affinis were acclimated at 0.15, 10 and 15 parts per thousand (ppt) salinity. DDT, DDD or DDE were introduced. A salinity of 15 ppt reduced the amount of DDT, DDE and DDD accumulated. DDT uptake was less than either DDE or DDD. DDT has been shown to impair the osmoregulatory system of the marine eel, Anguilla rostrata.[76] This effect may explain reduced DDT uptake with increased salinity.

The fathead minnow, Pimephales promelas, was exposed to Endrin or DDT under static and dynamic conditions.[99] Comparative 48- and 96-hour Endrin exposure indicated a slightly higher LC_{50} value during static as compared with dynamic tests. The higher toxicity of Endrin under static conditions was not explained. However, the sharp increase in toxicity of DDT in static conditions as opposed to dynamic was attributed to decreasing oxygen concentrations and/or synergism with fish-produced metabolites (e.g., ammonia or CO). Assessing toxicity of pesticides, under static test conditions, can result in significant error.[99] The pesticides could interact synergistically with numerous and varying physical and chemical factors of the aquatic environment. A greater emphasis must be placed on dynamic bioassay testing under natural conditions.

Certain chemical compounds have been shown to increase the toxicity of specific pesticides. Copper sulfate pentahydrate (CSP) has been applied in conjunction with Diquat to control hydrilla, egeria and Southern naiad.[100] This combined treatment yields better control than does individual application. Submerged plants absorbed more copper from pools containing both substances than from pools containing only CSP.

Pesticides can synergize with pH. This could be a result of pH induction of hydrolysis products that are more toxic than the parent compound. The fathead minnow has been exposed to Malathion under varying pH conditions.[101] When Malathion was introduced under high pH conditions, the metabolic product, Diethyl fumarate was formed. The metabolite was found to be more toxic in the presence of the parent compound than either substance acting alone. More information is needed on synergisms between parent compound and degradation products. Oysters exposed to a mixture of 1.0 μg/l each of DDT, Toxaphene and Parathion showed less growth and developed tissue pathology.[56] Changes were not evident in organisms reared in 1.0 μg/l of either DDT, Toxaphene or Parathion. The results suggest that the effects may have been caused by a synergism among the three toxicants.

In summary, the abiotic environment can alter the effect of a pesticide by either increasing or decreasing biological uptake and activity. Physical and chemical factors of the environment must be considered in conjunction with pesticide usage.

The egg stage of an animal can be relatively resistant to pesticides. The yolk material nourishes the developing embryo. Oxygen and water are obtained from the external environment. The offspring may not be exposed to pesticides until the yolk material has been depleted and/or hatching occurs.

Fingerling mosquito fish have been grouped into size-class and exposed to 41 ppt concentrations of DDT.[104] The smaller fish were more efficient in DDT uptake than were older fish within a 48-hour period. This was attributed to increased surface area to volume ratios in the smaller fish relative to those of larger fish. This relationship may be another factor that acts synergistically to alter toxicological effects.

Pesticide synergisms with such factors as temperature, pH, other pesticides, and stage of biological development have been established to species native to the Southeast. Synergisms, resulting from multiple-pesticide usage, have not been investigated thoroughly. Static bioassays are likely to result in limited toxicity information that do not recognize synergestic effects. The results would be of little use in predicting the effect in natural systems. Dynamic, carefully-designed tests are needed.

5. Health Implication of Pesticide Contaminated Water

The routes of pesticides from the contaminated-water environment directly to man are limited. Potable water is the most obvious route. Less obvious is the route through consumption of pesticide-contaminated food such as crabs, shrimp, fish and waterfowl.

a. Contamination of Potable Water Supplies

DDT residues were found in the Tennessee and Chattachoochee Rivers, while Dieldrin was reported in the Savannah River during 1962.[105] A 1964 survey of 56 U. S. rivers revealed that 44 were contaminated with chlorinated hydrocarbons in concentrations ranging from 0.002 to more than 0.118 µg/l.[106] Dieldrin occurred in 39 rivers, DDT or DDE in 25 rivers, and Endrin in 22 rivers. Between 1964 and 1967 water samples were obtained from 10 selected municipal water supplies and analyzed for chlorinated hydrocarbons.[107] Raw water sources for these systems were either the Missouri or Missippi Rivers. The only sampling site located in the Southeast was at Vicksburg, Mississippi. Of the 41 samples obtained at this site in 1964, four were positive for Aldrin, 29 for DDE, 28 for DDT, 23 for Dieldrin and 34 for Endrin. The survey was expanded to monitor 5 additional pesticides in 1965. Lindane was present in 4 of 6 samples, BHC in 5 of 6, Aldrin in 3 of 45, Heptachlor in 1 of 24, HCE in 6 of 37. Chlordane was not detected in 6 samples. Ingestion of at least 9 known pesticides was involved in consumption of this water.

The Flint Creek basin of Alabama was monitored for pesticides between 1959 and 1962.[108] The entire 400 square mile basin is located in a predominately cotton producing area. Flint Creek and the West Fork of Flint Creek are the principal streams of the basin. A water treatment plant is located downstream from the junction of the forks and serves Hartselle and Flint, Alabama. Pesticide analyses of treated and raw water samples at the treatment plant revealed chronic contamination by Toxaphene and BHC. Treated water contained pesticide concentrations comparable to the raw water. DDT was not found although it was used extensively within the basin. BHC contamination was attributed to crop dusting in the basin. The concentration of pesticide reaching the public via drinking water was less than 1 µg/l. Such levels go unnoticed by the consumer.

Five municipal wells in Florida were found to be contaminated with 1 µg/l of Parathion.[100] Canal water in the area contained Parathion as a result of extensive agricultural use. It was postulated that the wells were contaminated by percolation of ground water.[109]

Chemical and biological evidence indicates that surface waters of the United States are contaminated with chlorinated hydrocarbon insecticides. In localized areas, surface waters are polluted with herbicides. Organic pesticides can contribute tastes and odors to potable water.[110] Several organic triphosphates and 2, 4-D produce tastes and odors far below toxic levels. Establishing standards for selected pesticides in drinking water based on taste and odor levels could offer a margin of safety to consumers in those specific cases.

Once pesticides reach water treatement plants, removal through conventional coagulation and sand filtration becomes selective.[111] This is attributable to variations in solubility and adsorption. In one case, DDT at a concentration of 10 µg/l was effectively removed while Lindane and Parathion were not. The latter was presumably a result of greater water solubility. Chlorine treatment did oxidize Parathion to its toxic derivative, Paraoxon. Potassium permanganate at 1 to 5 mg/l and ozone at dosages up to 38 mg/l were ineffective. Powdered activated charcoal was of limited effectiveness. Lindane reduction from 10 to 1 µg/l, required 29 mg/l carbon. Percolation through a bed of granular carbon was the most effective means of treatment. More than 99 percent of the applied DDT, Lindane, Parathion, Dieldrin, 2, 4-D, 2, 4, 5-T ester, and Endrin concentrations were removed. Recent information indicates that occasional high pesticide concentrations may be reduced to acceptable levels by standard water treatment practices.[112] However, chronic, low-level concentrations are difficult to remove by current practices. At present, removal of pesticides from large bodies of water is economically unfeasible.[113] Therefore, long periods will be required for renovation by natural processes. As persistent pesticides are replaced by more readily-degradable compounds will be facilitated.

Increasing population growth and industrialization of the Southeast has resulted in more intensive use of available surface waters. Major supplies in this area are contaminated with persistent pesticides. Removal of low-level concentrations is not accomplished by conventional treatment practice. Hence, pesticides become available to humans in their drinking water. These low-level concentrations, if accumulated, may constitute health hazards.

b. Ingestion via Food Products

The main source of general population exposure to DDT and Dieldrin occurs via ingestion of residues in food.[114] Residues of DDT and its metabolites have been reported in processed fisheries products (fishmeal, oyster, and shrimp). These residues ranged from 0.02 to 0.063 mg/l.[115] Nine of fifty river monitoring stations in the United States are located in the Southeast.[116] Game fish from these stations have been shown to contain chlorinated hydrocarbons. Channel catfish of the St. Lucie canal in Florida and largemouth bass from the Tombigbee River in Alabama contained 58 mg/l and 10 mg/l of DDT and its metabolites, respectively. These levels were greater than those generally reported for other species of fish in other locations. These results were obtained from whole body samples and not exclusively from edible portions. Chlorinated hydrocarbons accumulate in the fatty tissues of fish. Once fish are processed for consumption, the pesticides generally remain with discarded visceral portions. Shrimp primarily accumulate pesticides in the non-consumed hepatopancreas. Oysters concentrated pesticides in their tissues to levels thousands of times greater than the water concentration. These tissues normally rid themselves of pesticides within a short period if placed in uncontaminated water. Where oyster-harvests are contaminated by pesticides, they can be decontaminated prior to marketing by placement in clean water.

Six of seven pesticide residue levels in domestically-processed seafood for the years 1964 to 1969 exceeded those of imported products.[117] BHC was the exception. Domestic fish products contained 74.4 percent of chlorinated hydrocarbon residues compared to 56.1 percent for imported varieties. DDE was present in 66.3 percent of the domestic varieties at an average of 0.49 mg/l. It was present in 49.1 percent of the imported varieties at an average of 0.06 mg/l. Heptachlor, Heptachlor epoxide, Aldin and Chlordane were not found in imported shellfish products. DDE ranked highest in terms of incidence and averaged 0.005 mg/l. Forty-eight percent of the domestic shellfish products contained chlorinated hydrocarbon residues compared to 16.8 percent for imported products. More agricultural pesticides are used in the United States than in any other country. Runoff amounts are deposited in streams and rivers. These are eventually deposited, in part, into estuaries and become available to estuarine organisms.

The effect of human ingestion of DDT over a two-year period has been determined.[118] Ninety men were divided into three groups: one group received no DDT, another received 3.5 mg/man/day, and the last received 35 mg/man/day over the two years. The dosages were established at 20 and 200 times the normal dietary intake level for DDT. The highest dosage was chosen to represent one-fifth of the smallest amount known to cause mild, transient sickness in man. Careful physical examination and laboratory testing failed to establish clinical evidence of adverse effects. DDT was confined to the body fat and was proportional to dosage. About one year was required to establish constant tissue storage levels of 234 to 340 mg/kg. Tissue biopsy examination revealed no further increase in storage level once equilibrium was attained. DDT release from body fat was found to be a much slower process than its deposition. The storage form was DDE.

Prolonged occupational exposure of an individual to DDT has been reported. A storage level of 64.8 mg/kg of DDT and its metabolites was established.[118] The individual exhibited no adverse effects.

Autopsies were conducted of 146 persons accidentally or violently killed in Dade County, Florida. These examinations included measurement of Dieldrin storage in the adipose tissue. A range of 0.19 to 0.24 mg/kg was obtained when samples were grouped according to age, race and sex.[119] This level was not statistically different from results obtained in other parts of the world. Worldwide distribution fell into a range of 0.15 to 0.29 mg/kg. However, a value of 0.03 mg/kg was reported in India.[120] It was concluded that Dieldrin storage does not vary significantly according to age, race, and sex. This contrasts with the significant differences calculated for concentrations of DDT and DDE associated with these demographic variables in the same fat samples.

Individuals ingesting persistent pesticides establish storage concentration relative to the amount ingested, i.e., storage is proportional to dosage. Information regarding the time required to establish equilibrium storage of DDE is not available. Pesticide concentrations in excess of storage levels are excreted in the urine. Amounts in fresh-water fish and marine shellfish are below storage levels. Continued monitoring is essential to maintaining low-level concentrations in the aquatic environment and resources derived therefrom. Low-level exposure of healthy adults to certain pesticides over periods of two-years[118], did not show obvious hazard. Such studies must be extended to provide a sound epedemiological basis for defining safe chronic exposure limits.

6. Conclusions

Aquatic vegetation can sorb large quantities of pesticides. These sorbed substances can be metabolically degraded or stored. The stored compounds may either become part of a food web or be returned to the sediment. Information is not available on sorption capacities and degradation of pesticides by aquatic vegetation of the Southeast.

Fish and filter-feeding sedentary invertebrates sorb pesticides directly from the water. Residue levels closely correlate with surface water concentrations, which relate to seasonal agricultural practices and rainfall.

Pesticides such as DDT, Dieldrin, Endrin, Toxaphene, Mirex and BHC are bioconcentrated. Food chain studies have been primarily focused on DDT without regard for other stable chlorinated hydrocarbons.

Herbicides, in general, are less toxic to fauna than other pesticides. This is attributed to the fact that these compounds degrade rapidly and do not bioconcentrate. The affects of herbicides on nontarget aquatic plant communities have not been specifically identified. For example, the reduction of consumer populations is accompanied by a shift in plant species to hardier algae that are not consumed by grazers.

Considerable emphasis has been placed on testing fish for acute toxicity. Acute toxicity levels have been established for several individual species under laboratory conditions. These values serve only as quantitative indices of toxicity under specific conditions and do not reflect accurate responses under varying natural environmental conditions.

There is a need for toxicological information on lower life forms obtained under dynamic test conditions. In such studies, continuous flow of natural waters under environmental conditions at the site, should be emphasized. Resulting information would be of greater value in assessing the effect of contaminants such as pesticides than that obtained under static monospecific test conditions.

More emphasis should be placed on the long-term (chronic) effects of pesticides. Toxicological information must be developed for the lower and intermediate aquatic organisms as well as for fish. Population changes in lower food chain organisms will ultimately be reflected in the long-term stability of higher consumers.

Quantitative data on residue transfers in fresh water and marine food webs are not available. There is a lack of information on the complex species interrelationships of food webs. Some forms establish an intake, storage and elimination equilibrium.

The presence of PCB compounds in Southeastern water, its biota and its sediments is widespread. These compounds are stable, bioconcentrate in tissues and interfere with calcium deposition in birds. This effect has been demonstrated with DDT.

Pesticide synergisms with such factors as temperature, water hardness, and stage of biological development have been established in species native to the Southeast. Synergisms, resulting from multiple pesticide residues, have not been investigated although many pesticides are applied in combination to ensure control of target species.

Chlorinated hydrocarbon residues at microgram per liter concentration are not completely removed by standard water treatment practices. The adverse effects of long-term, low-level, pesticide exposure in humans is not known.

Monitored pesticide residues in fish, shellfish and ducks are not directly useful in assessing quantities of pesticides reaching humans via these foods. Analyses are typically made on a whole-produce basis and not the edible portions only.

7. Recommendations

1. The Environmental Protection Agency should expand in-house and supported monitoring activities to identify pesticides and their metabolites in the aquatic environment (surface and ground fresh waters and estuarine). This activity should be complemented by an expanded program of development of improved pesticide concentration and analytical procedures. The elimination of the masking effect of polychlorinated biphenyls (PCB) in analyses of pesticides is a specific analytical need.

2. The Environmental Protection Agency should expand in-house and supported toxicological measurements of the effect of pesticides on aquatic flora and fauna. Emphasis must be given to dynamic rather than static test procedures. Under these conditions the simultaneous effect of multiple contaminants and environmental factors can be determined.

3. Long-term (chronic) epidimeological information should be developed for the effect on life forms ranging from microflora and microfauna to man. Programs of the National Institutes of Health should be oriented to fill this need.

4. The Environmental Protection Agency should sponsor the development of water quality standards for pesticides based upon residue tolerances of sensitive and essential members of the food web.

5. The activities of the Working Group of Pesticides, an intergovernmental agency organization, should be continued and expanded if necessary This liaison minimizes the possibility of duplication of in-house and sponsored studies. It provides a potentially valuable forum for input to development of improved analytical techniques and water quality standards.

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E. THE DEGRADATION OF PESTICIDES IN THE AQUATIC ENVIRONMENT

1. Introduction

Surveys show that most of the surface waters of the U. S. contain chlorinated hydrocarbon insecticides and certain herbicides.[1] These pesticide residues and their degradation products are of particular concern because of their potential toxicity to many aquatic organisms. Subsequently, they could exhibit adverse effects on man through his drinking water and food. Before it is possible to adequately protect the aquatic system it will be necessary to assess the effect of current pesticide practices and to adjust efforts accordingly. There are gaps in the knowledge. A large number of variables are associated with the fate of pesticide residues. Many are only poorly defined and others must be identified and evaluated.

The term "degradation" is used in a broad sense and will refer to any measurable chemical change in a pesticide under natural environmental conditions. Degradation may be "complete degradation" to inorganic end-products or "partial degradation" to intermediate organic products.[2]

2. Degradation Mechanisms, Rates and Products

The rates at which pesticides and their by-products degrade under natural conditions are the first consideration in examining the effect on the aquatic environment. A compilation of 58 potentially waterborne pesticide compounds for which degradation rates and product information are available is presented in Table E-1. The great majority of these results were obtained under laboratory conditions. A wide variety of procedures and test conditions were

HERBICIDES

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
I INORGANIC			
1) Sodium Arsenite	To remove filamentous algae and rooted aquatic vegetation in fish farm ponds		Dupree (1960) - Removal from water phase by bottom mud -- but desorption back into water phase possible; absorption by phytoplankton up to 714 ppm
Organic Arsenicals	Used extensively in cotton farming as selective post-emergence herbicides		
2) Copper Sulfate	Algae control in water	Increase copper uptake when CSP applied with diquat. 215	Large percent of applied quantities adsorb onto bottom muds. Residue readily uptaken by plants.
II. CARBOXYLIC AROMATICS			
A. Phenoxy Herbicides			
1) 2,4-D (Ester form and Na-Salt)	Used to control aquatic vegetation in water systems; also broad-leafed cereal grain crops and military defoliant	1) 2,4-D (acid) photolyzed in aqueous solution under lab conditions to humic acid 216 2,4-D (acid) → 2,4-Dichlorophenol → 4-Chlorocatechol 2,4-D (acid) → (to very small extent) → 2-Hydroxy-4-Chlorophenoxy-acetic Acid 4-Chlorocatechol → UV → 1,2,4-Benzenetriol → (light-independent) Rapidly Air Oxidized → Mixture of Polyquinoid humid acids (insoluble) Accompanying decrease in pH during degradation due to the production of 2 moles HCL/ 1 mole 2,4-D degraded 2) Esters of 2,4-D → UV - Distilled H_2O, 20 min → 2,4-Dichlorophenol - Accompanying pH decrease from 7 to 3 - Rate of decomposition increasing with pH increase being much faster at pH 9 than pH 4 or 7 - Degradation of Phenol form much faster at pH 9 than 4 -- biological degradation of Phenol form - 2,4-D biologically decomposed in relatively short time in lake bottom mud 4) Strong 2.1 unit decrease in pH within two weeks of application. Normal pH after 1 month. Control of plants up to and over 1 year, depending on flow rate of water	2) Sorption of the sodium salt form of the three 2,4-D Ester forms onto Bentonite, Illite and Kaolinite is small and considered insignificant 218 2,4-D persisted up to 120 days in lake water aerobically incubated in lab. Phenol may persist much longer in low pH, O_2 conditions. Removal of 2,4-D from water by Ca- or Mg-precipitation unlikely 3) 2,4-D spray on watershed at 4 lb/acre showed 1,800 ppb in water 2 days after and only 40 ppb 21 days after spray. 219 4) DMA 2,4-D removal by water treatment plants, little, if any 186 - Dimethylamine salt of 2,4-D appears to be non-cumulative - Within 24 hours - 100% 2,4-D that was in water column was adsorbed onto Plankton and retained it for 6 months. 5) 1 hour after treatment - 37 ug/l detected in water column; less than 1 ug/l present after 8 hours. However, 0.14 mg/kg to 58.8 mg/kg present in mud samples - lasting up to 10 months after application. 185
2) 4-(2,4-DB)	Aquatic weed control	1) 4-(2,4-Dichlorophenoxybutyric) acid → Bluegills (Fish) → 2,4-D 217 Bluegills = <u>Lepomis gibbosus</u> - Linear increase in 2,4-D production with time - No toxicity as result of conversion 2) Based on 2,4-D as model for Phenoxy herbicides, 4-(2,4-DB) predicted to undergo photodecomposition to yield Phenols	

HERBICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
3) 2,4,5-T	Used most effectively on woody plant species and such crops as hay, rice, pasture and sugar cane	1) Predicted photodecomposition in aqueous solutions to Phenol products, similar to 2,4-D	2) Applied at rate of 4 lb/acre to watershed, 680 ppb in water after 2 days; 90 ppb after 21 days 219
4) Silvex	Effectively used against woody plants and soybeans	1) Photodecomposition to Phenol products 2) In water and water-sediment systems, PGBE ester produced. Rate of PGBE degradation dependent on initial concentration but completely degraded.	2) Silvex concentrations continually decreased for 5 months 229
B. Phthalic Acid Compounds			
1) Endothal Derivatives (Disodium Endothal and TD-47)	Control of aquatic vegetation in fishery habitats when water temperature > 60°F - Also used as preemergence herbicide to prevent weed germination	1) Decomposition of TD-47 lowered D.O. to sufficiently low concentration to kill fish (~4) 220 - Higher Ca-concentration tended to reduce toxicity - Increased temperature - increased toxicity - Degradation of TD-47 in aquaria is rapid in first week. Rate is direct function of time and concentration - Immediate absorption by plants after application. Endothal amines released	Effective control of weeds for 1 month - Endothal (amines) residues may concentrate in organic matter associated with bottom muds - Some residues found in fish food organisms 3 weeks after application - 10 ppm residues required 25 days to disappear
C. Benzoic Acid Compounds			
1) Amiben	Soil sterilant used on soybeans, tomato plants and other vegetable crops	1) (Sheets, 1963 and Crosby, 1966) - Report rapid photolysis by sunlight in aqueous solutions 216 - Phenolic degradation products detected 2) Amiben and its Methyl ester photolyzed in daylight to dark color indicating hydrolysis and dechlorination. Products recovered were not identified. 222 3) (Isensee, 1969) - Biological activity diminishes during irradiation. N-Benzoyl derivative is more light stable. 216	
D. Phenylacetic Acid 1) Fenac	Used in agriculture, aquatic weed control and right-of-way weed control	1) Irradiation of Na-Salt by UV light yields mixture acidic and neutral compounds. Major identified product is 2,5-Dichlorobenzyl alcohol. Di- and Trichlorobenzaldehydes probable minor products themselves are photolabile (Crosby, 1966) 216 - Irradiation of one of the more simple constituents of Fenac, Monochlorophenylacetic acid ↓ Benzyl Alcohol + Benzaldehyde + O-Chlorobenzaldehyde	
III. ALIPHATIC ACID HERBICIDES			
1) PCP	As an insecticide, molluscicide, herbicide, fungicide and bactericide. Controls termites, wood insects, snails. Used as weed killer, cotton defoliant and wood preservative	1) Decomposes in sunlight - monomeric and dimeric oxidation products formed by photolysis of the Na-Salt in H_2O (Kuwahara, et al, 1966) 223 - Violet colored solution. Major products identified as Chloranilic acid are 3,4,5-Trichloro-6-(2'-Hydroxy-3', 4', 5', 6'-tetrachlorophenoxy)-O-Benzo Quinone 216	
2) Bromoxynil	Treatment for broadleaf weeds	1. Decomposes in light, in aqueous solution, to polyphenols and colored polymeric materials.	
3) Dichlobenil	Preemergence herbicide effective against many submerged aquatic weeds - not filamentous algae - controls alfalfa weeds	1) Temperature strongly influences degradation rate. In 77 to 39°F pond, only 3% of compound left after 11 days; in 47 to 73°F pond, 3 weeks before maximum concentration in water - measurable after 189 days Greater toxic action with time for invertebrates - suspected bottom accumulation 225	1) Dichlobenil present in bottom sediments of warmer pond after 312 days and after 166 days in colder pond (due to mode of application) 225 - Residues in fish reduced to negligible levels in 2 months 2) Residues found in water, hydrosoil and organisms. After 14 days, hydrosoil contained larger amounts than water; present in water and soil 64 days after treatment but not in organisms. The metabolite 2,6-Dichorobenzoic acid never detected.

HERBICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
IV HETEROCYCLIC NITROGEN DERIVATIVE HERBICIDES			
A. S-Triazines	Weed control among vegetable crops	Low water solubility	
1) Simazine	Used to control weeds in maize. Also, effectively used to control aquatic weeds in ponds, lakes, and fish hatcheries.	1) Slight degradation evidenced after 21 days 226	1) Sunfish absorb amounts directly proportional to solution concentration - Residue located in Viscera - Released after 7 days in clean H_2O No storage
V ALIPHATIC ORGANIC NITROGEN HERBICIDES			
A. Substituted Ureas			
1) Monuron	Agricultural herbicides and soil sterilants	1) In river water, pH 7.3 (lab conditions), complete degradation in 8 weeks. Suspected this compound would hydrolyze to its amine and Dimethyl carbamic acid. 181 2) One identified photolysis, aqueous product is 3-(4-Chloro-2-hydroxyphenyl)-1,1-dimethylurea (Tang and Crosby, 1968). 216	
2) Fenuron	Agricultural herbicide	1) In river water, pH 7.3 (lab conditions), complete degradation in 8 weeks. Suspected hyrolysis to its amine and dimethyl carbamic acid. 181	
3) Diuron	Soil sterilant action	1) Partial detoxification by bacterial organisms 193	
4) Linuron	Agricultural herbicide	After 2 months of sunlight, aqueous exposure, 13% 3-(3-Chloro-4-hydroxyphenyl)-1-mehtoxy-1-methylurea, 10% 3,4-Dichloro-phenylurea and 2% 3-(3,4-Dichlorophenyl)-1-methylurea (Rosen, et al, 1969) 216	
5) Metabromuron	Agricultural herbicide	Irradiation in aqueous solution for 17 days yielded - 80% original parent composition+15% 3-(p-hydroxyphenyl)-1-Methoxy-1-Methylurea+3-(p-bromophenyl)-1-methylurea+p-bromophenylurea+unidentified products (Rosen and Strusz, 1968) 216	
B. Carbamates	Agriculture - most effective in preemergence application	Refer to insecticide chart for individual compounds	
IV. MISCELLANEOUS			
1. Merphos (organophosphate)	Defoliant	In river water, ph 7.3, lab conditions, merphos converted within 1 hour via oxidation to DEF - 100% conversion. However, after 1 week, only 50% of DEF was recovered; after 8 weeks, less than 5% was recovered. $P(C_4H_9S)_3 \xrightarrow{[O]} PO(C_4H_9S)_3$ 181	
2. Pichloram	Brush killer and aquatic herbicide	1) Photodecomposition in aqueous solution yields nonphytotoxic products 223 2) Products of photolysis in water not isolated by suspected hydroxyl replacement of chloride (Redemann, et al, 1968) 216	3) More persistent than 2,4-D or 2,4,5-T residues of 6 ppb lasted up to 180 days after spray into shallow pond
3. Dursban	Very similar to pichloram	1) In aqueous solution, ph 8.0, 3,5,6-Trichloro-pyridinol rapidly degraded - All chlorires liberated - 14 products detected (Smith, 1968) 216	
4. Diquat	Aquatic herbicides	1) At 3 ppm application, negligible residues were detected after 21 days - A significant portion being lost after 3 days. - Loss may be degradation or adsorption - The majority of the 16 chemicals listed: Dichcone, Molinate, Propanil, Na-Arsenite, Diquat, Dichlobenil, Paraquat, Amitrole, Amitrole T, Endothall, Diuron, Silvex, Fenac, Monuron, MCPA and 2,4-D have been found to readily decompose in aqueous, sunlight solutions (Crosby, et al, 1965)	

HERBICIDES (Concluded)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS		ACCUMULATION AND/OR LONGEVITY
				2) Diquat, upon contact with sediments, is immediately and completely in activation. (Fundburk and Lawrence - 1964) Reported rapid adsorption and concentration of diquat by plants 40 to 60 times amount in water
		3) Very water soluble - decomposes above pH 9 - colored products - Strongly adsorbs onto clay. Photodegradable	223	
5. Paraquat	Aquatic herbicide	1) More stable than diquat	223	1) Very strong adsorption onto clay

INSECTICIDES

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
CHLORINATED HYDROCARBONS			
A Aldrin	Used as soil insecticide for control of ants, cutworms, grubs, beetles and cotton pests	a Photoisomerization to photoaldrin - can be converted to more toxic lipophilic ketones Photoisomerization produced by sunlight or microorganisms c) Aldrin $\xrightarrow[\text{Epoxidation}]{\text{River water - pH 7.3}}$ Dieldrin - Same in distilled H_2O d Aerobic and anaerobic degradation of Aldrin - rate under anaerobic sludge conditions slightly greater than aerobic - neither temperature (between 20° to 30°C) nor biological activity significantly altered rate (pH 7.3) e) Photodecomposition via sunlight (Photoaldrin 11 times more toxic than Aldrin) 188	a) Persisting residues may be magnified by concentration of lipophilic metabolites in food chains 187 b) Floc-forming bacteria can remove ~ 100 percent Aldrin from solution in 20 minutes in river water 178 c) Conversion 80 percent complete after 8 weeks, complete conversion possible 181 d) Anaerobic half-life approximately 1 week in biologically active wastewater sludge 172
B. Dieldrin	Control insects which infest vegetable and fruit crops - general soil inhabiting pests primary use is for termite control	a) No chemical conversion in river water - pH 7.3 - or in distilled water b) Photoisomerized (in water via sunlight - may be microorganisms) to Photodieldrin, which can be further converted to more toxic lipophilic ketones (Photodieldrin 11 times more toxic to vert than Dieldrin) c) Under dilute aerobic sludge and anaerobic sludge, at pH 7 to 8, temperature 20°C and 35°C - no degradation	a) For 8 weeks, no conversion 181 b) Very persistent, residues may be magnified by concentration of lipophilic metabolites in food chains 187, 188 c) Very persistent under aerobic-anaerobic and microbial activity 172 d) Sediment sorption, initial sorption (0 to 26 percent) rapid within pH range 3 to 9 0, decrease with time. After 7 days, pH > 8, sorbed Dieldrin = 0, pH decreased - Uptake of Dieldrin by sediment time-dependent, salinity independent 184
C. DDT	Broad spectrum - cotton, soybean and peanut pests; also, timber, industrial and mosquitoes	a Bacterial degradation of dichlorodiphenylmethane, a DDT metabolic product - Hydrogenomonas + DDT $\xrightarrow{\text{metabolized}}$ DCM → p-chlorophenylacetate 195 b DDT $\xrightarrow{\text{lake water}}$ TDE, principal product (also known as DDD) DDT $\xrightarrow{\text{porphyrins}}$ DDD, an intermediate of DDT c) DDT, DDD, DDE underwent no change in river water, pH 7.3 - no change in distilled water d) DDT $\xrightarrow[\text{lake water}]{\text{microbial isolates}}$ TDE → DDNS (both highly acridal) DDE also detected Greater DDNS percentage in eutrophic water 197 f) Under anaerobic conditions DDT $\xrightarrow{\text{A aerogenes pH 7}}$ DDD → DDE (70%) ↕ Dechlorination due to reduced (FeII) cytochrome oxidase - DDT conversion requires O_2 in higher animals, but not microorganisms i DDT $\xrightarrow[\text{rate dependent on available food supply}]{\text{trout intestinal microflora}}$ DDD → DDE DDT → DDD → DDE 20% conversion after 7 days	b) DDT - very persistent, minimally 7 years 196 c) No change after 8 weeks 181 e) Detroit River W/I percent sedimented oils contained DDT concentration near 1 ppm 198 f) Cytochrome oxidase-Fe complex dissociated by light and O_2, this complex is believed responsible for dechlorination of DDT, [illegible] may explain persistence of DDT in sediments 199 g No metabolic breakdown of DDD after 10 days 200

INSECTICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
		h) Anaerobic conditions: at pH 7 DDA —A. aerogenes→ DPM → DBH → DBP - most highly degraded product reported	h Anaerobic conditions had little effect on dissipation 201
		i) DDT —A. aerogenes, pH 7→ DDD → DDMU → DDMS → DDNU → DDA → DBP or DDT → DDE Aerobic conditions produced considerably less conversion than anaerobic	i) Metabolic fate of DDT believed dependent on exogenous energy source - Conversions DDT → DDD in mineral media with tyrosine complete in 100 hours and apparently direct linear function of temperature 202
		j In waste water sludge. Anaerobic conditions: DDT —a-reducing cofactor, 1 to 2 days→ DDD - microbial activity produced rapid conversion Aerobic conditions No DDT conversion at 40°C - but some degradation at 35°C	j) Under biologically active, anaerobic conditions, DDD had half-life < 1 week 173
			k) Rate of DDT → DDD conversion inversely related to O_2 concentrations 203
			l) Decay time of DDT is seven years in man, birds, insects and fish 204
D Endrin	Major domestic use as a cotton insecticide	a) No conversion in river water, pH 7.3, or in distilled H_2O	a After 8 weeks, no change 181
		b Anaerobic conditions in wastewater sludge: Endrin → 2 unidentified, extractable degradation products	b) Ranking in order of increasing persistence under anaerobic conditions. Lindane, Heptachlor, Endrin, DDT, DDD, Aldrin, Heptachlor epoxide and Dieldrin 172
			c Uptake of Endrin by bottom sediment: at pH range of 3 to 10.5, rapid initial uptake, decrease sharply with time → after 7 days contact, pH > 7, Endrin sorption = 0 184 At salinity 13 to 17 0/00, rapid initial uptake, after 7 days contact, Endrin = 0. Above salinity 17 0/00, no Endrin sorption onto sediment
E Chlordane	Control cotton pests, grasshoppers, termites and as a soil sterilant	a) Of major components of technical chlordane, only a- and γ-chlordane stable completely for 8 weeks in river water, pH 7.3 b Photoisomerize in sunlight 205	a 15 percent degradation in 8 weeks of other components 181
F Endosulfan	Agricultural application for control of vegetable pests, cotton pests and as a soil sterilant	a) Contains two active isomers. Endosulfan I and II. Both isomers 70 percent reduced within one week in river water at pH 7.3. - Endosulfan alcohol believed decomposition product - Same results in distilled H_2O	a) Complete isomer decomposition within 8 weeks 181
G Isodrin	For agricultural and forest pests. Similar use as Dieldrin and Endrin	a) Photoisomerization to photoisodrin	a) "Rapid" detoxification 187
H Heptachlor	Primarily a soil insecticide - primarily for corn, secondarily for commercial pest control	a) Photoisomerized —sunlight→ Photoheptachlor	a) Persisting lipophilic residues food chain 187
		b Heptachlor —river water, pH 7.3→ 1-Hydroxychlordene - Same reaction observed in distilled water, however, by second week Heptachlor epoxide produced	b) Complete conversion within 2 weeks 181 At end of 4 weeks, equilibrium exists → (60 percent) 1-Hydroxychlordene and Heptachlor epoxide (40 percent) Heptachlor epoxide remained stable for 8 weeks
		c. Heptachlor rapid degrades in anaerobic and aerobic waste water sludge	c) Anaerobic degradation products more persistent than initial Heptachlor. Product persisted in biologically anaerobic conditions 42 days, but completely degraded after 266 days 172
		d) Removal of Heptachlor from distilled water was 99.4 percent in 4 days 206	d) Losses from volatilization included - can be a quite significant amount 203

INSECTICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
		Heptachlor —Degraded→ 1-Hydroxychlordene + Unidentified Product e Heptachlor —H_2O / Metabol.→ 1-hydroxychlordene —H_2O / Metabol.→ 1-Keto-Chlordene Photoheptachlor-Ketone ←hv / Photoisomerization— (1-Keto-Chlordene) 205	
Telodrin	Agricultural	In river water, pH 7.3, 75 percent alteration in one week and 90 percent after two weeks - Same results in distilled water	At end of 4 weeks completely decomposed rather than chemically converted to a compound 181
J Toxaphene	For control of grasshoppers, soil pests and pests which attack forage crops, cotton, soybeans and livestock ectoparasites		a) In a lake environment, toxaphene vertically transported 5 to 15 cm in sediment - sorption irreversible. Decreased from maximum concentration by factor of 2 every 4 months 177 b) Contrary to Veith and Lee (1971), desorption of toxaphene from sediments produces yearly fluctuations of μg/ℓ in toxaphene concentration in the water. Aquatic plants significantly concentrate toxaphene in large amounts 207
K γ-Benzene Hexachloride also, Lindane	Wide use for control of cotton insects and rice stem borer. Also use on wood infesting pests.	a) In river water, pH 7.3, no BHC degradation b) Anaerobic degradation in thick sludge at 35°C. Lower Lindane concentration 95 percent in 2 days. - Rate depends on Lindane and sludge concentration - Anaerobic degradation temperature sensitive, at 35°C, rate of 0.3 μg/day/mℓ. At 20°C, very little degradation. Under aerobic conditions with dilute sludge at 20°C, daily small doses of Lindane for 57 days, had < 8 percent degradation after 117 days. Unidentified product produced which persisted for 42 days but completely removed within 266 days in thick 35°C anaerobic sludge. :) At pH 11.5 in aqueous solution, 98.5 percent Lindane removed in 6.5 hours. The first degradation product present only few hours, replaced by second decomposition product which eventually disappeared. 206 Lindane, little, if any, degraded by microbial activity in an aerobic environment. 1, 2, 4-trichlorobene, reported in Okey and Bogan and Metcalf, as an alkaline dechlorination product of Lindane, was also resistant to metabolic (microbial) attack. f) Under anaerobic conditions, volatilization of degradation products, produced in aqueous environment, accounted for loss of 83.2 percent of γ-BHC. Half-life calculated at 16 days. Biological mechanisms responsible for isomerization 16.1 percent degradation at end of 2,100 hours Under aerobic conditions, identifiable degradation products were: The α-isomer of γ-BHC and δ-BHC In anaerobic conditions: α-BHC and δ-BHC but no δ-BHC. 203 g) In sea water, the α, δ and γ isomers decay at different rates, α being the slowest (35 percent in 31 days). Chemical degradation rather than biological.	a No degradation after 8 weeks 181 b) Half-life in anaerobic microbially active sludge was 1 day; half-life in anaerobic non-microbially active sludge was ~ 170 days 172 d) Lindane adsorption onto lake sediments affected by sediment suspension concentration, organic matter content, Lindane concentration, clay content and Lindane to sediment ratio. 203 «) Half-life of ~ 18 hours when tested in aquaria with fish 208 Stored samples of reaction mixture showed considerable γ-BHC concentration after 12 months at 20°C 205
L Mirex	Fire ant control	No degradation biologically (fish). Chemically (in ponds) after 284 days.	High residuality, after 56 days very little decrease in residues in mud, water and vegetation 21? Residues up to 200 ppm found in goldfish 308 days after exposure to 1 ppm for 1 day

INSECTICIDES (Continued)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
II. ORGANOPHOSPHATES			
A Parathion	Used as larvicide for mosquito control ∴ direct spray entry into water Also, to control peach pests and other fruit and vegetable pests	The general rule for hydrolysis in distilled H_2O is the increase in rate with decrease in sulfur content of the organophospate ester. 211 a) In river water, pH 7.3, Parathion and Methyl parathion Hydrolyzed → p-Nitrophenol Hydrolyzed → Diethyl and Dimethyl-o-thio-phosphoric acid In distilled H_2O, no change in compound, suggesting a biological degradation b) In sterilized sediment systems, adsorbed and in solution Parathion —Hydrolyzed→ Diethylthiophosphoric acid Parathion —Hydrolyzed→ p-Nitrophenol - In natural sediment, only parathion is solution was hydrolyzed. Rate of hydrolysis 0.15 to 0.18 percent/day. Catalyzed at pH > 7. In anaerobic, microbial environment: Parathion → Aminoparathion, stable for 150 days In aerobic, microbial environment: Parathion → Aminoparathion + x-compound (w/Benzenoid and Phosphoric Acid moieties) d) At pH 6.6 to 7.3, Parathion present in water (0.01 ppb), 4 months after last application e) After 6 weeks in aqueous solution, 82.2 percent degraded (ph 6.0) f) W/B subtilis - under aerobic conditions - Unable to oxidized methyl parathion but formed aminomethylparathion, dimethylthiophosphoric acid and aminodesmethyl parathion. The amino-form was the main product. - W/B subtilis - anaerobically, only amino-form produced. 180	a) Less than 5 percent Parathion compound remained after fourth week 181 10 percent Methyl parathion remained by 2 weeks, 0 percent by fourth week b) In sediment (from lake with pH 4.7), solutions 26 percent degraded in 92 days 180 In sediment (from lake with pH 7.2), solutions 28 to 39 percent degraded in 54 days ∴ w/o microbial activity, Parathion would persist for months, while in biologically active (anaerobic or aerobic) environments, persist only few weeks c) 50 percent hydrolyzed in water in 120 days 212 d) Parathion stable indefinitely in neutral and acid solutions at room temperature at pH > 9, and temperature increase - considerable hydrolysis e) Most persistent of the organo phosphates 211 i) Methyl parathion and Parathion were much more persistent in lake water than soil water. Residues in lake water up to nine months, whereas only 1 month in soil water. 179
B Ciodrin	Agricultural	a) Hydrolysis is acid-catalyzed, resistant to chemical hydrolysis 180	
C Diazon	Effective against many fruit and vegetable pests	a) Hydrolysis is acid or base catalyzed, forms 2-isopropyl-4-methyl-6-hydroxypyrimidine, which is microbially degradable - Resistant to chemical hydrolysis 180 b) 95 percent degraded after 5 weeks, is distilled H_2O, pH 6.0 211	
D Sumithion	Agricultural	a) W/Bacillus subtilis - aerobic degradation 180	
E Malathion	Used to control certain pests of fruits, vegetables and ornamentals. Also used for public mosquito control.	a Malathion can be, under aerobic conditions, microbially degraded - 99 percent in 24 hours 182 With aeration alone, 55 percent hydrolyzed in 24 hours b) Easily hydrolyzed in water above pH 7.0 c) Completely degraded in river water, pH 7.3, within four weeks - Metabolites not identified - Same test run in distilled water, no hydrolysis 181	a) (Weiss and Gakstatter - 1965) Persistence dependent on pH. Half-life in solution of pH 6, 7, and 8 ranged from 3 months to 1 week, respectively. 213

INSECTICIDES (Concluded)

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS)	ACCUMULATION AND/OR LONGEVITY
			e) Uptake from solution by carp is a function of time - up to 5 mg/l
		f) 91 percent degraded after 4 weeks in distilled H_2O, pH 6.0 211	Half-life of metabolic residues calculated at 12 hours 213
		g) Main hydrolysis product, Diethyl fumarate (more toxic to minnows than parent) and dimethyl phophorodithioic acid in basic solutions - In acid solutions, degradation products are dimethyl phophorothionic acid and 2-mercaptodiethyl succinate. However, below pH 7, hydrolysis will not proceed for prolonged periods. Other hydrolysis products: Diethyl maleate and maleic acid - Pronounced toxic synergism between malathion and diethyl fumarate 191	
F Ethion	Primarily used in agriculture	a) River water, pH 7.3, 50 percent decrease in concentration in 8 weeks - In distilled water, no change 181 b) Approximately 95 percent degraded after 6 weeks in distilled H_2O, pH 6 211	
G Trithion	Primarily used in agriculture	a) In river water, pH 7.3, 90 percent reduction after 2 weeks - Decomposition products not identified 181	Complete disappearance in four weeks
H Fenthion	Mosquito larvicide. Also, agricultural use	a) 90 percent degradation after 2 weeks in river water, pH 7.3 181 Believed Fenthion → *4-Methylthio-m-cresol*; → Dimethyl-o-thio-phosphoric acid - No change in distilled H_2O Residual life up to 4 days in lakes and ponds, not greatly influenced by pH (Mulla, 1963) 214	Complete degradation by fourth week
Dimethoate	Agricultural	a) 15 percent degradation in 2 weeks in river water, pH 7.3 181	50 percent degradation after 8 weeks
J. Azodrin	Agricultural	a) After 8 weeks in river water, pH 7.3, no change 181	
K. Fenitrothion (MeP)	Agricultural	a) 73.8 percent degraded in 3 weeks in pH 6.0 distilled H_2O 211	
L. Phosdrin	Agricultural	a) At pH 6 in distilled water rapid hydrolysis. After 4 weeks approximately 98 percent degraded. However, according to Porter-1964, the half-life in slightly acidic solutions was 3 months. 211	
M Ronnel	Agricultural	a Approximately 95 percent degraded after 1 week, in pH 6.0 distilled H_2O 211	
N Dursban	Agricultural	a) Conversion to phosphate analog by rainbow trout but such conversion does not occur in goldfish	
III. CABAMATES			
A Sevin	Broad spectrum application	a) In river water, pH 7.3, 95 percent reduction in one week 181 1-Naphthol, suspected degradation product was not detected after parent decomposition, perhaps rapid decomposition b) Sevin and 1-Naphthol metabolite completely degraded in lake water after 3 days, pH 8.5 179	Complete degradation by second week
B Zectran		a) 85 percent degradation after one week in river water at pH 7.3 181 Suspected degradation product, *4-Dimethyl-amino-3, 5-Dimethyl* Phenol, was not detected	Complete degradation by second week
C Matacil		a) 90 percent degradation by second week in river water, pH 7.3 - No suspected decomposition products detected 181	Complete degradation by fourth week
D Mesurol		a) 100 percent degradation within one week in river water, pH 7.3 181 Decomposed to → Methyl carbamic acid; → 4-Methylthio-3, 5-Dimethyl Phenol	*The phenol degraded slowly*, by fourth week it was not detectable
E Baygon		a) After one week in river water, pH 7.3, 50 percent hydrolyzed to its phenol; after 2 weeks, 70 percent, 4 weeks, 90 percent; and 8 weeks, 95 percent degraded 181 - The phenol was also degraded such that it was not detected after 8 weeks.	

FUNGICIDES

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND PRODUCTS	ACCUMULATION AND/OR LONGEVITY
1. PCP	Fungicidal use, in addition to its herbicidal use	Discussed under herbicides	
2. Carboxin	First synthetic fungicide	Oxidation retarded at high pH. Main degradation pathway was carboxin $\xrightarrow[H_2O]{}$ Sulfoxide form. At pH 2 and 4, further oxidation of Sulfoxide to Sulfone 227	

MISCELLANEOUS PESTICIDES

CHEMICAL CLASSIFICATION	USAGE	DEGRADATION (SPECIFIC CONDITIONS) AND METABOLITES	ACCUMULATION AND/OR LONGEVITY
Rotenone	Piscicide	Time dependent changes in Rotenone toxicity - Correlated to the transition from colloid to a dissolved state. - Toxic change proceeds at greater rate at high temperature - Inactivation 6 to 15 days in water solution - Unstable in light, temperature increase increases effectiveness 192	
2 Cabaryl	Used to control ghost shrimp in oyster beds Also used as insecticide against pests of fruit, nuts, vegetables, forage crops and cotton	a) In sea water, hydrolyzes to 1-Naphthol (Karinen, et al., 1967). 1-Napthol is quite unstable in alkaline sea water. 190 1-Naphthol (more toxic to clams and fish than parent compound) —Light and Microorganisms→ CO_2 + Unidentified Products - Degradation in light and dark produced different degradation products - Precipitate forms upon exposure to light (red color) contains stable free radical (2/3 toxic as 1-Napthol) - In sterile, anaerobic, light-exposed systems, 1-Napthol decreased 0.3 percent per day for 30 days - With O_2, degradation rate was 1.6 percent for 40 days; its degradation attributed to photooxidation rather than photodecomposition - Optimum stability of 1-Napthol is pH 6.3, but unstable at pH 8.2, the pH of sea water b) Degradation by the fresh water algae, Scenedesmus, suspected hydrolysis and oxidation to form N-Methyl carbamic acid + NH_3 + Formic Acid 193	Treatment of mud flats with Cabaryl failed to recolonize with mussels for 18 months
3 Antimycin	Piscicide - used in marine habitats	a) Rapid breakdown above pH 8.5, increase in toxicity as temperature increases - Degradation in fresh water directly related to hardness. Exposure to light and warm alkaline waters, becomes sublethal in 7 to 10 days. Detoxification first to occur in surface waters 194	Residuality in fresh water - 24 to 96 hours (Walker, et.al. - 1964) Residuality in salt water - 5 days

employed in these studies. The results, though valuable, are not readily interpretable on a common basis. Only a limited number of field studies have been reported for the Southeastern region. Extrapolation of the laboratory results to field conditions is not valid. For example, discrete differences in time of persistence may occur for a single compound because it may be degraded via several physical, biological, chemical or a combination of these ways. The pathway depends on such environmental parameters as temperature, oxygen concentration and the presence of other reactive substances. To facilitate evaluation of existing knowledge the pesticides will be considered as chemically-related groups.

a. Chlorinated Hydrocarbons

The chlorinated hydrocarbons include DDT. This was one of the first and most extensively used of this group. It has been of great benefit but belatedly, concern has been expressed regarding its effect on life systems. Certain generalized statements can be made about chlorinated hydrocarbons subsequent to inspection of the laboratory and field studies presented in Table E-1. The chlorinated hydrocarbons are synthetic organic compounds of which a number are known for their "persistence" or longevity (periods longer than one year) of residues. Chlorinated hydrocarbon compounds which have received considerable public attention are Endrin, Dieldrin, Toxaphene and Mirex. In fact, these compounds are the ones most commonly found in Southeastern waters.[3] Persistent residues of these compounds have a low water solubility and have strong tendencies to sorb onto soil and sediment particles within natural waters.[1,4] The biological persistence of DDT is attributable to the high lipophilic character of the molecule. This characteristic enables it to be stored and concentrated in the fat deposits of aquatic organisms and higher life forms. The residues become magnified with each successive step in the food chain.[5] Degradation of chlorinated hydrocarbons has been shown to occur faster under anaerobic conditions than under aerobic conditions, wherein high bacterial numbers and high temperature regimes were utilized.[2] This is an important consideration. The waters of the southeastern United States are classified as warm since the annual average is 65° F. This condition would appear to favor accelerated degradation in this region as compared to colder regions of the United States. However, quantitative documentation for such a deduction is not available.

Understanding of the degradation of chlorinated hydrocarbon pesticides in the Southeastern region is deficient. Especially important is the need to intensify long-term degradation field studies under natural conditions.

b. Organophosphates

In recent years, there has been a gradual increase in the use of more readily degradable organophosphates in place of chlorinated hydrocarbons. These compounds are classified as non-persistent because their residues last for only a few months, under normal application rates.[4] This group includes Malathion, Methyl parathion Parathion, and Diazinon. These compounds undergo hydrolysis in the aquatic environment where microbial activity and pH greatly influence this rate.[6] The hydrolysis rate in distilled water increases with decreasing sulfur content of the phosphate ester.[7] At pH greater than 7.0, the duration or half-life is decreased.[8]

Southeastern field work has included limited identification and measurement of persistence in sediment residues. These studies have not been designed to define degradation rates "in situ".

c. Carbamates

Another class of non-persistent pesticides are the carbamates. The compounds have agricultural applications and are a comparatively new class of chemicals. These compounds contain neither chlorine nor phosphorus but their cholinesterase-inhibitory action is similar to that of organophosphates. Carbamates are generally referred to as non-persistent pesticides. Carbaryl has been shown to degrade in sea water to form unidentified toxic products.[9]

d. Herbicidal Compounds

Herbicides are included in a variety of chemical classes (see Table E-1) including a few chlorinated hydrocarbons, organophosphates and carbamates. These compounds have a range of persistence from several weeks to months and exhibit varying degrees of water solubility. Photo-induced transformations of halogenated herbicides have been widely demonstrated under laboratory conditions[10]. Water yields hydroxylated and reduced products. Degradation mechanisms for other types of herbicides involve oxidation or hydrolysis to nonphytotoxic products.

e. Inorganic Pesticides

The inorganic pesticides often yield residues that are virtually non-degradable. The cation remaining is often potentially toxic and is represented by such metals as mercury, arsenic, copper, and lead. Copper sulfate has been widely used to control the growth of some submerged vascular plants.[11] Mercury compounds, on the other hand, have found great usage as fungicidal agents.[12] These fungicides may be transported to water systems. However, once applied, the elemental forms remain in soils unless removed through leaching.[4]

Laboratory studies which have been performed are not readily applicable to field conditions for the Southeast. Therefore, any correlation which exists between these respective degradation rates and pathways remain undefined.

3. Physical Influences on Degradation

The degradation of pesticides in the aqueous environment is influenced by physical factors unique to each individual system. The physical factors may be sorption onto organic or inorganic particulate surfaces, transport between the aqueous and benthic phases along a waterway, or volatilization into the atmosphere. The result is concomitant adjustment in the concentration of residue at the original site. Quantitative information on these processes has been obtained only very recently and is still meager. The interrelationship of the physical processes and degradation mechanisms and their rates is still largely undefined.

a. Adsorption

Many pesticides are almost insoluble in water but can be found in significant quantities in the aqueous and sediment phases of water bodies. Often, they are present because they have been sorbed by various solids that act as condensation nuclei.[13] Therefore, it is important to understand the phenomena of sorption prior to evaluation of degradation and transport processes. Sorption is not a degradation mechanism "per se" but it alters the availability of the pesticide for subsequent chemical or biological degradation.

The extent of pesticide sorption is related to the solubility of the compound, the nature of the material on which it is sorbed and other properties of the aqueous system. Strong sorption bonds to clay minerals are characteristic of some pesticides, such as DDT.[14]

(1) Chemical Reactions

Hydrolytic mechanisms are accelerated by sediment sorption. The rate of reaction is time and pH dependent, i. e., if the pH is held constant, the rate of degradation is related to time by first-order kinetics. Atrazine hydrolyzes to the non-toxic compound, Hydroxyatrazine. The reaction has been shown to be catalyzed by sorption onto colloidal surfaces.[15, 16] The catalysis is apparently associated with sorption at -COOH groups of the sediment. The literature is generally deficient in similar sediment-catalyzed degradation for other chlorinated hydrocarbons. The relationship of the sorption process to chemical degradation mechanisms of pesticides has not been specifically established.

(2) Biological Degradation

Sorption onto sediment influences degradation by enabling pesticide compounds to settle to the bottom of water systems where they become subject to microbial activity.[13, 17] Bacteria have been found to sorb pesticides during flocculation and settling processes. Gram-positive bacteria isolated from Lake Erie have demonstrated the capacity to sorb 1 part per million (ppm) of Aldrin from water in 20 minutes.[18] Chlorinated hydrocarbon degradation, subsequent to settling of the pesticide particle complex to microbially active sediments, has been demonstrated.[17, 19]

Organophosphate degradation in sediments is also catalyzed by the presence of microbiological organisms.[6, 20, 21]

Parathion is considered the most resistent of the organophosphates. However, this compound has been shown to be readily subject to biodegradation in microbially active lake sediments. It has been concluded that without microbial activity, Parathion would remain in the natural environment for months, while in microbially active environments, is degraded in a matter of weeks.[6]

(3) Cycling (Physical)

Sorption of pesticides followed by settling does not assure that the resulting material remains in the bottom sediments of aquatic systems. Eventually the pesticide may be cycled into overlying waters. This could result from spring and fall overturns in lake and reservoirs, and from an increase in the scouring velocity of flowing streams.[13] Changes in pesticide concentrations can also occur as a result of release or desorption of the pesticide from the particle through stresses on dynamic equilibrium processes. Heptachlor, Dieldrin and DDT sorb very quickly onto clay materials.[14] After sorption, desorption may occur although the rate of desorption is usually lower than for sorption.[22] Sorption-desorption rates in aqueous systems are particularly influenced by salinity, pH and organic materials. A study conducted with Endrin and Dieldrin demonstrated this effect.[23] An analysis of the estuarine sediment showed 14 to 18% organic content, 31% sand, 25% silt, 16% clay, and the balance other organic material and compounds. Table E-2 relates the effects of added organic material, pH and salinity to sorption of Endrin and Dieldrin.

Table E-2

Factors Influencing Sorption of Endrin and Dieldrin[23]

Pesticide	Presence of organic materials	pH	Salinity
Endrin	High initial sorption however, after 7 days of contact, insignificant amount of Endrin associated with sediment	38-43% uptake within one day in pH range 3 to 10.5 after 7 days at pH 7.0 most of initially sorbed Endrin released from sediments	Sorption maximum in range 13 to 17% after 1 hour. Complete desorption after 7 days. Salinity above 17% and pH 7 to 8-no-sorption occurred.
Dieldrin	Insignificant influence during 7 day period.	Initial uptake at pH 3.8 was 26%; At pH 8.0, initial uptake was 0%, after approximately 70 hrs. of contact, maximum sorbed quantities ranged from 58-64%. At pH 8.0 complete desorption after approx. 170 hrs. of contact.	Sorption independent of salinity

Source: Rowe, et. al.

It can be concluded that sorption of both Endrin and Dieldrin is the time-dependent and pH sensitive. Endrin sorption is salinity dependent but Dieldrin sorption is not. These processes of sorption, sedimentation and subsequent return to solution suggests a mechanism by which aquatic organisms can be exposed to pesticide effects long after the initial release. Very little has been documented regarding the relationship between sorption-desorption and degradation mechanisms.

b. Translocation

(1) Reservoirs

Natural hydrological dynamics involve consideration of factors such as current, turbidity and temperature. These control the transport of pesticides in the aqueous media. The distribution of pesticides in the water influences the rate and mechanisms of chemical degradation and the availability of these substances for biological uptake. These factors can be observed in the case of direct application of a pesticide to a reservoirs' surface. Widescale applications of the herbicide 2, 4-Dichloro-phenoxyacetic acid (2, 4-D) have been made to reservoirs of southern Tennessee, northern Alabama and northern Georgia. The Tennessee Valley Authority (TVA) made these in 1967 and 1971 to control the aquatic plant, Eurasin Water Milfoil.[24, 25] The area of application was extensive. Pesticide was monitored in flowing and static zones.

In the first study, 888 tons of the 20% butoxy ethanol ester form of 2, 4-D were applied in granular form to 8, 000 surface acres of seven reservoirs in eastern Tennessee and northern Alabama. These resevoirs are spread over a main-channel distance of 352 river miles. Application varied from 60 to 100 lbs. of 2, 4-D, acid equivalent, per acre. Seven monitoring stations were located on the Guntersville Reservoir in Alabama. Five stations were located on Watts Bar Reservoir in Tennessee. Twenty-four hours after application, water milfoil samples contained concentrations up to 8. 26 milligram per kilogram (mg/kg) indicating active uptake of the herbicide. Sediment samples, taken from static water areas (embayments), contained higher and more persistent residue concentrations than did areas of rapid current. In Watts Bar Reservoir, significant concentrations of 2, 4-D were found in mud samples as high as 58. 8 mg/kg after 10 months . At eight of nine water treatment plants located along the Tennessee River concentrations of 2, 4-D were less than 1 micrograms per liter (μg/1) 2 to 3 weeks after application. At the ninth plant 2, 4-D was applied directly above the water supply intake. Concentrations were 2 μg/l three days after application and 1 μ g/l nine days after application. Municipally-treated water samples contained less than 1 μ g/l of the herbicide.

In the 1971 study, over 18,000 surface areas in the Nickajack and Guntersville reservoirs in Tennessee and Alabama, respectively, were treated with approximately 170,000 gallons of the Dimethylamine salt (DMA) of 2, 4-D in April. Postreatment monitoring continued for four months. Application amounts were 20-40 lb./acre. The liquid form proved to be more suitable than the granular form because of its direct toxic action to the root crowns of the water milfoil and dispersal to marginal areas of the beds. One monitoring station was located such that it was restricted to static water. At this site, vertical stratification of 2, 4-D occurred between the time of application and the eight-hour sampling period in Guntersville Reservoir. A concentration of 5 mg/l was present at the surface while only 1.5 mg/l occurred at the level of milfoil root crowns following a 40 lb./acre application. Within two weeks, the 2, 4-D content in this embayed area was uniform at 0.65 mg/l. One month later it was 1.0 μg/l. This treatment level prevented regrowth for approximately 12 months. A pH decrease of 2.1 units, from 8.5 to 6.4, occurred between first and the fourteenth day after treatment. The pH returned to the pretreatment value a month later. Another monitoring station was established in an area adjacent to the main channel of the Tennessee River where conditions were favorable for rapid dilution of the herbicide. Less than 0.87 mg/l was present in the water within 24 hours after treatment with 40 lb./acre. Less than 5.0 μg/l was measured 14 days later. Lower applications rates of DMA 2, 4-D, as opposed to the granular form, led to variable residence times in the water. Concentration level and residence time were closely related to water flow rates and effectiveness of plant control. Liquid DMA 2, 4-D was readily sorbed by planktonic organisms. The plankton removed 24% of the herbicide within 1 hour after application and a proportional amount during the next 7 hours. A trend of progressive downstream dilution of waterborne 2, 4-D was observed over 214 miles. This was indicated by the concentrations of 2, 4-D that accumulated in mussels located on the bank edges of tributaries and channel slopes. One anomalous pretreatment sample of mussels below Guntersville dam contained the highest 2, 4-D concentration found at any time during the monitoring. The source of 2, 4-D was unknown. Water from the treated areas continued to be used for domestic purposes during this period without user complaints. Finished drinking water contained 1 to 2 ppb concentrations of 2, 4-D after standard treatment practices.

Hydrological influences on the distribution of other chlorinated hydrocarbons and organophosphates under natural flowing and static fresh water systems have not been reported for the Southeastern region.

A number of conclusions can be formulated regarding the transport and distribution of pesticides in reservoirs:

- Pesticides are more persistent in static water areas (both aqueous and sedimental levels considered) than in those subjected to dynamic current action.

- Pesticide concentrations in the aqueous-phase are further influenced by: (a) presence of thermal stratification and (b) the amount of plankton present.

- The physical form in which the pesticide is applied (aqueous vs. granular) influences the degree of desired effectiveness upon application to water.

- Pesticides such as 2, 4-D are not completely removed from raw water during conventional treatment practices.

(2) Estuaries

Pesticides can reach estuarine basins from direct application to its waters and from discharges of municipal and industrial wastes. But the largest contribution of pesticides to the estuary occurs through run-off from orchards and farmlands.[26] Clay, silt and detritus sorb insoluble, persistent pesticides and, depending on the degree of erosion, transport them to estuarine basins. It has been estimated that 11 tons of soil per acre may be washed away in a year where farming practices are poor. However, under optimum practices, there is no erosional loss.[26] The exact quantities of pesticides which reach the estuary by this process are not known. There is a seasonal fluctuation in the concentrations detected in the water and in the sediments. Since most pesticides are introduced into hydrological systems between early spring and late summer, the highest levels in the sediments are expected several months later. A majority of streams are at low flow during October and November; hence, most of the erosion product transported during and immediately following the pesticide application season are deposited in the streams beds by this time. Relatively little amounts would have an opportunity to pass from subbasins to costal waters. During the spring rains of April and May, however, the streams are at high flow, transporting a near maximum suspended sediment load to the estuary just prior to pesticide application season. Thus, the detected residues in the estuaries may be indicative of the residual effect of the previous year's (or years') applications of pesticides.[27]

Published results of pesticide distribution in an estuarine environment are limited to a single study on the movement of DDT in a tidal marsh ditch.[28] DDT distribution after direct application of 0.2 lb./acre was immediately influenced by the wind and by the ocean-directed flow of the water. The amount of vegetation and fauna influenced the amount of DDT which moved out of the marsh outlet through biological uptake and sorption of the pesticide. The amount of DDT detected in the sediment and vegetation and the times of survey are given in Table E-3.

Table E-3
DDT Uptake by Selected Southeastern Estuarine Substrates[26]

Substrate	Max. Concentration (mg/kg)	Average Concentration (mg/kg) 7 wks. postreatment
vegetation (sedges and grasses)	75-3 to 5 wks. post treatment	9.1
sediment	3.35 - 6 wks. post treatment	0.76

Source: Croker and Wilson

It was demonstrated that fish and vegetation accumulated 1500 times the maximum concentration of DDT detected in the water. Snails, crabs and sediments accumulated 144, 99, and 66 times as much, respectively. The persistence of residues in the water, sediments and biota beyond 4 months was not measured. The amount of DDT which moved out of the tidal marsh was detected in the sediment at the marsh outlet 11 weeks after treatment.

It has been assumed that a major portion of the pesticides which enter estuaries are dissipated through the processes of dilution, chemical decay, flocculation and precipitation to bottom sediments, and biological uptake.[26, 29]

Preliminary results of studies on the stability of pesticides in seawater were reported by the Bureau of Commerical Fisheries in Gulf Breeze, Florida. The degradation rates of 4 pesticides in seawater maintained under laboratory conditions, are shown in Table E-4.[30] Degradation under natural conditions has not been reported for other chlorinated hydrocarbons and organophosphate compounds.

Table E-4
Stability of Pesticides in Natural Seawater [30]
(salinity 29.8 ppt; pH 8.1) Concentrations in μg/l [30]

	Day After Start of Experiment					
Pesticide	0	6	17	24	31	38
p,p'-DDT	2.9	.75	1.0	.27	.18	.16
p,p'-DDE*		.096	.95	.065	.034	.037
p,p'-DDD*			.081	.041	.038	.037
Aldrin**	2.6	.58	.096	0.01	0.01	0.01
Dieldrin*		.74	1.0	1.0	.75	.56
Malathion	3.0	0.2	0.2	---	---	---
Parathion	2.9	1.9	1.25	1.0	.71	.37

Source: Wilson, et. al.

* Metabolites of parent compound.
** From the seventeenth day onward, 2 unidentified peaks appeared on the chromatographic charts after Aldrin had eluted.

Pelagic animals may consume pesticide-laden detritus or food organisms and transport the pesticide to other parts of the environment. Oysters can concentrate up to 70,000 times the test water concentration of DDT. Pinfish and Atlantic Croker populations in Pensacola Bay move offshore to spawn. During the Spawning process they deposit 1/2 lb. of DDT, previously accumulated in the estuary.[26]

It may be concluded that:

- The physical factors influencing pesticide translocation in estuaries are, in the main, undefined. The physical stability of pesticides under laboratory conditions bears little relationship to natural systems.

- Biological organisms influence translocation through uptake. Sessile macrophytes inhibit translocation, whereas, motile forms (fish) enhance translocation.

(3) Closed-Water Systems

The majority of degradation studies have been performed under laboratory and closed-water field conditions. Closed water or standing water systems (lotic) are those confined within a basin (lakes, ponds, swamps, etc.) and possessing limited horizontal movement.

During sediment-water simulations and field monitoring,[15, 31, 32] pesticide concentrations have been shown to decrease in the aqueous phase while increasing in the sediment. The rate of removal from the aqueous phase depends on the chemical characteristics and concentration of the pesticide, the chemical and physical aspects of the water, the sediment characteristics, and the ratio of pesticide compound to sediment.[16, 31] Results of a laboratory study show that the ratio of Lindane to sediment, controls sorption.[30] The lower the ratio, the greater the extent of sorption. Influencing the process are the concentration of organics in the sediment, the concentration of suspended matter, the initial Lindane concentration, and the quantity of clay. These variables were ranked in order of importance. They were sediment concentration, Lindane concentration, clay content and Lindane to sediment ratio.[33] In another study, approximately 57% of γ-BHC added to a simulated lake impoundment system, was sorbed within 24 hrs.[32] With Parathion, approximately 60% of the applied concentration was associated with lake sediments after a 24 hour period.[6] Thermal stratification effects on the settling characteristics of sorbed particles are not available.

The presence of biota strongly affects the distribution of pesticides in lotic systems. Sorption by algae was reported to be several orders of magnitude greater than it is by clay, which in turn is greater than it is by sand.[2] A natural pond in Florida was treated with Dichlorobenil to yield a final concentration of 1.0 mg/l and compared with a similar pond which was untreated.[31] Thermal stratification did not occur in either pond. Seven days after treatment, the hydrosoil zone contained greater quantities of Dichlorobenil than did the aqueous phase. Within 4 months, the concentration within the aqueous phase had returned to pretreatment levels. Biological organisms concentrated significant quantities of the pesticide. One day after treatment, Gambusia affinis (a minnow fish) contained approximately 11 mg/kg; Poecilia latipinna (sailfin mollie) approximately 5.0 mg/kg; plankton 7.2 mg/kg; and Chara 1.16 mg/kg. By the second day, plankton contained 2.9 mg/kg; G. affinis, 6.62 mg/kg; P. Latipinna, 4.2 mg/kg; and Chara, 0.77 mg/kg. In summary, sorption of pesticides by particulate matter (biological and inorganic) is an important mechanism in the translocation of pesticides between the aqueous-phase and the sediment of the system. The rates of translocation have been determined to be pesticide concentration dependent.

The results published for these rate studies must be considered as applicable only to those particular systems. Extrapolation to other systems is not valid because of limitations of the experimental design and inadequate assessment of all of the important environmental parameters. Only approximations of the effect of pesticidal translocation on degradation rates and mechanisms in closed-systems can be presently made.

Determination of the physical behavior of a specific pesticide, under conditions simulating those of the natural system to which the compound is to be introduced, must be established prior to "in situ" application. Without appropriately designed experimental efforts, using dynamic systems, there is little likelihood that substantial progress will be made in identification and evaluation of physical degradation mechanisms.

4. Biological Degradation

Flora and fauna are important factors in the translocation and degradation of many pesticides. Residues of certain chlorinated hydrocarbons persist in biological material for extended periods and are magnified through the food chain.[5] Research has been mainly focused on DDT.

a. Microbiological

Microbial degradation plays a major role in the degradation of pesticides. Even the persistent chlorinated hydrocarbons show some degree of microbial degradation. Environmental factors, such as, oxygen concentration and the amount of light exert significant influence on the rate of microbial degradation.[2, 34, 35]

Partial dechlorination of DDT leads to DDD. In invertebrates (fish) the process requires molecular oxygen, but in microorganisms, the presence of oxygen has been reported to inhibit the reaction. Dechlorination in microbial systems is believed to involve the cytochrome oxidase iron-carbonyl complex.[34, 37] The absence of oxygen enables the cytochrome-Fe to remain in an activity-dependent reduced state. Facultative anaerobes, such as, Escherichia coli, Aerobacter aerogenes and Klebsiella pneumoniae have demonstrated the ability to convert 80% of DDT to DDD within 12 hours.[34] The cytochrome oxidase iron-carbonyl complex has also been shown to dissociate under the influence of light. These two factors may partially explain the persistence of DDT residues in aerobic sediments.

In comparative sediment studies, anaerobically-catalyzed microbial degradation of chlorinated hydrocarbons occurred faster than aerobically-catalyzed microbial degradation.[2, 6, 32] The by-products produced under each condition were different. Heptachlor epoxide and Dieldrin have demonstrated the strongest resistance to either anaerobic or aerobic degradation. Chlorinated hydrocarbons have been ranked in order of increasing persistence as follows: Lindane, Heptachlor, Endrin, DDT, DDD, Aldrin, Heptachlor epoxide, Dieldrin.[2]

Degradation of DDT occurs in the presence of oxygen and a common shallow-water bacterium native to Florida, *Pseudomonas piscicida.*[8] The cultured bacterium was able to degrade 90% of an applied 1 ppb DDT in 24 hours. Direct removal (presumably sorption) of DDT from solution was also demonstrated. The metabolized end-products were DDD and DDE. The latter is considered less toxic than DDT. Because of the liposoluble character of DDT and the large lipoprotein surface area of the bacterial cell, it was postulated that uptake was enhanced.

Organophosphates break down at a pH greater than 7.0 and since bacteria create a microenvironment of high pH (9.5) immediately adjacent to the cell, it has been proposed that *P. piscicidas* readily metabolizes Malathion in this fashion.[8]

b. Plants

Plants rapidly sorb and accumulate large quantities of herbicides. Other pesticides may be accumulated with little or no degradation occurring.[38] Marsh grasses and sedges accumulate large quantities of DDT (1500 times the maximum water concentration of DDT). Subsequently plant death leads to deposition of the previously stored DDT in the sediment. The extent of degradation by plants varies with the type of plant and pesticide. Field studies of aquatic plant residues in the Southeast have been cursory. There is a need for information regarding these degradation pathways.

c. Animals

Some invertebrates and vertebrates can remove pesticide compounds directly from the water.[39, 40, 41] There is considerable variation with species in the amount of pesticides accumulated and the extent of degradation.[37, 40, 41, 43] Most degradation studies have been focused on DDT. Fish and oysters are capable of eliminating accumulated concentrations when placed in pesticide-free water.[41,45] It was demonstrated in a laboratory investigation that *Tilapia* and sunfish, exposed for 31 days to DDT and Methoxychlor, concentrated these substances 10,600-fold and 200-fold, respectively. *Tilapia* were able to metabolize DDT to a greater extent than sunfish. DDD was the major metabolic product. *Tilapia* were able to metabolize Methoxychlor faster than sunfish. *Tilapia* contained higher amounts of the bis-phenols, produced by o-demethylation of the parent compound.

5. Degradation-Effects

When agricultural chemicals are introduced into the aquatic system, two effects may occur as a result of degradation processes: alteration of the water quality and formation of compounds more toxic than the parent compound. These secondary effects may stress nontarget organisms.

a. Water Quality

Water quality may be altered as a result of the degradation of a pesticide or its target species, producing a temporary toxic effect to non-target species. Such alterations may be, for example, a sharp decrease in pH due to acidic degradation by-products, or a depletion of the oxygen due to decaying organisms.[46,47] Silvex application to a backwater of the Santee River in South Carolina was made to control alligator weed.[47] The herbicide killed the weed which then settled to the bottom and began decomposing. After several weeks, there was no dissolved oxygen in the bottom two feet of water. This contrasted with oxygen concentration of 6-8 mg/l in adjacent untreated areas.

b. Toxicity

Laboratory studies have shown that photoisomers of Aldrin, Dieldrin, and Heptachlor are more toxic than the parent compounds to such freshwater organisms as fish, amphibia, flatworms and crustacea. Sunlight catalyzes the production of such photoisomers.[48, 49] Photoaldrin is 11 times more toxic to mosquito larvae than Aldrin.[50] Photoisodin, however, was shown to be less toxic than either Isodrin or Endrin.

The seawater hydrolysis product, 1-Napthol,of Carbaryl (Sevin) has been shown to be twice as toxic to fish as the parent compound when both were tested at 1.3 mg/l. It is also more toxic to young clams at a concentration of 6.4 mg/l than Carbaryl.[9] A reddish precipitate results from the instability of 1-Napthol under alkaline conditions. This precipitate was found to be two-thirds as toxic as 1-Napthol to bay mussels.[9]

It was demonstrated with the fathead minnow, Pimephales promelas that the basic hydrolysis product, Diethyl fumarate, was more toxic than Malathion.[51] A pronounced synergistic effect between Malathion and its basic hydrolysis products was shown. Diethyl fumarate could be produced in an amount sufficient to produce a TLm (median tolerance limit) concentration. This would occur when 64% of the TLm concentration of Malathion had hydrolyzed to form Diethyl fumarate. Therefore, the difference of a day or two in the application time of Malathion on two adjacent areas could result in a condition in which a considerable quantity of the breakdown product, along with a substantial quantity of the parent compound, could be washed into a common water source.

Two areas of degradation research which are in need of greater support are: (1) determination of the toxicities of degradation compounds to nontarget species and (2) determination of the synergisms between mixtures of the parent and degradation compounds.

6. Conclusions

The most frequently occurring pesticides in Southeastern waters are chlorinated hydrocarbons whose persistence may be in the order of years. In general, organophosphates, carbamates, and herbicidal compounds disappear from the water within a matter of a few weeks or months.

Available data on degradation rates, mechanisms, and products is very limited. Information is based on laboratory studies which cannot be extrapolated to natural environmental conditions. For example, halogenated herbicides are readily degraded through photo-induced mechanisms. How these mechanisms relate to degradation of herbicides in the natural environment has not been established.

The sorption of pesticides by suspended material and substrates in natural waters is an important factor in the degradation process. It may facilitate chemical reactions and translocation of pesticides to the estuary or to areas favorable for degradation.

Information on the occurrence and distribution of pesticides reveal that, while no concentrations may be detected in the water, concentrations in the μg/kg. range are found in the sediments of small ponds and estuaries. The transport of pesticides in the aqueous medium including that which is associated with particulate matter and sediments, has not been defined.

Pesticides concentrations which reach bottom sediments may be recycled into the overlying water. Recycling can result from fall and spring overturns following thermal de-stratification or from the release or desorption of pesticides from the sediments.

The chemical degradation products of certain chlorinated hydrocarbons and carbamates are many times more toxic than the parent compounds. Such toxicities are vital considerations of impact on non-target organisms.

7. Recommendations

1. The Environmental Protection Agency and U. S. Department of Agriculture should jointly support programs to develop information regarding the effect of pesticide sorption by particulate and organic matter on the subsequent chemical and biological degradation mechanism.

2. The Environmental Protection Agency should increase inhouse and supported research to develop information regarding specific pesticide degradation rates, mechanisms, products and toxicities in fresh, brackish and salt water.

3. A coordinated surveillance system must be established to provide in-depth information on reservoirs, lakes, rivers, and estuaries. The results must relate the movement of pesticides to hydrological conditions. Quantification of the amounts and types of pesticides being transported to the estuaries relative to climatic and seasonal factors is needed. Rates of interchange between biological organisms and sediment, must be established.

4. Federal and State requirements must be established to insure that extended field analyses are performed in conjunction with pesticide - related fish kills and go beyond the minimum establishment of a cause. These analyses should include those factors enumerated in the aforementioned recommendations as much as the individual case permits.

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F. APPLICABLE REGULATIONS AND LAWS GOVERNING PESTICIDES USE

1. Introduction

Public concern for the environment has created another area to challenge the efficiency and effectiveness of our form of legal and administrative framework. Among the concerns is adequacy and effectiveness of existing state statutes regulating the sale and use of pesticides. This section analyzes the applicable laws and regulations of the eight states in the southeastern case study area. The provisions of the Federal Insecticide. Fungicide and Rodenticide Act, (FIFRA) as amended[1] and the Miller Amendment to the Federal Food, Drug and Cosmetic Act, as amended[2], provide the foundation for a comparative approach. Additional laws extending beyond the scope of federal statutes have been deemed necessary in many of the southeastern states. These are examined and generate recommendations for amending the federal pesticides program.

Pesticides have been regulated by both federal and state governments for many years. When the FIFRA was first enacted in 1947, there were relatively few pesticides used on the agricultural croplands. The initial objective was threefold: (1) to protect the farmer by insuring that the pesticides marketed would be effective, (2) to assure sufficient food and fiber supply by controlling pests. and (3) to protect the public health. These original purposes remain viable.

New factors have been introduced which provide an additional legislative intent. Many new agricultural chemicals have been formulated marketed and are in use. Knowledge has been expanded regarding the effects of pesticides on beneficial and harmful insects. There is also an increased awareness within the scientific community regarding the relationships of man to the ecological system. These developments add a regulatory requirement or purpose --"to protect the environment"-- under the concept that each generation is the trustee of the environment for succeeding generations. Throughout this section analyses and assessments are predicated upon these four objectives which also served as criteria for testing the adequacy of current statutes and regulatory controls.

2. Scope of Local Laws and Regulations

State laws regulating pesticides fall into three classifications. These are statutes:

- Requiring economic poisons to be registered
- Governing pesticide application and use controls
- Providing for the detection of pesticide residues on crops.

a. Registration

Each of the eight states in the southeastern case study area has enacted laws to regulate the intrastate commerce of economic poisons. These laws require the manufacturer, dealer or any person to register the pesticide with the state department of agriculture or another designated administrative agency, such as South Carolina's Crop Pest Commission[3] and Kentucky's Agricultural Experiment Station[4].

There was a considerable lag in the time between the passage in 1947 of the FIFRA regulating interstate commerce of economic poisons and the date the last southeastern state had comparable laws. Table 1 indicates the date registration laws for economic poisons were passed in each southeastern state.

TABLE F1

Initial Pesticide Law - Southeastern States

State	Year Enacted	Registration Laws
Alabama	1951	Insecticide, Fungicide, and Rodenticide Act[5]
Florida	1953	Pesticide Law[6]
Georgia	1949	Economic Poisons Act[7]
Kentucky	1956	Economic Poisons Law[4]
Mississippi	1950	Economic Poisons Act[8]
North Carolina	1947	Insecticide, Fungicide, and Rodenticide Act[9]
South Carolina	1953	Economic Poisons Law[3]
Tennessee	1951	Insecticide, Fungicide and Rodenticide Act[10]

Four years was the median time required for these states to enact legislation after the federal statute was passed. Amendments to the federal statute since 1947 have generally required a period of several years before there were counterpart state laws.

Most state laws adopted the basic definitions used in the original FIFRA, substituting only the names of governmental offices. Where there are differences in language the intent in the FIFRA is preserved although the actual language may be dissimilar. In 1959, the FIFRA was amended to expand coverage of the act to include the agricultural chemicals known as nematocides, defoliants, desiccants and plant growth regulators. Until 1971, the Alabama statute[5] and currently the Kentucky statute[4] have not been amended to add the expanded coverage of the 1959 amendeme to the FIFRA. The pre-1971 Alabama law and the current Mississippi statute[8] do not cover, by definition, the term "device". Mississippi's statute as amended does include other coverage by adding in their definitions the terms "disinfectant", "bactericide", and "adjuvant". These three terms are not found in the registration statutes of the other southeastern states nor in the FIFRA.

The lack of uniformity in the state laws does not significantly influence whether or not each and every economic poison is registered. Instead, where there is a difference between state and federal coverage (regardless of which is stronger) a loophole exists which allows a reduced level of regulatory protection. For example, the FIFRA controls the registration of devices intended for sale and distribution in interstate commerce but devices manufactured in Kentucky solely for intrastate sale and distribution are technically unregulated.

There is a high degree of uniformity in the acts prohibited by the state registration statutes. Basic prohibitions are keyed to the commercial and selected consumer protection functions. Other typical prohibitions relate to enforcement and the unauthorized disclosure of formula information by officials. Table F2 lists the prohibited functions or acts and illustrates the uniformity among the southeastern states.

Only two states include provisions prohibiting persons from giving a false guaranty in product registration. Other states limit restrictive language on falseness to the relationship between the contents in the original container and the label of the original container under the term, "misbranded". There are two regulatory concepts involved. One pertains to all matter, material and documentation submitted in support of registering the product and the other to the generally implied warranty of all manufacturers that the product is as stated on its label.

TABLE F2 BASIC PROHIBITED ACTS -- PESTICIDE REGISTRATION STATUTES
SOUTHEASTERN STATES

ACTS PROHIBITED	ALA.	FLA.	GA.	KY.	MISS.	N.C.	S.C.	TENN.
Distribute an unregistered, adulterated, or misbranded product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sell an unregistered, adulterated, or misbranded product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Offer for sale an unregistered, adulterated or misbranded product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Deliver for transport an unregistered, adulterated, or misbranded product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transport in intrastate commerce an unregistered, adulterated, or misbranded product	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Detach a label or an original container	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Alter the label of an original container	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Add substance to an original container	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Take substance from an original container	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Any official to reveal formula information to unauthorized persons	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Any person to deny officials access to records							Yes	Yes
Any person to give a false guarantee		Yes						Yes
Any person to interfere with the Commissioner or his designee		Yes		Yes				Yes

This discussion of guaranties is not significant in terms of the litigation produced nor administrative activity created. Rather, it discloses two aspects of regulatory control which have not been uniformily adopted by the southeastern states. It also considers the sensitivity of the statutory language to the various controlling concepts.

There are many situations in which registration of pesticides are exempted and penalties for violation of the state statutes are not applicable. The provisions are reasonably uniform among the southeastern states. These exemptions are:

- Any carrier while lawfully engaged in transporting economic poisons within the state provided that he will permit the administrative agency to copy all records showing the transactions in and movement of articles.

- Public officials of the state and of the federal government engaged in the performance of their official duties.

- The manufacturer or shipper of an economic poison for experimental use only.

- By other parties if the economic poison is not sold, and if the container is plainly marked "for experimental use only--not to be sold", etc.

- Shipments of economic poisons between plants within the state.

These exemptions appear reasonable when examined under the doctrine of laissez-faire. On the other hand, when viewed under the concept of environmental protection they provide a loophole by not requiring registration of products used by state and federal public officials in the performance of their official duties. This loophole allows agencies such as fish and game commissions, forest service, park service, and the U. S. Army Corps of Engineers to introduce into the environment pesticides formulated by their personnel for which:

- Composition and quantity are known only to that agency,
- Effectiveness in pest control is not subjected to the same criteria as commercial items, and
- Toxicological implications are not readily determinable.

There are significant dissimilarities in the authorities granted to state administrative agencies for the enforcement of their respective pesticide registration statutes. Table F3 presents an analysis of the enforcement authorities granted.

TABLE F3

Enforcement Authorities Granted by Current Pesticide Registration Statutes

State	Enforcement Authorities Granted				
	Emercency Suspension of Registration	Registration	Stop Sale Stop Use Removal	Seizure	Injunction
Alabama (pre-1971)	NES	Yes	NES	Yes	NES
Florida	NES	Yes	Yes	Yes	Yes
Georgia	NES	Yes	Yes	Yes	Yes
Kentucky	NES	Yes	Yes	Yes	NES
Mississippi	Yes	Yes	NES	Yes	NES
North Carolina	Yes	Yes	Yes	Yes	Yes
South Carolina	NES	Yes	Yes	Yes	NES
Tennessee	NES	Yes	Yes	Yes	Yes

NES - Not expressly stated

Most of the administering agencies in the southeastern states do not have authority to invoke the emergency suspension of registration. Without such authority the agency may not have the legal power to act promptly to protect the public against hazards disclosed by new scientific information. The 1971 Alabama Law[11] did not grant emergency suspension authority to the Commissioner of Agriculture.

Mississippi's agencies have no authority to stop sale of products found in violation nor do these agencies have authority to obtain injunctions. Prior to the 1971 act Alabama's Commissioner of Agriculture could not issue a "stop sale order" nor obtain an injunction. Such authorities are important. Their absence has been the reason why state and federal enforcement officials have not always been able to cooperate fully. The FIFRA gives the Agricultural Research Service (now Environmental Protection Agency's Pesticide Office) no authority to issue stop sale orders. Federal enforcement officials have frequently requested state officials to use their stop sale authority to assist in a federal enforcement action. Cooperation has been good but on some occasions cooperation could not be obtained because the action sought by the federal enforcement officials was not in violation of the state statutes. Detailed records on the cooperative effort are not available, but the magnitude of federal enforcement activities in the southeastern states is shown in Table F4.[12]

There has been a significant increase in federal enforcement activities since 1969. A 250 percent increase occurred in seizure actions from 1969 to 1970. Likewise a 285 percent increase in recalls occurred over the same period. For 1971 actions are at an even higher rate. This surge in federal enforcement activities coincides with the timing of Congressional hearings concerning deficiencies in the administration of FIFRA.

The North Carolina Pesticide Report for 1970[13] contains selected enforcement statistics. The following enforcement data are shown:

Total number of inspections made	1743
Total number of "Stop Sale Orders" issued	315
Total number of "Stop Sale Orders" resulting from failure to register	230

TABLE F-4

FEDERAL ENFORCEMENT ACTIONS
SOUTHEASTERN STATES[12]

Year and Month	Citations: Shipper Located in Region IV	Citations: Consignee Located in Region IV	Seizures	Recalls
1969				
January	3	8	0	1
February	1	1	0	0
March	7	5	0	0
April	20	15	0	1
May	18	20	0	4
June	10	8	1	0
July	23	23	0	0
August	9	14	0	2
September	39	28	0	3
October	14	14	1	0
November	11	17	0	2
December	14	19	0	0
Total	169	172 = 341	2	13
1970				
January	31	21	0	2
February	15	17	0	0
March	28	23	0	0
April	8	11	1	17
May	20	15	0	3
June	13	12	0	1
July	13	11	0	0
August	10	11	4	0
September	1	4	1	2
October	11	11	1	8
November	9	10	0	5
December	28	18	0	12
Total	187	164 = 351	7	50
1971				
January	16	13	1	9
February	22	25	0	5
March	20	21	1	9
April	11	8	2	7
May	24	30	2	4
June	18	21	0	2
July	26	26	1	2
Total (7 mos)	137	144 = 281	7	38

Source: Environmental Protection Agency

It is significant that among the 1970 pesticide enforcement activities in North Carolina, 18 percent of the inspections made resulted in the use of "stop sale orders". This is an enforcement authority which Federal officials do not possess. Of the "stop sale orders" issued, 73 percent were for failure to register. This high incidence of failure to register and the substantial percent of inspections requiring the issuance of "stop sale orders" indicates that North Carolina relies heavily on this provision of its law.

The penalty provisions for violation of the registration statutes of the southeastern states are lenient. Table F5 summarizes the statutory provisions on penalties.

TABLE F5

Penalties for Violating Provisions of Economic Poisons Law

State	Type Offense	Penalty (First Offense)
Alabama	Misdemeanor	Punished as prescribed by law
Florida	Misdemeanor	Fine of $100 or $500 or imprisonment from 10 to 30 days based on provision violated
Georgia	Misdemeanor	Fine not less than $100 and not more than $1000, or six months imprisonment, or both
Kentucky	Misdemeanor	Fine not less than $25 nor more than $500
Mississippi	Misdemeanor	Fine not more than $500, or imprisonment for not more than one year, or both based on the provision violated
North Carolina	Misdemeanor	Fine not less than $100, nor more than $1000, or imprisonment for not more than 60 days or both
South Carolina	Misdemeanor	Fine of not more than $100, or imprisonment for not more than 30 days, or both
Tennessee	Misdemeanor	Punished at the discretion of the court

There is a high degree of uniformity between the provisions in the registration statutes of the southeastern states and the provisions included in FIFRA. Penalty provisions of the FIFRA--misdemeanor with first offense conviction subject to fine or not more than $500, or imprisonment for not more than one year, or both fine and imprisonment--are somewhat stronger than the penalties shown in Table F5.

Many of the regulations[14,15,16] issued for the administration of FIFRA are similar in scope of coverage to the type regulations issued by Florida[17], Tennessee[18] and Georgia[19]. The Mississippi regulations[20] are not as complete as FIFRA regulations. The regulations in Alabama[21], North Carolina[22] and in South Carolina[23] are limited to one printed page. Kentucky has no regulations and considers their statute sufficiently clear so as not to require regulations[24]. None of the southeastern states has found it necessary to issue interpretations of its regulations similar to the interpretations[25-44] issued by the Agricultural Research Service on the FIFRA regulations.

The primary reason for the large number of interpretations at the federal level is the volume of registrations handled. In processing a large volume the incidence rate of registration cases requiring clarification on a particular point is likely to be higher than when the volume is small. Administratively these clarifications are handled at the federal level by promulgating interpretations for general distribution. At the state level the volume of registrations is substantially less and clarifications are handled administratively on a case-by-case basis.

b. Application and Use Controls

The laws used to regulate the application and use of pesticides generally fall into three classes[45]. These are laws:

- Requiring the examination and licensing of persons engaged in the business of applying pesticides (custom applicators).

- Regulating persons in professions concerned with the use or application of pesticides; e.g. entomologists, horticulturists, plant pathologists, tree surgeons, etc.

- Prohibiting the use of certain pesticides, or requiring the purchaser to obtain a permit before purchasing or using highly toxic pesticides, or requiring dealers in restricted use pesticides to be licensed, or any combination of these provisions.

In keeping with the scope of this study, a fourth class of application and use laws known as structural pest control laws has been intentionally omitted. These regulate entomological or pest control or eradication work in household structures, commercial buildings, or other structures where pesticides are employed.

The oldest major area of application and use control in the case study area is the regulation of custom or aerial application of pesticides. Such regulatory control is used by only four of the southeastern states. North Carolina's law[46] and regulations[47] came into being in 1953. Tennessee's law[48] is dated 1965. Mississippi's two laws[49,50] with accompanying regulations[51,52] were enacted and published in 1966. Kentucky does not have a separate statute but exercises control by regulation of aerial applicators through the Kentucky Department of Aeronautics[53]. This regulation was promulgated in 1954.

An analysis of the National Transportation Safety Board's aerial application accident records[54-58] for the period 1964-68 disclosed that generally there were fewer accidents in those four southeastern states controlling custom application than in the four states without this class of law. Table F6 shows the southeastern trend in aerial application accidents. The findings in 1968 by Reich and Berner reflects a similar trend for the southeastern states[59]. The use pattern for aerial applications versus vehicular or manual application by state is unknown. The cotton crop in Mississippi is more susceptible to aerial application than the tobacco crop in Kentucky so the frequency factor of usage is reflected in the accident statistics.

The period covered by Table F6 was a period of increased use of aircraft. The regional accident total as a percent of the national total has remained fairly even since 1964. Table F7 indicates the kinds of operations in which the aerial applicators involved in the accidents were engaged. It is obvious that the majority of the accidents occurred while the applicator was engaged in dusting and spraying crops. Tables F8 and F9 show that the aerial application accidents are concentrated among the pilots whose ages fell in the 25-39 year bracket and with pilots having more than 1000 hours flying experience.

The information in Tables F7 through F9 suggests that the most common kinds of aerial application operations involving pesticides were being performed by experienced and mature pilots. At this point a separate investigation was initiated to ascertain the need for provisions in aerial application laws to protect the pilot against the toxicological effects of pesticides. In addition to the risk of accident associated with flying there is also present the hazard of contact with the pesticide chemicals. Tables F10, F11 and F12 provide information on chemical types and the seriousness of toxicological effects and accident injuries on pilots engaged in aerial applications.

TABLE F6

Aerial Application Accidents - Southeastern Region
Analysis by State 1964-68[54-58]

State / Year	Ala.	Ga.	Fla.	Ky.*	Miss.*	N.C.*	S.C.	Tenn.*	Regional Total	National Total	Region as Percent of National
1964	12	18	18	1	14	10	4	1	78	388	20.10
1965	10	15	13	1	15	2	5	2	63	341	18.47
1966	4	15	10	2	8	1	9	1	50	323	15.47
1967	11	17	14	3	16	4	2	3	70	405	17.28
1968	11	16	6	0	14	3	6	3	59	369	15.98
Five Year Total	48	81	61	7	67	20	26	10	320	1862	17.52
State Five Year Total As Percent Of Regional Total	15.0	25.3	19.0	2.1	20.9	6.3	8.1	3.1			

* States controlling aerial applicators

TABLE F7

Aerial Application Accidents by Kinds of Operations
Southeastern Region 1964-68[54-58]

Kinds of Operations	Number of Accidents					
	1964	1965	1966	1967	1968	5 Year Total
Dusting Crops	25	17	16	15	13	86
Dusting Other	0	0	0	1	0	1
Seeding Crops	0	0	0	2	0	2
Fertilizing (Dust)	3	5	1	6	3	18
Fertilizing (Liquid)	0	0	0	0	1	1
Defoliation (Dust)	2	1	2	0	1	6
Defoliation (Liquid)	7	4	5	2	2	20
Spraying Crops	33	30	20	28	33	144
Spraying Forest	1	0	0	2	0	3
Spraying Towns	0	1	0	1	1	3
Other	4	2	4	2	5	17
Unknown/Not Reported	3	3	2	11	0	19

TABLE F8

Pilot Age in Aerial Application Accidents
Southeastern Region 1964-68[54-58]

Pilot Age	Number of Accidents				
	1964	1965	1966	1967	1968
Less than 20 years	0	0	1	0	1
20 years but less than 25 years	7	6	6	9	4
25 years but less than 40 years	45	34	21	43	38
40 years but less than 50 years	16	18	16	14	14
50 years or over	7	5	6	2	2
Unknown	3	0	0	2	0

TABLE F9

Pilot Experience in Aerial Application Accidents
Southeastern Region 1964-68[54-58]

Number of Pilot Flying Hours	Number of Accidents				
	1964	1965	1966	1967	1968
Less than 250 hours	3	0	1	2	0
250 hours but less than 500 hours	4	9	3	9	5
500 hours but less than 1000 hours	10	7	8	8	5
1000 hours but less than 2500 hours	17	15	10	19	19
2500 hours but less than 5000 hours	12	12	8	13	7
5000 hours or over	26	19	20	17	18
Unknown	6	1	0	2	5

TABLE F10

Aerial Application Accidents by Type of Chemical Used
Southeastern Region 1964-68[54-58]

Types of Chemical Used	Number of Accidents				
	1964	1965	1966	1967	1968
Dry Chemical, Toxic	16	11	12	13	10
Dry Chemical, Nontoxic	18	12	5	12	7
Liquid Chemical, Toxic	26	31	22	27	27
Liquid Chemical, Nontoxic	13	4	8	6	10
Unknown/Not Reported	5	5	3	12	5

TABLE F11

Aerial Application Accidents by Toxic Effect on Pilots
Southeastern Region 1964-68[54-58]

Toxic Effect on Pilot	Number of Accidents				
	1964	1965	1966	1967	1968
Not Affected	50	36	28	42	34
Affected in Flight	0	0	0	0	0
Affected Prior to Flight	0	0	0	0	0
Unknown/Not Reported	28	27	22	28	25

Most of the aircraft involved in aerial application accidents were rigged with spray tanks containing toxic liquid chemicals (Table F10). The Table F11 suggests that the chemical hazard is not a threat to pilot health, although the number of accidents in which this type data was unknown or not reported is sufficient that such an observation is only conjectural. Injuries statistics directly attributable to the accidents reflect that 76% of the pilot injuries were classed as minor or were not reported, 12% involved pilot fatalities and another 12% resulted in serious pilot injury.

TABLE F12

Aerial Application Accidents by Pilot Injury Seriousness
Southeastern Region 1964-68[54-58]

Pilot Injury Seriousness	Number of Accidents				
	1964	1965	1966	1967	1968
Fatility	6	8	6	8	9
Serious	10	6	5	6	10
Minor/Not Reported	62	47	39	56	40
Total	78	63	50	70	59

There are considerable differences among the four southeastern states which regulate aerial applicators as to the scope and detailed coverage included in the regulations implementing aerial applicator type laws. All four states (Kentucky, Mississippi, North Carolina, Tennessee) have regulations on the requirements for obtaining a license.[51, 52, 53, 60] These requirements typically include a provision for an examination of the applicant by a board to determine the applicant's ability and knowledge to perform within limits and standards. These regulations typically include information on requirements pertaining to license fees, revocation, suspension, financial responsibility and penalties for violation.

The laws and regulations of the State of Mississippi provide the most comprehensive controls of these four states. Their structure consists of an agricultural aviation licensing act with regulations administered by the Agricultural Aviation Board, and an act regulating the application of hormone-type herbicides by aircraft with its regulations. The latter is administered by the Commissioner of Agriculture through his agent, the State Entomologist. Both acts contain provisions linking the responsibilities of the two administering agencies. The aspects of the aircraft, aircraft equipment, materials used and methods of application are within the purview of one of the agencies.

Despite what appears to be adequate statutory authority, none of the four states controlling aerial applicators has promulgated a complete set of environmentally-sensitive regulations. Environmental factors which are not generally covered in present regulations are:

- Particle size (Mississippi regulations cover nozzle size and PSI),
- Formulation (dust and spray),
  - (a) viscosity additives
  - (b) foam
  - (c) encapsulation
- Weather at the time of application (there are state exceptions on this factor).

Another class of application and use laws are those designed to control the time and condition of sale, the distribution and the use of particular pesticide chemicals.[61,62] Also included in this class of laws are other provisions for the handling, storage and disposal of pesticides, control of unused pesticides and contaminated containers. The Council of State Governments' 1971 suggested State Legislation, Volume XXX contains a Model Pesticide Use and Application Act[63]. Another model statute, the State Pesticide Use and Applications Act, was prepared in 1969 by the Public Health Service[64].

Application and use laws have been enacted in Alabama, Florida, Kentucky and North Carolina. The Florida Pesticide Law on economic poison registration was amended in 1969 to grant authority to the Commissioner of Agriculture to establish rules and regulations to designate chemicals as "restricted pesticides". In 1970 Kentucky passed an act relating to the restriction of the use of DDT for pest control. This act prohibits the use of DDT on agricultural croplands by prescription. New laws were passed in the 1971 legislative sessions in Alabama and North Carolina in September and July respectively. These laws repealed the earlier economic poison laws, made new pesticide acts incorporating registration of economic poisons essentially as before, created a Pesticide Advisory Board or Committee with membership including conservation interest, and established a new chemical category entitled "restricted use" pesticide. The regulatory trend in the three states with restricted pesticides laws is to require the licensing of dealers who are to sell restricted use pesticides and to require use permits for persons to purchase and use restricted pesticides.

The State of Florida in 1970 further amended their basic pesticide law to provide coverage in an area of environmental concern--the persistency of the pesticide chemical in the environment. The Florida statute defines a "persistent pesticide" as one which will persist in the environment beyond one year from date of application. It makes it unlawful to broadcast persistent pesticides except under specified conditions. The regulations implementing this act contain the names of a dozen chemicals designated as persistent pesticides. The new 1971 North Carolina law[65] permits the Pesticide Board to designate a pesticide after a public hearing, as a "restricted-use pesticide" either because of its persistence, its toxicity or by other criteria. These new provisions demonstrate recognition by legislatures of the public concern regarding misuse and misapplication of pesticides and their environmental impact.

c. Residue Detection

The state food, drug and cosmetic acts or equivalents follow the federal act closely.[66-73] Food residues and tolerances established by the Food and Drug Administration under the Miller amendment of 1959 are immediately accepted and promulgated by states for intrastate regulation of produce and feed. States do not attempt to establish these type standards through their research and regulatory organizations. A comprehensive discussion of tolerances and residue detection was prepared and published in 1968 by the Food and Drug Administration.[74]

3. Effectiveness of Current Local Statutes

There are no established criteria for the evaluation of statutes for effectiveness. For the purposes of this study four factors have been isolated as indicators of the effectiveness. These are:

- Adequacy of statutory authority to control areas of potential abuse of public health and the environment,
- Relative economic burden imposed on the private sector by the statutes to achieve compliance,
- Relative ease of public administration, and
- Ecological sensitivity of present statutes.

The present registration laws for economic poisons are generally adequate to achieve an inventory-type control of pesticide chemicals. These laws also serve the purpose of insuring that the farmer who is not skilled in chemical formulation receives a product approved by government. This kind of consumer protection is essential to prevent false gurantees and misleading or false advertising. The requirement for specific testing to determine effectiveness is beyond the scope of the average individual. This places the determinations of efficacy, toxicological significance, residual amounts on agricultural crops and tolerance level solely and properly within the purview of the institutions of government.

Table F4 indicates federal enforcement actions in the southeastern states citing all types of violations, including labeling and failure to register. These citations average only about 31 per month for the eight states, or approximately four citations per state per month. This low level of enforcement activity is one indicator that the provisions of the registration statutes are generally under compliance. State-level enforcement actions are also at a low level. Alabama's statistics indicate no seizures, approximately 75 "stop-sale orders" and approximately 150 administrative citations or notices annually.[75] North Carolina's 1970 "stop-sale orders" amounted to 315.

A cooperative spirit exists between the agricultural chemicals industry and federal and state enforcement officials. This cooperation is evidenced by the small number of enforcement actions which reach the seizure category in the application of regulatory authority granted to the administering agencies.

The statutes and regulations pertaining to label requirements for economic poisons are generally adequate. In making this judgement observations of the report of the General Accounting Office and a part of the 1969 Congressional hearings,[76] the Committee on Governmental Operations eleventh report,[77] the House of Representatives hearings[78] and the Senate hearings[79] each were considered. Such a judgement does not mean that administrative mistakes have not been made. Rather it means that as a whole the labeling requirements of the state statutes, which closely follow those of the FIFRA, are satisfactory to warn and caution users of hazards.

There is evidence, however, labeling may not by itself be sufficient warning when the age of individuals who come in contact with pesticides is considered. Table F13 disclosed that nationwide pesticides ingestion accounts for approximately 5.6% of the accidental ingestions of children under five years of age and this statistic includes only those cases reported by poison control centers to the National Clearinghouse.

Table F14 provides a tabulation of the accidental pesticides ingestions by children in the southeastern states under 5 years of age for a three and one-half year period. The incident rate in the State of Florida appears disproportionate. This is probably because of the substantially higher number of reporting poison control centers in Florida than in the other states. Florida in 1971 has 32 centers listed in the directory to South Carolina's two centers and Kentucky's six centers.

TABLE F13

Accidental Pesticide Ingestions by
Children Under 5 Years of Age
Reported by All Poison Control Centers 1965-69[80, 81]

Year	Total No. of Cases All Substances	Number of Pesticide Cases	Pesticide Cases As a % of Total
1965	63, 352	3, 856	6.1
1966	64, 634	3, 715	5.8
1967	72, 661	4, 087	5.6
1968	71, 563	3, 965	5.5
1969	76, 155	3, 952	5.2

Source: Food and Drug Administration

TABLE F14

Accidental Pesticide Ingestion by Children
Under 5 Years of Age Southeastern States
Reported by Poison Control Centers 1968, 1969, 1970
and First Six Months 1971[82]

	Number of Accidental Ingestions Children Under 5 Yrs.							
	Ala.	Fla.	Ga.	Ky.	Miss.	N. C.	S. C.	Tenn.
1968	19	377	61	7	25	77	59	96
1969	24	254	43	13	29	69	19	114
1970	13	192	57	12	13	82	16	94
1971 (1st 6 mos.)	4	104	28	2	5	32	3	44
3 1/2 yr. Average	17	265	54	9	21	74	27	99

Source: Food and Drug Administration

The actual number of accidental pesticide ingestions occurring is suspected to be much higher than the national or individual state figures indicate. In 1969 a survey of South Carolina physicians was conducted.[83] Of 1157 queried, 667 reported they had seen 572 cases of pesticide poisoning during the year ending July 1969. The records of the National Clearinghouse for Poison Control Centers indicate only 26 cases were reported for the calendar year 1969 and 72 cases for 1968. A similar survey was again conducted in South Carolina[84] for the year ending July 1971 and a total of 624 pesticide poisoning cases were seen by physicians.

There is an absence of a completely reliable national reporting system of the number of accidental ingestions of pesticide by children under five years of age. However, the high incidence of such events suggests that present packaging methods for pesticides may be creating a condition in the home which is unsafe for small children. The state registration statutes do not grant authority to the administering agency to regulate product packaging.

Since application and use statutes are only found in four of the eight southeastern states and these statutes are relatively new, their adequacy cannot be assessed with the same completeness as the long-standing registration statutes. For example, the Kentucky act relates only to one of the organochlorine pesticides, DDT. There are many other pesticides of related chemical composition. This and similar statutes are deficient since they fail to provide adequate controls for the range of products in a class and regulate only a single product within the class.

Amendments to the registration statute in Florida provide the statutory authority for application and use regulation. These amendments commencing in 1969 are the oldest of this class of law in the case study area. Authorities granted to the Commissioner of Agriculture delegate responsibility for the classification of highly toxic and persistent pesticides. These authorities also establish licensing of dealers and user permit requirements for restricted and persistent pesticides. The new Alabama and North Carolina laws provide similar authorities. The significant difference in the application and use laws of these states is that the North Carolina law[65] calls for the licensing of ground equipment used in pesticide application. As such, it is more extensive in coverage than the laws of Alabama and Florida.

There is a hazard in writing laws with extensive regulatory coverage. Unless adequate funding provisions for administration and enforcement is assured, the law cannot be rendered effective. It is estimated that there are 30,000 pieces of ground application equipment in North Carolina but the 1971 legislative session did not appropriate adequate funds to permit staffing for ground equipment inspection.

The key economic significance associated with the state registration statutes in the southeast is threefold. First, the burden on chemical formulators in terms of registration fees is nominal. Table F15 indicates the statutory or regulatory annual license and fee requirements in the eight states of the case study area.

Second, none of the southeastern states has required of manufacturers and formulators any specialized labeling, or unique requirements for information to be supplied as a part of the registration. The requirements imposed on manufacturers and formulators are essentially those imposed by FIFRA. In fact, many of the laws authorize the state administering agency to accept the FIFRA registration without protest.

Third, the type of agricultural crops and acreage involved in the southeastern states is such that without pesticide chemicals the farmer would not be able to achieve the production levels currently being attained. A comprehensive discussion of the economic consequences of restricting the use pesticides is beyond the purview of this study and is adequately treated in a U.S.D.A. symposium.[85] The impact on

TABLE F15

Statutory or Regulatory Annual License and Fees Requirements for Pesticide Products and Applicator, Dealers and Consultant Services Southeastern States

State \ Type of License & Fee	Registration Fee Each Brand	Dealers License	Pesticide Applications License	Pest Control Consultant License	Each Aircraft License	Each Piece Ground Equipment License
Alabama	$15	NSC	NSC	NSC	NSC	NSC
Florida	$10	NES	NES	NSC	NSC	NSC
Georgia	$5 up to $200 annual	NSC	NSC	NSC	NSC	NSC
Kentucky	$5 ea up to $50 annual	NSC	Aerial-$25	NSC	NSC	NSC
Mississippi	$15 up to 10 then $5	NSC	Aerial-DA	NSC	Up to $50	NSC
North Carolina	$25	$25	$25	$25	$10	$5
South Carolina	$20 ea up to 10, $10 ea add'l	NSC	NSC	NSC	NSC	NSC
Tennessee	$10 up to 10, $5 ea add'l	NSC	$10	NSC	NES	NSC

DA - Determined annually
NSC - No statutory coverage
NES - Not expressly stated

cotton, corn, peanuts and tobacco have been studied by the Economic Research Service of the U. S. Department of Agriculture.[86] These are principal crops in the case study area.

The administration and enforcement of the state registration statutes is being accomplished in the southeast without any apparent difficulty. State chemists and pesticide laboratories have borne a significant part of the total federal-state effort. Most of the administering agencies and laboratories are operated with a modest staff. The level of staffing of inspection personnel likewise has been modest.

The introduction of application and use statutes tends to increase the administrative burden because of the inherent requirement to process large numbers of dealer licenses and use permit applications. Currently Florida has issued approximately 1400 licenses to dealers and 12,000 user permits. They needed four additional inspectors for the restricted and persistent pesticide administration. Another four are to be added when the law licensing of applicators is enacted. Adjustments were made in territory size to be covered by a single inspector, and some responsibilities were realigned. Forty-two persons are engaged as inspectors.[87]

Ecological accidents in the southeast investigated by the Environmental Protection Agency (formerly Agricultural Research Service) staff for the years 1967 through October 1971 have involved injury to humans, animals and plants. Table F16 presents the number of investigations conducted.[88]

TABLE F16

Ecological Accident Investigations
1967 - October 1971[88]

State/Region National	Number of Investigations					
	1967	1968	1969	1970	(10 mos) 1971	5 Year Total
Alabama	-	3	6	4	4	17
Florida	7	5	4	12	16	44
Georgia	5	4	2	5	17	33
Kentucky	-	-	-	2	1	3
Mississippi	-	5	2	-	3	10
North Carolina	5	3	3	28	10	49
South Carolina	3	1	2	6	4	16
Tennessee	-	1	1	5	2	9
SE Regional Total	20	22	20	62	57	181
National Total	95	131	118	197	203	744
SE as % of National	21.1%	16.8%	16.9%	31.5%	28.1%	24.3%

Source: Environmental Protection Agency

Of the 744 ecological accidents in the southeast 52.5 percent involved humans, 39 percent involved animals, 5.5 percent involved plants and miscellaneous accidents accounted for 3 percent. The miscellaneous category includes such accidents as spills into wells.

The increased number of investigations in 1970 and 1971 coincides with the Congressional hearings on pesticide regulations and greater public awareness attributed to news media coverage of major incidents such as the parathion investigations in North Carolina in 1970. Many incidences of ecological accidents involving pesticides are reported to the national level. Only the more serious incidents are investigated. The staff available is insufficient to check out each incident reported. This investigative function should be expanded.

Current pesticide statutes rarely consider the need to protect the environment. There is no reference to differentiate between harmful and beneficial insects, magnification of toxicological components via the food chain, or beyond the production of food and fiber is the need to recognize other beneficial uses. To a large extent the void reflects prior influence of the agarian element in our society and only a recent awareness of the environmental implications.

The number of people living on farms has steadily declined. Correspondingly, the new application and use statutes include controls affecting both urban and farm dweller. For example, recent laws address control of unused pesticides and contaminated containers. Other provisions are concerned with the handling, storage and disposal of pesticides. Recently enacted controls often emphasize environmental awareness.

4. Assessment of Important Litigation

There is a relative absence of litigation involving the registration statutes of the southeastern states. The legal reporting services document no cases for the region. A telephone survey of each of the administering agencies verified that there has been no litigation.[89] Cases between private parties are generally settled out-of-court. There have been no cases of private actions against public agencies to compel environmental protection despite a legal trend elsewhere.[90-92] Such actions may occur as consumer knowledge and awareness of the effects of pesticides increase.

Three explanations for the absence of litigation are suggested. The first is that manufacturers and formulators have reacted as responsible citizens to citations for violation of statutory provision or regulation. For minor violations most of the statutes do not require legal citation. Administrative citations are used generally for such violations.

The second is that the nature of violations which are occurring require only a limited action by the manufacturer or formulator. Label violations are frequently handled by sending dealers new labels. Discounts to invoices are given for the relabeling service. Violations involving variance of active ingredient guarantees are typically handled by the dealer returning the product to the manufacturer or formulator. Then it is re-formulated to bring the levels and strengths of active ingredients in compliance with the label and registration statements.

The third reason is that 100% inspection of labels and laboratory testing is not performed at either the federal level or in the southeastern states. At the federal level approximately 5000-6000 samples are taken annually for the 30,000-40,000 registered products to determine variance from the registration statements on active and inactive ingredients. This equates to federal inspection approximately once every five years. In 1970 North Carolina reported 1743 inspections for its 4854 registered products with the following results:

Samples analyzed	1074
Passed	855
Deficient	111
Excessive ingredient	6
Misbranded	1
Not registered	134

South Carolina's 1970 report[93] indicates that 1139 samples were analyzed and 133 or 11.69% were found deficient.

There is litigation on the application and use laws of two southeastern states. North Carolina has experienced 12 cases where litigation resulted from the enforcement of its aerial crop-dusting laws. Briefs of these cases are shown in Appendix __ . The fundamental issue in each of these cases was engaging in custom application of pesticides without a license as required by the 1953 statute. Litigants involve three classes of persons: persons soliciting business for aerial applicators, pilots operating aircraft engaged in aerial applications, and owners of aircraft engaged in aerial applications. Theses cases were litigated in county courts with no jury involved. Eight of the 12 cases resulted in guilty pleas by defendants and three cases were nol-prossed.

One case has been litigated in Florida challenging the legality of regulating application and use in terms of the persistency of the chemical. This case, Great Lakes Biochemical Co., Inc., v. Doyle Conner, as Commissioner of Agriculture of the State of Florida[94] was a civil action in the Circuit Court of the Second Judicial Circuit, Leon County, Florida. The court found that the state erred in failing to register the plaintiff's products. The persistency of phenylmercuric acetate, was a fundamental issue in the action. Subsequently, the Environmental Protection Agency cancelled registration in October of 1971 of three products of the Great Lakes Biochemical Co., Inc.[95] These were included in the four products Great Lakes Biochemical sought to register in the State of Florida.

Private lawsuits involving implied or expressed warranties of pesticides and negligence in the application of pesticides are few. Rohrman[62] cites six such cases. These cases raised no significant issues not presently covered by the guarantee provisions in the registration statutes, or the negligence aspects in common law.

5. Conclusions

The provisions of registration statutes of the southeastern states are quite similar to the statutory provisions of the original FIFRA. All states have not kept pace in modifying their statutes to comply with changes in the FIFRA in terms of coverage of categories of pesticides. The states took an excessive amount of time to enact comparable legislation to the FIFRA to regulate intrastate commerce of pesticides. Amendments have required several years before enactment.

It is questionable whether states should be permitted such time period because of the potential environmental damage which could occur during the interim. It is similarly doubtful or even logical to expect states to invest sufficient funds to initiate research on the short and long-term impacts on human health and the environment so that effective and timely legislation can be enacted. The monitoring activities are chiefly performed in the states by the state officials, land-grant colleges, county farm agents, and water and air pollution authorities. Because of their proximity to the physical environment and the agricultural crop-lands, a fairly effective state surveillance program of pesticides does exist with respect to annual registration of pesticides. This affords protection of the farmer, the food supply, and to a lesser extent, the protection of public health. The present state registration statutes modeled after the FIFRA are inadequate to protect the environment, but their annual registration requirement exceeds FIFRA requirements.

There are significant differences in scope of coverage in some states pesticide laws compared to the coverage of the amended FIFRA. There are also considerable differences in the enforcement authorities granted to the state administering agencies. The penalties enacted for violations are weak and are not deterrents to violations. On the other hand the volume of litigation does not indicate that a strong penalty deterrent is required.

Two major loopholes exist in the present registration statutes: First, the exemption of officials of state and federal agencies from registering products used in their official activities provides an opportunity for the aquatic environment to be subject to pesticide contamination. This occurs without any possibility of assessing the type and volume of chemicals entering the waters. Second, the registration statutes do not provide coverage of an important consumer protection need. This relates to the packaging aspect of pesticide containers to provide for child safety.

The level of enforcement of the state registration statutes is comparable to the level of enforcement of the FIFRA. Federal recall and seizure actions in the southeastern states have been infrequent and several states have made liberal use of their authority to issue "stop-sale orders". Enforcement cooperation between the state and federal levels of government has been high.

Some of the southeastern states are ahead of the federal government in the enactment of pesticide application and use controls. Until recently these controls have been limited to regulation of aerial applicators in only four of the eight states. There is no federal statute governing aerial applicators despite the fact that the aircraft are regulated by the Federal Aviation Administration. The bulk of the current application and use litigation has been concerned with aerial application licensing. Aerial applicators frequently engage in interstate operations which require separate licensing for each of the states served. Farmers needing an urgent pesticide application are not prone to investigate whether or not an applicator is licensed in his state.

Two information systems used, or which should be used, for decisions affecting the federal pesticide program are either woefully inadequate or warrant some improvement. Only a small number of the incidences of pesticide poisonings which occur are being reported (alledgely 10-15 percent) to the National Clearinghouse for Poison Control Centers. This level of reporting is inadequate to base federal or state policy decisions. The South Carolina community pesticide surveys for two separate years would indicate that the 10-15 percent figure for the nation is a reliable estimate of the situation in the southeastern states.

One aspect of the National Transportation Safety Board's reporting system on aerial application accidents needs improvement. This relates to the toxicological effects on pilots. The high incidence of "unknown or not reported" for this data category limits the usefulness of this system. This is a crucial consideration which could be used in health research program and pesticide program policy decisions.

The inclusion in state application and use laws of provisions requiring the inspection and licensing of ground application equipment is commendable from the viewpoint of environmental protection. On the other hand it is doubtful if an effective enforcement program can be initiated and operated within the present and anticipated funding constraints. There is also the inherent implication that this area of control and enforcement could create chaos for equipment manufacturers if each state adopts different inspection standards for licensing.

None of the southeastern states have enacted legislation requiring the posting of signs for fields which have been treated with pesticides. The employment of migratory workers often of limited education throughout the southeast makes any such future practice questionable unless a standardized program is established.

In summary, the southeastern states registration statutes are slightly less adequate than the FIFRA. There are some states with application and use controls offering limited protection of the aquatic environment. The pesticide laws and common law principles applicable to the use of pesticides do a reasonably adequate job of protecting persons and property from injury. There is a need for improvement in the administration of present controls. Present state registration laws are inadequate with respect to protection of the environment. On the whole, envrionmental protection is just now being written into the statutory language of the southeastern states in the form of application and use laws.

6. Recommendations

1. The Southeastern states must reduce the time required to formulate pesticide legislation, enact legislation and implement pesticide programs as technical advances elucidate the complex interaction between man and the other factors affecting the environment. Alternatives available include (a) pre-emption of registration and use controls by the federal government,

(b) adoption of federal standards for compliance by states under new federal legislation, (c) improved education to develop an informed public, and (d) combinations of these.

2. Annual registration of pesticide products as practiced by the states should be adopted for federal registration thus providing a more frequent review of ingredient statements and the mechanism for readily challenging efficacy statements as new scientific findings are made available. A no-change registration form would facilitate administration of annual registration processes.

3. The national data collection systems supporting the federal pesticide program should be improved. The federal government should encourage legislation at the state and federal levels to make mandatory reporting by physicians of treatment of pesticide poisonings. The U. S. Public Health Service should promote effective diagnosis and reporting of pesticide poisonings among its physicians and physicians at large. The National Transportation Safety Board should cause improved reporting of the toxicological effects on pilots by requiring investigation and re-submission of future reports where this data category is improperly completed. The Department of Commerce should expand its annual reporting requirements. Information should be collected from manufacturers and distributors on the quantity of pesticides shipped as final sales to retailers or direct to consumers by county.

4. The registration procedures on pesticides should include an assessment of packaging adequacy from the viewpoint of child safety. Participation by the Office of Consumer Protection, by the Federal Trade Commission, and the Food and Drug Administration might be necessary to avoid duplicate staffing of qualified specialists.

5. An Executive Order should be issued by the President which would cause all federal agencies introducing pesticide substances into public waters and onto public lands to file with state water pollution agencies the chemicals used, the amount, the time of use and the purpose. This

recommendation accepts the Congressional intent that states have primary responsibility for water pollution control.

6. The federal government should encourage state water pollution control agencies to issue regulations requiring all state government agencies using pesticides in state waters and on public lands to file similar statements.

7. The focus of the federal pesticide program should be shifted to provide incentives for the states to enact and enforce a high quality state pesticide program. Federal standards on registration, inspection, and enforcements, etc. should be established. States should be provided with federal grant assistance to operate and administer their pesticide programs which satisfy the federal standards. The grants could cover planning, inspection, laboratory services, enforcement and personnel training similar to the type policies being adopted to implement the Occupational Safety and Health Act of 1970. Reduction of federal inspection and enforcement staffs could be accomplished when state programs attain a satisfactory level. Other federal programs such as the Wholesome Meat Inspection Act and the Atomic Energy Commission's state radiation agency agreements provide adequate precedent for states meeting federal standards to manage both the state and federal program within their geographical boundary.

8. The FIFRA should be amended to provide for a joint comprehensive federal-state pesticide program and to grant federal officials authority to issue "stop-sale" and "stop-use" orders.

9. The investigative function performed by the Accident Investigation Section in the Pesticides Office of the Environmental Protection Agency should be expanded.

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G. ALTERNATIVES TO PESTICIDES IN SOUTHEASTERN UNITED STATES

1. Introduction

Pest management should be predicated on the totality of knowledge of all pest control methods and the ecological impact. Effective control measures should be those which consider the long term ecological and economic aspects. The indiscriminate use of any single control method may produce undesirable and unintended side effects.[1]

On balance, the introduction of chemicals such as pesticides to agricultural practice was beneficial. However, not all the effects are positive. Problems have arisen, some quite serious, which detract from the benefits.[2,3] This is attributed in a large measure to the disregard of ecological considerations. Only chemical, toxiological and economic criteria were used. Pest control has consequently engendered serious problems through disruptive impact on the ecosystem.

The benefits of pesticides were so evident that alternatives were not evaluated with equal vigor. All practices, whether chemical, cultural, physical, genetic or biological, must bring about the most effective, least ecologically disruptive, pest control possible. The objective is to reduce the impact of pesticides upon the aquatic environment by critically analyzing the available alternatives.

Although alternative methods are sought, it is generally conceded that pesticides will be used to control pests into the foreseeable future.[4] Subsequent to the discovery of organic pesticides in the early forties, major research effort was not devoted to alternatives. This accounts for continued and often excessive reliance on pesticides.

Methods of control are effective because they either directly affect the pest species or adversely modify environmental conditions for its survival (Fig. G-1). Principles and examples of current and proposed methods are considered.

2. Cultural Methods of Pest Control

Cultural methods are routinely utilized in agriculture to reduce pest problems. These usually involve adjusting the time or manner of performing operations for the production of crops or animals, and in improved management procedures. Examples of such cultural methods [6-10] and the pest species against which it is directed are:

- Sanitation

  -Destruction of crop refuse (boll weevil, bollworm, corn borer)

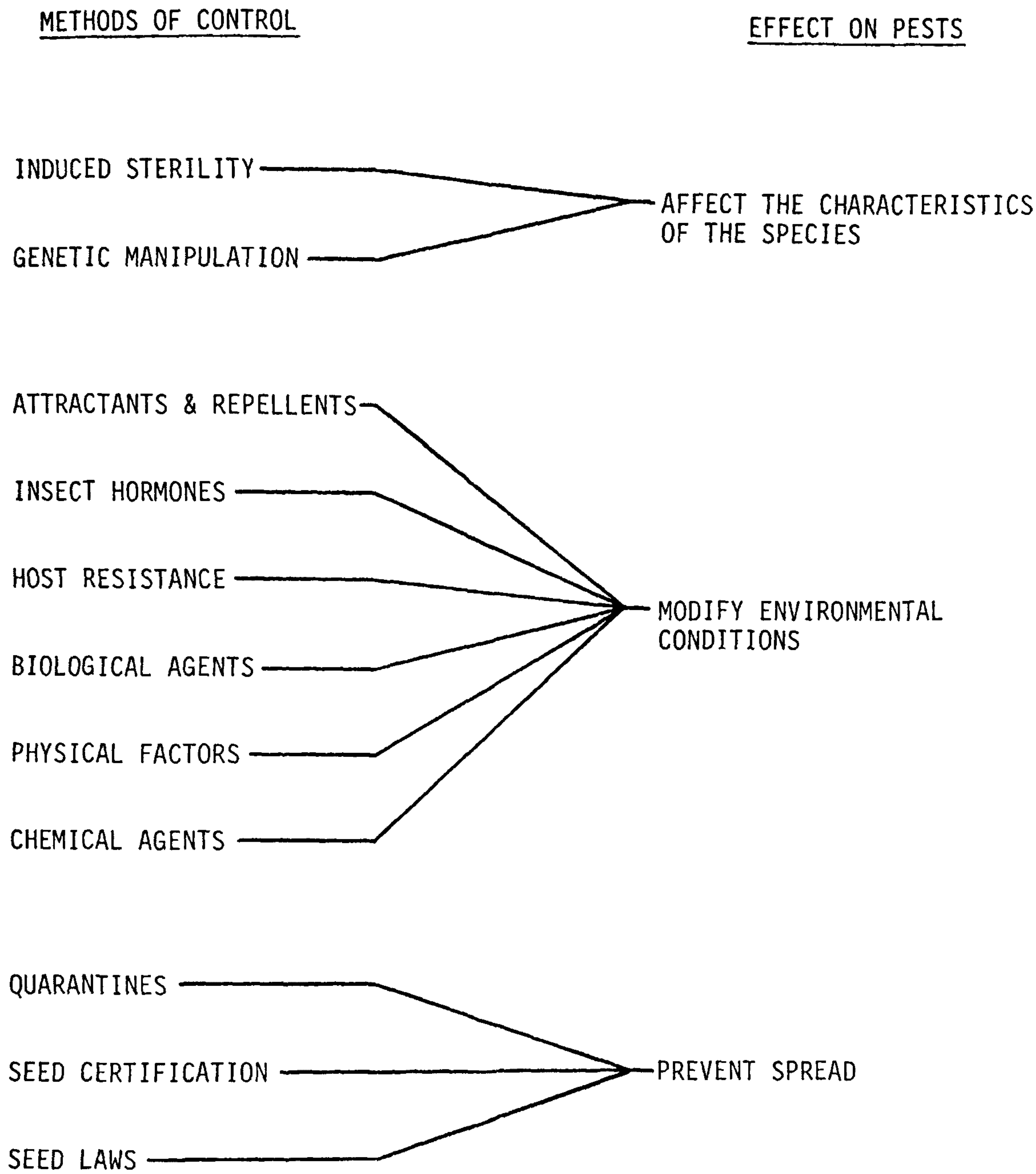
  -Cleaning of field borders (weed control)

  -Disposal of wastes (fly control)

- Rotations

  -Crop rotation (specific pests for all crops, diseases, fungal spores, bacteria, mites, insects and viruses, eg. golden nematodes of potatoes, soybean cyst nematodes, northern corn rootworm)

  -Animal rotation (cattle tick control)



Source: Rabb and Guthrie (Modified)[5]

FIGURE G-1. POSSIBLE METHODS OF PEST CONTROL

- Farm Management

  - Land bank and fallowing (cyst nematodes)

  - Strip cropping (alfalfa aphid)

  - Fertilizers (chinch bugs, weeds)

  - Time of planting (southeastern corn borer, sugar-beet nematode)

  - Pest free seeds and seed certification (weed control, wheat nematode control)

  - Destruction of volunteer plants (potato aphids)

  - Destruction of alternate hosts (wheat and apple rusts, beet leaf hoppers, sweet potato weevils)

  - Destruction of early blooms (sorghum midge)

  - Tillage (grape berry moths)

  - Crop spacing (weeds)

  - Cleaning of farm equipment (weed control)

- Trap crops (citrus red mite)

- Regulation of plant stands (citrus pests)

- Selection of site (various forest insects)

- Thinning, Topping, Pruning and Defoliating

  (Tobacco hornworm, mite, and control of dutch elm disease)

- Water Management

  - Irrigation and flooding, (root knot and white tip nematodes)

  - Impoundment and improved pond management (acquatic weeds, mosquitoes, biting midges)

  - Drainage (nematodes)

a. Cultural Control of the Southwestern Corn Borer

This southwestern corn borer, Diatrea grandiosella, is primarily a pest in the western U. S. However, it has slowly moved eastward and is found in western Tennessee and Alabama.[11] Cultural practices which increase exposure of the larvae of this insect to the environment and to predators are effective in increasing overwintering mortality. Burying is not detrimental to the larvae but the moths are unable to emerge from the soil. Early-planted corn escapes some of the damage. The primary advantage for early planting is reduction in girdling. Although corn planted in Tennessee before May 1 is damaged less by girdling in all years and locations, infestation and lodging are not consistently reduced. It has been established that the use of an early maturing hybrid is not an acceptable substitute for early planting as a means of reducing damage caused by this borer.[11]

b. Cultural Control of Cotton Pests

(1) Insect Control

The pink bollworm provides a classic example of a major cotton pest controlled by cultural practices. The feature of the control program includes stalk destruction and deep plowing of the residue after the crop is harvested. Two factors, namely, overwintering as larvae and a single host plant (cotton), makes it highly susceptible to this method of control. Cultural measures in conjunction with good agronomic practices provide a means by which the pink bollworm population may be reduced to extremely low levels. Often damaging populations do not develop the following year.

A modification of this approach is quite effective in reducing boll weevil populations. The great majority of the dispausing boll weevils leave the cotton fields for hibernation sites during the harvest period of late September and October. Further, the adult requires a feeding period of 1 to 3 weeks to accumulate sufficient fat reserve to attain diapause or overwintering stage. Any practice which eliminates either food or breeding sites during this critical period will be detrimental.

The most important practice that can be effected during the fall to reduce populations of diapausing boll weevils is defoliation or desiccation of the cotton plants. This eliminates squares and young bolls necessary for development of the diapausing population. The next most important practice for reducing overwintering populations is to harvest the crop as quickly as possible and then destroy the stalks.

Attacking the boll weevil and pink bollworm during the fall of the year is a biologically and operationally sound practice aimed at destruction of the diapausing population. Only bollworms that are in diapause are able to survive the winter. This is the weakest link in its life cycle. A factor in the success of this method is that these two major cotton pests do not develop large populations on wild or alternate host plants.[12]

(2) Disease and Nematode Control

The principal cotton diseases and their control with cultural and other control methods are presented in Table G-1.

TABLE G-1. Various cotton diseases and their control by cultural and other methods.[13]

Name of Disease and Causal Organism	Control Measures
Anthracnose (the fungus *Glomeralla gossypii*). (South.) Edg.	Seed treatment; destruction of diseased plant residues; suitable crop rotations
Ascochyta, or wet weather, blight (the fungus *Ascochyta gossypii*). Syd.	Seed treatment; destruction of diseased plant residues; suitable crop rotations
Bacterial blight (the bacterium *Xanthomonas malvacearum*). (E. F. Smi.) Dows.	Seed treatment; use of resistant varieties; destruction of diseased plant residues
Fusarium with (the fungus *Fusarium oxysporum* Schlecht. f. *vasinfectum*). (Atk.) Snyder and Hansen.	Use of resistant varieties; suitable rotations; fumigation to reduce nematodes; addition of humus to soil; use of fertilizers high in potash
Root-knot (the nematode *Meloidogyne incognita*). Chitwood.	Fumigation with locally recommended fumigants; suitable crop rotations; tolerant varieties
Root rot (the fungus *Phymatotrichum omnivorum*). (Shear) Dug.	Fall plowing with phosphate additions; use of Hubam clover as cover crop; suitable crop rotations; heavy applications of organic manures in irrigated areas
Seedling diseases (several seedborne and soil-inhabiting fungi and bacteria).	Seed treatment; destruction of diseased plant residues; use of bacterial-blight resistant varieties
Verticillium wilt (the fungus *Verticillium albo-atrum*). Reinke and Berth.	Use of tolerant varieties; rotation with grain crops in irrigated areas; planting on high beds; increasing of plant population; avoiding heavy irrigation that lowers soil temperatures for prolonged periods

Source: Presley and Bird (Modified).

(3) Weed Control

Cultural methods of controlling weeds in cotton are important. Production practices which promote rapid emergence and growth tend to control weeds by shading. Crop rotation or fallowing sometimes offer another practical solution. These two practices permit the use of alternate herbicide on weeds that are difficult to control in any single crop. For example, cocklebur is very difficult to control in cotton fields but relatively easy to control in corn. Disking or plowing six to eight times during a single growing season effectively reduces the number of viable johnson grass rhizomes present at the beginning of succeeding growing season. Plowing or disking every four weeks for two successive growing seasons has been reported to eradicate nutsedge essentially.[14]

Cultural practices tend to create adverse conditions during the pest's active or overwintering stage and result in reduced pest infestation. Expansion of such agronomic practices together with integrated control programs could reduce the use of the pesticides.

3. Physical and Mechanical Methods of Pest Control

Physical and mechanical methods differ from cultural methods since they are intended specifically to control the pest and are not routine agricultural practices. They may either be preventive or corrective. Their effectiveness lies in the fact that all biological species exhibit thresholds of tolerance with regard to extreme temperature, humidity, sound, physical durability and response to various regions of the electromagnetic spectrum. Among central approaches, the possibilities inherent in the spectrum of radiant energy and devices such as light traps are especially promising.[15,16]

Temperature is utilized in the control of soil-borne diseases caused by bacteria, viruses, fungi and nematodes.[6] Fire has been found to be an effective method of control of alfalfa weevil, Hypera postica.[17] In many cases stored seeds are protected by exposure to temperatures 4 and 10°C, since most grain infesting insects are inactive at these temperatures.

a. Inactivation of Plant Pathogenic Viruses by Heat in Vegetatively Propagated Plant Materials

Temperature may affect the susceptibility of host plants to virus infection, the time required for development of symptoms, and the degree of damage. The principle may be extended to those cases where the majority or all of the plants in a vegetatively propagated clones are infected. A summary of viruses (Table G-2) that have been inactivated in plants by heat illustrates the effectiveness of this measure.[18]

b. Disinfection of Plant Parasitic Nematodes by Heat

A hot water treatment, alone or together with a nematicidal dip, is used to treat plants contaminated with ectoparasitic nematodes such as Hemicycliophora sp. or Criconemoides sp. These pests are difficult to dislodge by mechanical means because their long stylets are inserted into the plant cells. Endoparasitic nematodes present within plant tissues or enclosed within the protective layers of plant parts require a penetrating chemical or physical agent to effect a kill. Heat is most commonly used. Externally applied heat is absorbed by the plant propagule and spreads within to reach the pathogens. When a differential in heat susceptibility exists between plant tissue and nematode and the latter is more sensitive, effective heat treatment is possible.

TABLE G-2. List of Viruses that Have Been Inactivated in Plants by Heat[18]

Virus	Plant	Treatment	Temperature (°C.)	Length of Treatment
Abutilon variegation	Abutilon striatum	Hot air	36	3-4 weeks
Apple mosaic	Budded seedlings	Hot air	37	28-40 days
Aster yellows	Vinca rosea and Nicotiana rustica (plants)	Hot air	38-42	2-3 weeks
	Vinca rosea (plants)	Hot water	40-45	2 1/2-24 hr.
Carnation ringspot	Carnation (plants)	Hot air	36	3-4 weeks
Cherry necrotic rusty mottle	Cherry bud sticks	Hot water	50	10 min.
Cherry ringspot	Cherry bud sticks	Hot air	100	17-24 days
Citrus tristeza	Potted plants	Hot air	95°F.±3°	121-360 days
Cranberry false blossom	Cranberry and Vinca rosea (plants)	Hot air	42	8 days
Cucumber mosaic	Cucumber, tobacco, Datura stramonium (plants)	Hot air	36	3-4 weeks
Little peach	Peach (bud sticks)	Hot water	50	3 min.
Peach red suture	Peach (bud sticks)	Hot water	50	3 min.
Peach rosette	Peach (bud sticks)	Hot water	50	8 min.
Peach X-disease (yellow-red virosis)	Peach (bud wood)	Hot water	50	6-15 min.
Peach yellows	Peach (trees)	Hot air	35	24 days
	Peach (dormant trees)	Hot water	50	10 min.
Phony peach	Peach (dormant trees)	Hot water	48	40 min.
Potato leaf roll	Potato (tubers)	Hot air	37	15-30 days
Potato witches' broom	Vinca rosea (plants)	Hot air	42	13 days
	Potato (tubers)	Hot air	36	6 days
Raspberry leaf mottle	Raspberry (plants)	Hot air	32-35	1-4 weeks
Raspberry leaf spot	Raspberry (plants)	Hot air	32-35	1-4 weeks
Raspberry unidentified latent virus	Raspberry (plants)	Hot air	32-35	1-4 weeks
Raspberry Rubus stunt	Raspberry (canes)	Hot water	45	1 1/2-2 hr.
Strawberry leaf burn or X	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 1 (mottle)	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 3 (crinkle)	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 4 (vein chlorosis)	Strawberry (plants)	Hot air	37	7-11 days
Strawberry virus 2 (mild yellow edge)	Strawberry (plants)	Hot air	37	16 days
Strawberry nonpersistant viruses	Strawberry (plants)	Hot water	43-48	1/2-7 hr.

TABLE G-2 (Continued)

Virus	Plant	Treatment	Temperature (°C.)	Length of Treatment
Strawberry nonpersistant viruses	Strawberry (plants)	Hot air	36-38	8-12 days
Strawberry type 2	Strawberry (plants)	Hot air	38	8 days
Strawberry viruses (unidentified)	Strawberry (plants)	Hot air	37	10 days
Sugarcane chlorotic streak	Sugarcane (cuttings)	Hot water	52	20 min.
Sugarcane ratoon stunt	Sugarcane (setts)	Hot water	50	2 hours
Sugarcane ratoon stunt	Sugarcane (cuttings)	Hot water	50	20 min.
Sugarcane sereh disease	Sugarcane (cuttings)	Hot water	52-55	30 min.
Tobacco ringspot	Tobacco (plants)	Hot air	37	3-4 weeks
Tomato aspermy	Tomato and tobacco (plants)	Hot air	36	3-4 weeks
Tomato aspermy	Chrysanthemum (plants)	Hot air	36	3-4 weeks
Tomato bushy stunt	*Datura stramonium* (plants)	Hot air	36	3-4 weeks

Source: Carter, W.

A few examples of recommended temperature-time combinations[9] found useful for control of parasitic nematodes include: Easter lily bulbs with spring crimp nematode, Aphelenchoides fragariae, 1 hour at 44°C in a water and formalin bath; citrus rootstock with borrowing nematode, Radopholus similis, 10 minutes at 50°C; seed with bentgrass seedgall nematode, Anguina agrostis, 15 minutes at 52.2°C in water containing a wetting agent; wheat seed with wheat nematode, A. tritici, 30 minutes at 49°C or 10 minutes at 50°C; begonia with spring crimp nematode, treat by submerging pot and contents for 1 minute at 49°C, 2 minutes at 47.8°C, or 3 minutes at 46.8°C; sweet potatoes with root-knot nematodes, Meloidogyne sp., 65 minutes at 46.8°C; and grape rootings with root-knot nematodes, 30 minutes at 47.8°C, 10 minutes at 49°C, 5 minutes at 51.6°C, or 3 minutes at 53°C[17,9].

c. Use of Light Traps in Insect Control

Light traps employing ultraviolet or blacklight lamps are being used in experiments to determine their effectiveness for attracting moths.[19] In one 113-square mile area in North Carolina 370 traps exterminated 50 to 60 percent of the adult tobacco hornworm moths in one growing season. A trap density of three per square mile in combination with stalk cuttings and insecticide treatment to prevent late season breeding of hornworms, further reduced infestation in tobacco about 80%. This reduction was measured in the center of the test area during the second year. About 20 times more males than females were captured. These results suggest the possibility of using this means to decrease mating in the field.

Other uses of black-light traps for insect control include the protection of cabbage from the attack of the cabbage looper, Trichoplusia ni (Hubner), and of celery from the celery looper, Anagrapha *falcifera* (Kirby)[8]. The deleterious effects of both the European corn borer and the cotton bollworm can be significantly reduced by light traps if population pressure is not extremely high. Damage to tomato fruit and foliage resulting from the attack of tobacco and tomato hornworms can be minimized[8]. The increase in yield of cucumbers from plants protected by light traps has been especially encouraging; populations of the striped cucumber beetle and the spotted cucumber beetle were reduced and the transmission of bacterial wilt was minimized. The benefit of the light trap is that it eliminates the need for chemical applications in those climatic areas where light attraction is consistently good.

Light traps may be used to attract moths and bring them into contact with chemosterilants. They can then be released. Not all moths and flying beetles are sufficiently attracted to black-light sources to affect control. Further, control over extensive areas is not feasible. Recommendation of this approach must be made within certain restraints. The limitations involve need for electrical power and the presence of pests that are photosensitive. The advantages are: no residues on crops; they detect moth emergence and can be used for timing of control applications; attraction irrespective of the physical condition of the field; integration with other control approaches (eg. post season stalk cutting in tobacco)[16, 19] and low operating cost.

Light attraction combined with chemical attractants is a promising means of effective pest control.

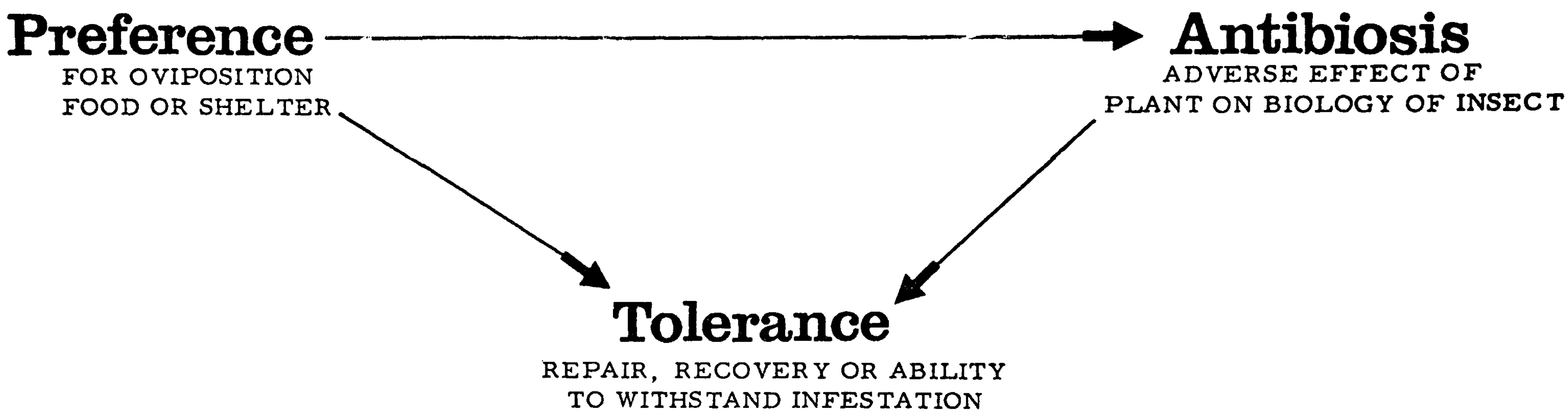
4. Use of Resistant Varieties of Crop Plants

Plants or animals that exhibit less damage or infestation by a pest (disease, nematode or insect) than others under comparable conditions in the field are considered to be resistant. Selection and improvement results in a resistant variety which becomes an integral part of the pest management program. One of the most important contributions of agricultural programs of the pre DDT era was the development of resistant varieties. This method of reducing pest damage has been used extensively since the turn of the century. Originally the case for natural resistance to plant pests was economic; it added nothing to the grower's cost of production. Now, pollution control is the consideration.

With alfalfa, small grains and tobacco, it is the availability of resistant varieties which makes the difference between profit or loss. In certain cases it is the resistance factor that makes culture of a crop possible. In the Southeast, diseases such as stem rot of peanuts; rusts and smuts of cereals; anthracnose of watermelon; fusarium wilt, mosaic, black shank, and black root rot of tobacco are only examples of the pathogens which are primarily controlled by resistant varieties.[10] At present, approximately 75 percent of the total acreage in agriculture production in the United States utilizes resistant varieties.[10]

Varietal resistance to insects and other pests is classified into three broad categories (Fig. G-2).

A classical example of the use of the plant genetics is the control of grape phylloxera in Europe over the past 90 years. Highly resistant American varieties saved the European viticulture.[5] An



Source: Painter, R. H.

Fig. G-2. The Nature and Categories of Pest Resistance.[20]

early search for plants resistant to insects was made in California over a period of 10 years beginning in 1881.[20] By turn of the century, programs were under way which were directed toward increased disease resistance through breeding. Among the better known were those programs concerned with mildew resistance in grapes in France; late blight of potato in several European countries; rust resistance in wheat in Australia, England and America; and, wilt resistance in flax, cotton, watermelon and cow pea in United States. These are still being pursued actively today along with scores of others.[21, 22] In the 1953 Yearbook of the United States Department of Agriculture there is a list of sources of resistance in crop plants which occupies more than 24 pages. Many of these crops are grown in the Southeastern states.[23] Each year many new resistant varieties are added. Effort is being directed toward incorporating multiple pest resistance into crop varieties.

The development of all the resistant varieties cannot be considered within the scope of this review. The few cited exemplify development and use of host plant resistance as one of the most effective methods of economic pest management in agricultural ecosystems.

a. Wilt Resistance in Tobacco

A bacterial disease known as Granville became a limiting factor in flue cured tobacco producing counties in North Carolina following the turn of the century. Losses in Granville County during the period from 1920-40, one of the key tobacco growing areas, were estimated at 30-40 million dollars.

Intensive efforts to develop wilt-resistant tobacco were initiated in 1935. This effort culminated in the release in 1944 of a resistant tobacco variety of acceptable quality at a program cost of about $150,000. By 1948, the value of the tobacco in the area of Granville was estimated as $2,000,000. In 1964, 416,000 acres were devoted to the tobacco crop in North Carolina and the value placed as $520,000,000. Approximately 95 percent of this acreage was planted to varieties which not only incorporated resistance to Granville wilt, but also to black shank. If resistant varieties were not available and only susceptible varieties were grown, it is estimated that yield would be reduced to less than one-fourth.[21,23] These major diseases involve soil-borne pathogens. No effective chemical controls would have been available to control these diseases and the effectiveness or practicality of other approaches, including rotation and related cultural practices, would have been limited.

b. Varietal Resistance to Cotton Pests

Varietal resistance has been generally ignored as a possible means of controlling cotton pests until recently. Research initiated to screen available germplasm has proved to be highly rewarding.

The possibility of controlling Heliothis sp. and other lepidopterous pests by incorporating high levels of gossypol and other pigments into commercial varieties appears to be especially promising. Plants having a gossypol content of 1.5 percent or greater would cause both larval mortality and inhibition in development of Heliothis larvae. Such levels have been attained in several lines.

High gossypol content is undesirable in cotton seed because of its toxicity to non-ruminant animals. A considerable amount of effort has been devoted to incorporating characteristics for low gossypol content into commercial varieties. This provides an excellent example of the necessity for a cooperative approach in developing varieties of cotton.[12]

The spread of the boll weevil, Anthonomus grandis (Boheman), throughout the Cotton Belt around the start of this century brought marked changes in the type of cotton grown. The late, vigorous, long-staple upland varieties were rapidly replaced by early-maturing, short-staple types which were less susceptible to damage by the weevil because of their shorter exposure period and thicker carpel walls. These short staple types tended to be inferior in quality; and breeding efforts were directed toward increased quality and length of staple.

Knipling estimated that $75 million was expended annually for control of the boll weevil.[4] In spite of this expenditure, control was far from complete and the annual loss from this insect was estimated at $200 million. Indications of the weevil developing resistance to insecticides renewed interest in the development of resistant types. The U. S. Cotton Boll Weevil Research Laboratory was established in 1962 at State College, Mississippi, with the objective of finding new approaches to boll weevil control or eradication with less emphasis on use of insecticides. In addition to the search for resistance, other alternative methods were also examined.

Extensive studies with cotton have demonstrated that several factors contribute significantly to differences in relative resistance and susceptibility to boll weevil attack. Some of these genetic factors are complex and quantitative in their inheritance; others are simply inherited. Frego bract is conditioned by a single recessive gene. In this mutant type, the normally adherent bracts become flared and twisted, leaving the squares relative exposed. Studies indicate that frego types are less attractive for oviposition (egg laying). In addition, the exposed squares permit ready penetration of insecticides and greater predation by birds and insects. Other simply inherited traits, such as, red leaf and smooth leaf, contribute to reduce oviposition. Combinations between certain of these traits appear to exhibit increased non-preference.

A large portion of worl's germ plasm of cotton has been screened at the U. S. Boll Weevil Research Laboratory, during the period 1962 to 1968. An oviposition suppression factor causing 25 to 40 percent reduction in the number of eggs laid by the weevil has been found in Gossypium bardadense and successfully moved into upland cotton, G. hirsutum. Research with five different genetic lines each carrying a frego gene showed a significant degree of non-preference for the oviposition to the boll weevil. Weevils were found to avoid the exposed bud for feeding and oviposition.[24]

Laboratory tests have been devised which permit the screening of large numbers of plant types under controlled levels of exposure. Marked differences in oviposition scores were obtained. Inheritance studies, involving some of the less-preferred versus standard types, indicated the oviposition factor to be under genetic control, but the results could not be satisfactorily interpreted on a single gene basis. More extensive studies involving backcross and F_2 progeny provided little additional information, due to difficulties in obtaining adequate information on an individual plant basis. The fact, however, that the resistance to oviposition can be satisfactorily transferred to other strains is most encouraging.

An extensive series of experiments has been conducted establishing the existence of both plant attractants and repellants. The attractants, still incompletely characterized, appear to be alcohols and esters, while the repellants may be terpenoids. Similarly, evidence exists for both feeding stimulants and deterrents. In neither case have the causal constituents been adequately identified.

The combination of morphological traits, oviposition factors, attractants, repellants and feeding stimulants to provide adequate field resistance in the absence of chemical control, together with the essential genetic factors for yield and fiber quality, poses a formidable task. Continued progress may be expected, however, as the intricacies are exposed.[25] This is an example of a case where considerable research effort over a long period has been directed toward development of an alternative technology to pesticidal control. Results from such efforts would ultimately be the basis for reduced use of pesticides.

c. Control of Cyst-Nematode in Soybeans by Resistance

Discovery in 1954 of nematodes attacking soybeans in North Carolina was the first report of this pest outside the Orient.[26] Damage to the crop posed a threat to the United States soybean industry. Control of the soybean cyst nematodes has been difficult. Multiple approaches have been necessary. Application of chemicals to the soil has not been economically feasible. Crop rotation of two to three years was effective, but resulted in limited production. Federal and state quarantines were only partially successful.

In 1957, some 2, 800 soybean varieties were screened for nematode resistance in heavily infested fields.[26] Four varieties were found on which the nematode did not reproduce. The desirable characteristic of resistance was transferred to a commercial variety and the new combination was called Pickett. This variety was developed cooperatively by the Agricultural Research Service and the Agricultural Experiment Stations of Arkansas, Missouri, North Carolina, Tennessee, and Virginia.[26]

d. Breeding Vegetable and Fruit Crops for Resistance to Diseases

Disease resistant vegetable varieties are especially noteworthy. A vegetable grower in the Southeastern states by proper selection of such varieties can now reduce the damage caused by such destructive diseases as fusarium wilt of cabbage, tomato, and watermelon; common mosaic of beans; celery leaf blights; spinach blight, cucumber scab; and many others. In many cases, the farmer will not sacrifice the quality or productivity of his crop through use of a resistant variety.[27]

Examples of vegetables and fruits grown in the Southeastern states, which have shown resistance to fungus, nematode, virus or bacterial diseases are listed in Table G-3.

e. Disease and Insect Resistance Research for Southern Forests

The greatest forest insect resistance research is presently concentrated on the fusiform rust of southern pines. Agencies, both governmental and private, are engaged.[28] In North Carolina, a "rust nursery" approach is being used for mass screening of known seed sources of southern pines. It also permits estimatation of the heritability of resistance in a natural population of southern and loblolly pine. Since 1954, a tree improvement program has been underway in Florida. This involves screening of select slash pines for reistance to fusiform rust. Selection and field testing of slash and loblolly pines of one parent and controlled progeny are being studied for their resistance.

Table G-3. Classification of Representative Vegetable and Fruit Disease Resistance Cases According to Causal Agent, Mode of Inheritance, and Field Experience[27]

Disease	Original source of resistance	Pathogen	Field reaction
		I. Fungus Diseases	
Monogenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Potato late blight	*Solanum demissum*	*Phytophthoracinfestans*	Immune
2. Lettuce downy mildew	European varieties	*Bremia lactucae*	Immune
3. Bean powdery mildew	Several varieties	*Erysiphe polygoni*	Immune
4. Cantaloupe powdery mildew	Indian varieties	*Erysiphe cichoracearum*	Immune
5. Bean rust	Several varieties	*Uromyces phaseoli typica*	Immune
6. Apple scab	*Malus baccata*	*Venturia inaequalis*	Immune
7. Tomato leaf mold	*Lycopersicon pimpinellifolium*	*Cladosporium fulvium*	Immune
8. Bean anthracnose	Several varieties	*Colletotrichum lindemuthianum*	Immune
b. Remaining resistant to prevalent races			
1. Spinach downy mildew[b]	Iranian variety	*Peronospora effusa*	Immune
2. Cucumber scab	Longfellow variety	*Cladosporium cucumerinum*	Immune
3. Tomato leaf sopt	*Lycopersicon hirsutum*	*Septoria lycopersici*	Resistant

Table G-3. (Continued)

Disease	Original source of resistance	Pathogen	Field reaction
4. Tomato gray leaf spot	*L. pimpinellifolium*	*Stemphylium solani*	Immune
5. Tomato fusarium wilt	*L. pimpinellifolium*	*F. oxysporum F. lycopersici*	Immune
6. Cabbage fusarium wilt	American varieties	*F. oxysporum F. conglutianans*	Immune
7. Ceder-apple rust	Several apple varieties	*Gymnosporangium juniperivirginianae*	Immune
8. Apple scab	Asiatic species of Malus	*Venturia inaequalis*	Immune
Polygenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Strawberry red stele	Aberdeen and other varieties	*Phytophthora fragariae*	Resistant
b. Remaining resistant to prevalent races			
1. Potato late blight	Selections of Solanum demissum and other species	*Phytophthora infestans*	Resistant
2. Apple scab	Antonovka	*Venturia inaequalis*	Immune
3. Cabbage fusarium wilt	American varieties	*F. oxysporum F. conglutinans*	Resistant
II. Nematode Diseases			
Monogenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Tomato root knot	*Lycopersicon peruvianum*	*Meloidogyne spp.*	Resistant
2. Pepper root knot	*Santanka X S variety*	*Meloidogyne spp.*	Resistant

Table G-3. (Continued)

Disease	Original source of resistance	Pathogen	Field reaction
Polygenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Lima beam root know	Hopi 5989 and Westan	*Meloidogyne spp.*	Resistant
2. Peach root knot	Shalil and Yannan varieties	*Meloidogyne incognita*	Resistant
	III. Virus Diseases		
Monogenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Tomato spotted wilt	Argentine variety	Spotted wilt virus	Resistant
b. Remaining resistant to prevalent races			
1. Bean mosaic	Corbett Refugee	Bean virus 1	Resistant
2. Bean pod mottle	Several varieties	Bean pod mottle virus	Immune
3. Bean southern Mosaic	Several varieties	Bean mosaic virus 4	Immune
4. Pepper mosaic	Tabasco variety	Tabasco mosaic virus	Immune
5. Spinach blight	Old Dominion; Va. Savoy	Cucumber virus 1	Immune
Polygenically[a] controlled resistance			
a. Proven susceptible to races of prevalence			
1. Tomato spotted wilt	*Lycopersicon pimpinellifolium*	Spotted wilt virus	Resistant
b. Remaining resistant to prevalent races			
1. Cabbage mosaic	Selections from varieties	Cabbage viruses A and B	Resistant

Table G-3 (Continued)

Disease	Original source of resistance	Pathogen	Field reaction
2. Cucumber mosaic	Oriental varieties	Cucumber virus 1	Resistant
3. Lima bean mosaic	Fordhook and others	Cucumber virus 1	Resistant
4. Bean curly top	Several varieties	Curly top virus	Resistant
5. Potato latent mosaic	S41956 variety	Potato virus	Immune
IV. Bacterial Diseases			
Monogenically controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Bean halo blight	Several dry bean varieties	*Pseudomonas phaseolicola*	Resistant
Polygenically controlled resistance			
a. Proven susceptible to races of prevalence			
None			
b. Remaining resistant to prevalent races			
1. Pear fireblight	Selections from *Pyrus spp.*	*Erwinia amylovora*	Resistant

[a]Resistances that have been found to be controlled by more than one factor pair are classified here as polygenic.

[b]In 1958, a race of *Pernospora effusa* developed extensively in California on this source of resistance.

Source: Shay, J. R.

f. Insect Resistance to Corn Earworm

Heliothis zea (Boddie) is adapted to feed on a wide range of hosts and has been given common names associated with the crop attacked, e.g., the corn earworm, the cotton bollworm, and the tomato fruitworm. The most widely used control has involved chemicals. Several million pounds are being used annually. Considerable effort has been devoted to corn and cotton to develop varieties which possess some degree of tolerance or resistance.

The corn earworm may feed on the leaves, silks, or the developing grains. Most studies on resistance have been concerned with damage to the grain. The literature is extensive and variation in earworm damage has been ascribed to variety, planting dates, spacings, date of maturity, soil fertility, concentration of feeding stimulant and nitrogen balance. Varietal differences have commonly been associated with husk characteristics, either extension or tightness. However, chemical differences also appear to be involved.

The effect of either husk extension or husk tightness are explicable from knowledge concerning the feeding habits and cannibalistic tendencies of the earworm. Either husk extension or tightness or their combination may ensure minimizing damage to the developing grain, but have little or no effect on population dynamics, and therefore, represent a special case of tolerance rather than one of antibiosis.[25] Extensive work should be under taken to find sources of resistance (amtibiosis) to leaf feeding.

g. Resistance to Potato Leaf Hopper

The nonhardy and Turkestan alfalfa varieties are highly susceptible to the potato leaf hopper while Medicago falcata or cultivars involving some degree of falcata introgression possess greater resistance.[25] Pubescent plants tend to be less attractive for oviposition than glabrous plants, although resistant types may be found in each category. After seven cycles of selection "cherokee" variety was released from such pubescent resistant plant types. This variety has been superior to 'Atlantic' and 'Williamsburg' in the area where it was developed, North Carolina.[25]

Resistant varieties are one of the least expensive means of avoiding pest damage. Such efforts however, do not and should not cease after a new variety is developed for a given crop. New disease strains develop for which further resistance needs to be incorporated. Multiple pest resistance is also in need of greater study. For many crop varieties, breeders have started to look for reduced weed competition. The potential benefits of pest resistance have, as yet, not been fully exploited.

5. Biological Agents for Pest Control

Biological control is the suppression of the reproductive potential of organisms through the actions of parasites, predators, or pathogens to restrict pest population at a lower average density than would occur if these were absent.[3]

The citrus industry in California once suffered a massive infestation of a mealy bug, cottony cushion-scale (Icerya purchasi), introduced from Australia on Acacia in 1868. The introduction of two Australian species, the ladybirds, Radola cardinalis (vedalia ladybird) and Cryptochetum iceryae, provided the necessary predator-prey regulation. They first reduced the mealy bug populations to levels at which they no longer constituted a major pest infestation. Unfortunately, however, as is shown in Figure G-3, cottony cushion-scale again reached major pest population levels when extensive use of DDT for citrus spraying eliminated the vedalia ladybird locally.[29]

This recurrence emphasizes an inherent danger of pesticide use. There may be a catastrophic effect on the natural regulatory mechanisms. While they temporarily diminish the numbers of a particular pest, the pesticides also reduce its natural enemies. The pest often undergoes a population explosion before its natural enemies can recover.

Successful biological control programs have engendered world-wide interest. The governments of several countries have established facilities for such research.

The interest in microbial insecticides has intensified because of such problems as development of resistant strains, emergence of secondary pests, and toxic residues. These have developed with the use of the broad spectrum chemical insecticides. Steinhaus[30] was the first to employ the term microbial control.

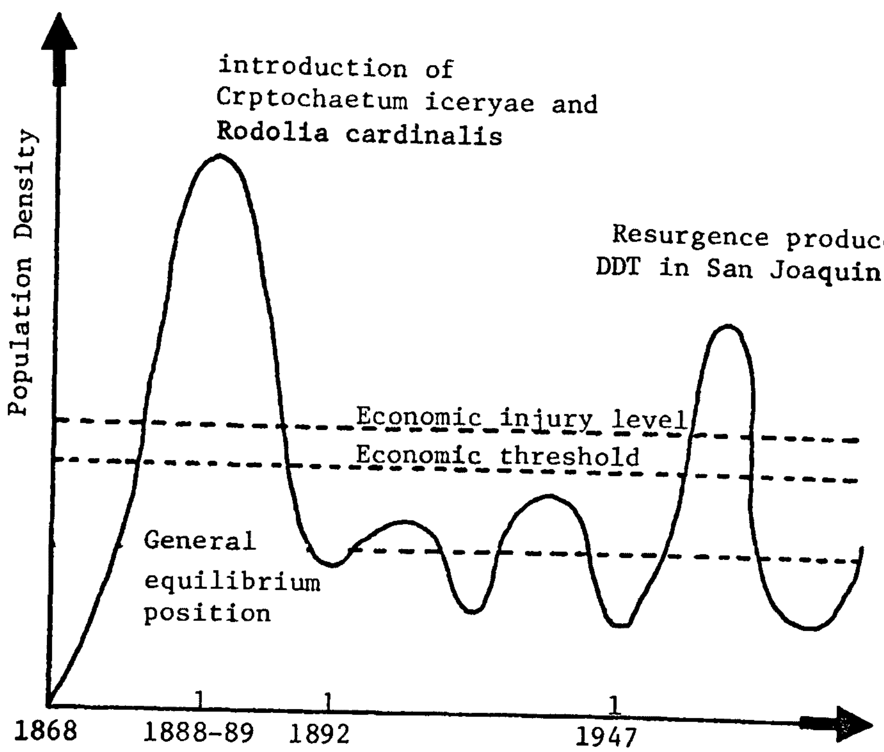


Figure G-3. Cottony cushion-scale (Icerya purchasi) incidence on citrus in California.[29]

Source: Stern, V. M. et al.

Insects, like animals, suffer from disease attacks. Under favorable conditions, a disease may reach epidemic proportions for an insect species. Within a few days or weeks it may reduce the species from a point of great abundance to one of scarcity. Insect diseases may be caused by protozoa, fungi, viruses and bacteria. During the last two decades, there has been an increasing awareness of the great potential of insect diseases as insect control agents. About 225 species of insect viruses have now been isolated. Of these, the nuclear polyhedroses (107 species) and the granuloses (80 species) are effective candidates for insect control.[31] Greer[32] reported over 300 insect viruses that can be utilized for control of specific pests.

The advantages offered by microbial pesticides are:

- Insect pathogens in general and viruses in particular, are very discriminating and infect only one species or members of closely related species.[33]

- Microbial control is a natural method of control and it increases the effectiveness naturally after once being introduced into an area. If conditions are optimum, the introduced microorganisms may spread of their own accord, resulting in widespread killing of the host.

- Microbial insecticides are biodegradable and leave no residue or buildup in the soil, as occurs with many chemical pesticides.

- Most microbial pesticides are essentially harmless to animals and plants and may be applied in heavy doses without damaging these forms of life.[30]

- Microbial pesticides are generally compatible with other pesticides.

Examples of pathogenic diseases associated with major economic arthopod pests are listed in Table G-4. Selected examples of arthopod pathogens used successfully to control arthropod pests are presented in Table G-5. Table G-6 lists the arthropod pathogens commercially or experimentally produced by commercial firms for use as microbial insecticides.

All methods of pest control have disadvantages. The perfect method of controlling pests is yet to be devised. The only intelligent approach to the evaluation of any method of control is through an honest acknowledgment of its limitations. Gaps may thus be filled by other control procedures. Some of the limitations of microbial pest control are:

- Perhaps the greatest single aspect not yet understood in the use of microorganisms in the control of insect pests has to do with the timing of application in relation to environmental conditions. Some researchers believe that high humidity has little effect on virus diseases, others, however, have associated virus epizootics with wet weather. In the laboratory, an excess of moisture often leads to the outbreak of bacterial diseases. Low humidity is generally considered a limiting factor in fungus diseases for the spore germination, infection and subsequent sporulation of the fungus on the host. High temperature generally accelerates the course of a disease. Much remains to be learned about optimum times to apply the microorganisms.

- There is a necessity of maintaining the vitality and virulence of the infecting agent especially for those microorganisms not possessing a cyst or spore stage. The possibility exists that resistant populations will develop after prolonged use of microorganisms.[30] This requires further study.

- The effect that heavily applied entomogenous microorganisms may have upon plants and higher animals always needs to be considered. There appears to be

TABLE G-4. Examples of Pathogenic Diseases Associated with Major Economic Arthropod Pests[34]

Arthropod Pest Complex	Pathogen Genus
	Forest, Ornamental and Shade Trees
Gypsy-Tussock moth, webworm-budworm	Aspergillus, Nosema, Thelohania, Bacillus, NPV, CPV GV
Tent caterpillars	Beauveria, Nosema, Thelohania, Clostridium, Bacillus, NPV
Sawflies	Beauvería, Entomophthora, Spicaría, Plistophora, Bacillus, NPV, CPV, GV
Scolytid-beetles	Beauveria, Metarrhizium, Spicaria, Brevibacterium, Flavobacterium, Nosema
	Fruits, Vegetables and Truck Crops
Aphids-plant bugs	Beauveria, Entomophthora, Acrostalagmus, Fusarium, Aspergillus, Pseudomonas, Vibrio
Citrus scale-mites	Beauveria, Aeschersonia, Cordyceps, Entomophthora, Fusarium, Hirsutella, Cephalosporium, Bacillus, NIV
Cutworms-cabbageworms	Beauveria, Entomophthora, Spicaria, Nosema, Mattesia, Serratia, Bacillus, Pseudomonas, NPV, CPV, GV
Grasshoppers-crickets	Entomophthora, Malameba, Aerobacter, Pseudomonas, Serratia, Rickettsiella, NPV, NIV
Leafrollers-codling moth-budworms	Beauveria, Metarrhizium, Aspergillus, Plistophora, Bacillus, NPV, CPV, GV
Wireworms-grubs-chrysomelid beetles	Beauveria, Metarrhizium, Sorosporella, Cordyceps, Bacillus, Clostridium, Streptococcus, Serratia, Rickettsiella, Enterella
	Grain, Grasses, Forage and Fiber Crops
Armyworms-leafworms	Entomophthora, Spicaria, Nosema, Bacillus, NPV, CPV, GV, NIV
Bollworms-Budworms	Beauveria, Spicaria, Nosema, Mattesia, Plistophora, Bacillus, Serratia, NPV CPV, GV
Boll-alfalfa-clover weevils	Beauveria, Hirsutella, Mattesia, Plistophora, Glugea, Bacillus, NIV
Stem-stalk borers	Beauveria, Aspergillus, Plistophora, Thelohania, Perezzia, Nosema, NPV, NIV

TABLE G-4 (Continued)

Arthropod Pest Complex	Pathogen Genus
Household, Stored Products, Man and Domesticated Animals	
Cattle grubs-flies	Entomophthora, Bacillus
Clothes moth	Nosema, Bacillus, NPV, CPV
Cockroaches-termites	Entomophthora, Serratia
Lice-mites	Aspergillus, Bacillus
Mosquitoes-midges-gnats	Entomophthora, Aspergillus, Coelomomyces, Thelohania, Plistophora, Nosema, Bacillus, Enterella, NPV
Stored products beetles	Nosema, Adelina, Mattesia, Farinocystis, Ophyocystis, Bacillus
Stored products caterpillars	Nosema, Mattesia, Bacillus, NPV, CPV, GV

Source: Ignoffo, C. M. (Modified).

TABLE G-5. Selected Examples of Arthropod Pathogens Used Successfully to Control Arthropod Pests [34]

Pathogen	Pest Species
Viruses	
Nuclear polyhedrosis	Bollworm-budworm complex
	European spruce sawfly
	Alfalfa caterpillar
	Cabbage looper
Cytoplasmic polyhedrosis	Pine processionary worm
Granulosis	Cabbageworm
	Spruce budworm
	Red-banded leaf roller
	Codling moth
Non-Inclusion	Citrus mite
Bacteria	
Bacillus popilliae	Japanese beetle
Bacillus thuringiensis	Many caterpillar spp.
Coccobacillus acridiorum	Grasshoppers
Serratia marcescens	Termites
Protozoa	
Thelohania hyphantriae	Fall webworm
Mattesia grandis	Boll weevil
Malameba locustiae	Grasshoppers
Fungi	
Entomophthora spp.	Brown-tailed moth
	Spotted alfalfa aphid
Beauveria spp.	Chinch bug
	Colorado potato beetle
Metarrhizium anisopliae	Corn borer
	Sugar beet curculio
	Froghopper
Aeschersonia spp.	White fly and Scale insects

Source: Ignoffo, C. M. (Modified).

TABLE G-6. Arthropod Pathogens Commercially or Experimentally Produced by Commercial Firms for Use as Microbial Insecticides.[34]

Disease Organism	Product Names[a]	Susceptible Pests
	Commercially Produced	
Bacillus popilliae	Doom, Japidemic	Japanese beetle, Scarabaeids
Bacillus thuringiensis	Agritrol, Amdol-6000, Bakthane L-69, Bactospeine, Bathurin, Biospor 2802, Biotrol BTB, Dendrobacilin, Entobakterin-3, Parasporin, Sporeine, Thuricide, Tribactur	Alfalfa caterpillar, Artichoke plume moth, Bagworm, Cabbage looper, Diamondback moth, Fruit-tree leaf roller, Grape leaf folder, Gypsy moth, Imported cabbageworm, Lawn moth, Linden looper, Oak moth, Orange dog, Rindworm complex, Saltmarsh caterpillar, Spring-Fall cankerworm, Tent caterpillar, Tobacco budworm, Tobacco budworm, Tobacco and tomato hornworm, Webworm complex, Winter moth
Heliothis NPV	Virex	Corn earworm, Cotton bollworm, Tobacco budworm, Tomato fruitworm
Trichoplusia NPV	Cabbage looper virus	Cabbage looper
Neodiprion NPV	Polyvirocide	Pine sawfly
	Experimentally Produced	
Bacillus sphaericus	IMC,B. sphaericus	Aquatic diptera, i.e., mosquitoes, midges, simulids
Beauveria bassiana	Biotrol FBB, IMC-B. bassiana	Alfalfa weevil, Cockroach, Codling moth, Coconut zygaenid, Colorado potato beetle, Cutworm, European corn borer, Grasshoppers, Horsefly, Japanese beetle, Larch sawfly, Stored products beetles, Websorms
Metarrhizium anisopliae	IMC,+M. anisopliae	Corn borer, Cutworm Frog hopper, Leafhopper, Rhinoceros beetle, Sugar beet curculio, Sugarcane-borer, Wheat cockchafer
Nuclear Polyhedrosis Virus Heliothis	Biotrol VHZ:VIRON/H	Corn earworm, Cotton bollworm, Tobacco budworm, Tomato fruitworm

TABLE G-6 (Continued)

Disease Organism	Product Names	Susceptible Pests
Prodenia	Biotrol VPO, VIRON/P	Cotton leafworm; Pacific, Southern, and Yellow-striped armyworm
Spodoptera	VIRON/S	Beet armyworm, Fall armyworm
Trichoplusia	Biotrol VTN; VIRON/T	Cabbage looper

[a] Only Doom, Japidemic, Biotrol BTB, and Thuricide are currently commercially available in U. S.

Source: Ignoffo, C. M. (Modified).

little likelihood, however, that microorganisms naturally pathogenic to insects could cause serious injury to animals or plants.

- A microbial insecticide can be used against one species only. Mixed formulations have not yet been widely tested.

- Of considerable importance is the effect that pathogenic microorganisms may have upon the insect parasites and predators of a pest. Only a few observations have been made, but enough has been learned to suggest that close attention must be paid to this relationship whenever the artificial dissemination of microorganisms is contemplated. Sometimes the insect parasites and the disease are related in a complementary or supplementary fashion. This has been observed in alfalfa fields infested with caterpillars of the alfalfa butterfly (*Colias*). In fields where the polyhedral wilt disease is present but not abundant among the caterpillars, the smaller larvae may be parasitized by *Apanteles* while the larger larvae may be killed by the polyhedral wilt disease.[30]

Herbicides have been used to control aquatic weeds. Aquatic weeds obstruct water flow, increase evaporation and induce large losses of water through transpiration. The management of aquatic vegetation has been revitalized recently because of increased demand on our fresh waters. Major aquatic weeds in the U. S. are water hyacinth, *Eichhornia crassipes*, water fern, *Salvinia auriculata*, water lettuce, *Pistia stratiotes*; submersed weeds belonging to genera, *Scipus*, *Typha*, *Nymphaea*, *Saggitaria*, and *Alternanthera*.[35, 36]

The demand for a clean environment is bringing close public and legislative scrutiny of all pesticides with the likely result of curtailment of certain herbicides that are used in aquatic weed control. This is forcing many state and federal research agencies to search for alternate methods. Mechanical methods are costly, usually temporary in effect, and difficult to employ in canals. Biological control offers a potential means of control over extensive areas where the cost of chemical or mechanical practices would be prohibitive.

To date, biological control of weeds has been accomplished mainly by insects; but use of mites, snails, pathogenic microorganisms, fish, ducks and geese, manatees, and parasitic higher plants are under investigation.[35] Caution is necessary for thorough screening of all animals which are introduced for control of weeds. In the absence of their preferred food there is danger in their becoming pests of alternate plant types. This caution is less necessary for agents introduced for insect control.

a. Biological Control of Red Scale and and Purple Scale in Florida

Florida red scale, Chrysomphalus anoidum (l.) and purple scale, Lepidosaphes beckii (Newman), were until recently the two most important armored scales on citrus. Control of purple scale by the introduction of the parasite Aphytis lepidosaphes has been reported.[37] Hymenopterous parasites represent the critical control factors for the Florida red scale. Pseudhomalopoda prima, the parasite attacking mature female red scale, is highly important. The most important parasite species appear to be Aspidiotiphagus lounsburyi and Phospaltella aurantii which attack male and second-stage female scales.[38] A special survey of Florida red scale and parasites was made between February and June 1967 in 104 groves. Parasites were identified as being either P. prima or A. holoxanthus. Parasitism by A. holoxanthus was very high. This parasite, which was introduced from California in 1960, appears to have much greater ability to survive adverse weather conditions than P. prima.[39, 40] Partial to complete control has been achieved using these parasites in most areas in Florida.

b. Biological Control of Cotton Bollworm and Tobacco Budworm in Mississippi

Several species of parasitic insects were reared from field collected larvae of the bollworm, Heliothis zea (Boddie); and the tobacco budworm, H. virescens (F.), in Mississippi.[41] The parasites belong to the families Braconidae, Ichmeumonidae, and Tachinidae. The predominant species were two Braconids, Microplitis croceipes and Cardiochiles nigriceps. Parasites provided a high percent of control on cranesbill, tomato, and spider flower. Observations were also reported on the effectiveness of Cardiochiles nigriceps in controlling H. virescens on tobacco in areas of Florida and Georgia.[42]

c. Control of Pea Aphid by Aphidius smithi in Kentucky

Since 1962, Aphidius smithi was found to be parasitizing increasingly large numbers of the pea aphid, Acyrthosiphon pisum, in clover and alfalfa fields in Kentucky.[43] In a 6-hour parasitization period, 60 pea aphids parasitization by Aphidius smithi was highest (82 percent average) with first-instar aphids, and lowest (0 percent) with post reproductive aphids. Such differences in degree of parasitization were not found in mixed groups of various instars. Progeny production by pea aphid ceased after the fourth day if they were parasitized on the first day of parturition (birth). A. pisum parasitized in the third instar did not mature to the reproductive state. This parasite was propagated and widely released in California and has since become an important factor in the control of pea aphid in that area.

d. Introduced Wasps for the Control of Gypsy Moth in Alabama

Twenty-thousand tiny parasitic wasps were released in 1971 in Russell County, Alabama, in an effort to prevent the spread of the gypsy moth, the world's most serious forest pest.[44] These moths were recently reported in Alabama. The wasps which are completely harmless to people, were shipped from New York, but are native to the Mediterranean countries. The wasps seek out egg masses of the moth and lay their eggs in the moth eggs. When the wasp eggs hatch, the larvae feed on the eggs of the moth and destroy them. In this case a biological agent prevents the establishment of this pest.

e. Field Control of the Nantucket Pine Tip Moth by the Nematode DD-136 in South Carolina

Field investigations have demonstrated that the nematode DD-136 will kill Nantucket pine tip moth, Rhyacionia frustrana, larvae under natural conditions.[45] More first-generation tip moth larvae were killed than secord or third generations. Nematode suspensions were aided in effectiveness by addition of 10 percent glycerin and to a lesser degree by addition of wetting agents or spreader-sticker, namely 2 percent solution of Emgard 2050, Sole-Onic CDS, and Igepon AO-78.[45] DD-136 did not provide sufficient control of the moth to recommend its use. This case suggests that biological agents cannot be successfully employed in all situations.

f. Heliothis Control with Virus

Virus, Viron/H^{TM}, attacks only species of the genus Heliothis virescens of which there are two major economic pests. One is H. virescens, the tobacco budworm and the other is H. zea commonly known as cotton bollworm. This virus has performed equal to or better than commonly used chemical insecticides in 80 to 90 percent of the cases. Its greatest advantages lie in the fact that it is completely specific and is absolutely safe and non-toxic. This virus is reasonably compatible with some chemical insecticides. These can be sprayed in mixtures as long as the pH of the solution is neutral. The formulated form contains 126 billion inclusion bodies per ounce and a quart will control the bollworms on 10 acres of cotton with a light to moderate infestation. The application of this virus in practically every cotton-growing state was permitted by the Food and Drug Administration (FDA) in 1970.[32]

g. Integration of the Heliothis Nuclear Polyhedrosis Virus into a Biological Control Program on Control in Mississippi

A biological control program for the control of bollworm, *H. zea*, and tobacco budworm, *H. virescens*, was integrated into an over-wintering boll-weevil control program on cotton in the Mississippi Delta in 1965.[46] The Heliothis program was designed to utilize biological control measures whereby chemical control would not be required during the growing season. The factors utilized in the Heliothis biological program consisted of the naturally occurring predator-parasite complex and the application of the nuclear polyhedrosis virus. Heliothis control with biological agents was compared with a toxaphene-DDT-methyl parathion control program using 25 to 30 acre plots. The virus was applied at 1.2×10^{11} (20 LU, Larval Units), 3.0×10^{11} (50 LU), and 6.0×10^{11} (100 LU) polyhedral inclusion bodies per acre. The initiation of virus applications was varied to evaluate the effectiveness of the virus against various ages of larvae. The Heliothis biological control program compared favorably with the insecticide program when virus application was initiated to coincide with hatch of egg populations.

h. Two-Spotted Spider Mite Control with Fungus in Alabama

A study was conducted in Alabama in 1968 to determine the importance of *Entomophthora* sp. as a natural control factor for field populations of the two-spotted spider mite, Tetranychus urticae Koch. Studies on the distribution of this fungus revealed its presence in 14 of the 15 counties where collections were made. Average infection rate by this fungus was 25 percent.[47] Five epizootics of the pathogenic fungus were observed in two-spotted spider mite populations in Lee County, Alabama. Each epizootic was characterized by a high degree of infection by Entomophthora sp. accompanied by a rapid decline in mite numbers. This was a preliminary study and no final conclusions can be drawn. Further research work is needed.

i. Control of Aquatic Weeds by the Snail in Florida

Experiments were conducted in the state of Florida in 200-gallon concrete tanks to evaluate the effectiveness of large fresh-water snails, Marisa cornuarietis, as a biological aquatic weed control agent. The snails controlled Ceratophyllum demersum, Najas guadalupensis, and Potamogeton illineonsis completely and Pistia stratiotes and Alternanthera philoxeroides partially. Marisa preferred submersed weeds to floating weeds. Little damage was done by Marisa to 4 and 5 week-old rice plants, but younger rice was killed when the snails had no other source of food.[48] Except for its possible deletarious effects in rice-growing areas, Marisa was regarded as very promising within Florida for the control of aquatic weeds at least in confined bodies of water.[49]

j. Biological Control of Alligatorweed with Flea Beetle in Southeastern States

Alligatorweed, Alternanthera philoxeroides, is an extremely prolific plant which is most difficult to control and even more difficult to kill. It does not pose a serious weed problem in South America, where 40 to 50 species of insects act as suppressing biotic agents.

Only one of these insects was known to occur in the United States and this insect, a flea beetle, belongs to genus Agasicles. During the fall of 1965 and spring of 1966, over 9,000 beetles were transferred to selected and approved locations throughout Florida, Georgia, South Carolina, and Mississippi.[50] Frequent observations were made in the vicinity of the release sites and at no time was there any evidence that the beetle fed on any plant other than alligatorweed. The beetles prefer the alligatorweed that is growing in the water. The results look very promising and should be extended to pilot studies on larger areas.[50]

k. Control of Pond Weeds by the Use of Herbivorous Fish

The possible use of herbivorous fish has received little attention in the United States. Common carp, Cyprinus carpie, may control some aquatic plants by keeping the water muddy and to a lesser degree by rooting out plants. In China, Japan, Israel, and Thailand; the grass carp, Ctenopharyngodon idellus, has been used successfully for the control of rooted aquatics.[36]

Species of fish that feed upon aquatic weeds and appear promising in Alabama are listed in Table G-7. Since 1957 eight species of fish have been field tested for effectiveness in aquatic weed control in Alabama. The Congo tilapia, Tilapia melanopleura; grass carp, Ctenopharyngodon idellus; and the Israeli carp, Cyprinus carpio have shown the best potential for weed control. In ponds, Congo tilapia, when stocked at rates of approximately 1,500 to 1,000 per acre, controlled in three months Pithophora sp., giant Spirogyra, E. acicularis, E. densa, Hydrochloa sp., U. biflora, and Rhizoclonium sp. Grass carp controlled Chara sp., P. oviersi folius and E. acicularis in one month when stocked at a rate of 20 to 40 per acre. Six to 9-inch Israeli carp, when stocked at rates of 25 to 50 per acre, were effective in reducing or eliminating

TABLE G-7 Species of fishes feeding upon filamentous algae and rooted aquatics that appear of promise in the biological control of pond weeds in Alabama.[35]

Common name	Scientific name	Feeding upon Filamentous algae	Feeding upon Rooted aquatics
Common carp	*Cyprinis carpio* (Lin.)	x	x
Grass carp	*Ctenopharyagodon idellus* (C. and V.)		x
Golden carp	*Carassium carassius* (Lin.)	x	
Goldfish	*Carassius auratus* Lin.	x	
Tawes	*Puntius javanicus* (Bleeker)	x	x
Nilem	*Osteochilus hasselti* (C. and V.)		x
Tilapia	*Tilapia mossambica* Peters	x	x
Tilapia	*Tilapia melanopleura* (Dum.)		x
Gourami	*Osphronemus goramy* (Lac.)		x
Sepat Siam	*Trichogaster pectoralis* (Regan)		x
Milkfish	*Chanos chanos* (Forskal)	x	x

Source: Swingle, H. S.

Pithophora sp., Rhizoclonium sp., and E. acicularis but in some ponds required 2 to 3 years to effect control.[51]

The species of fish receiving most of the attention in Georgia are: Tilapia nilotica, Tilapia mossambica, T. melanopleura, Cyprinus carpio, and Ctenopharyngodon idellus. All observations on Chinese or grass carp, C. idellus, are most favorable.[52] In the spring of 1967, 2,000 grass carp were stocked in a 20-acre pond in Georgia that had a 5-year history of excessive growths of Najas, and Potamogeton. Within 6 weeks, grass carp was able to consume most of the rooted aquatic vegetation.

Table G-8 contains a list of insect parasites and predators successfully colonized in the Continental United States.[53] Many of the pests listed in the table are also of economic importance in the southeastern part of the United States.

Many of the economic pests in the United States have come from other countries without their biological parasites or predators. Through lack of biological agents and abundance of food in agro-ecosystems some of these pests have themselves become important problems. Importation and release of biological agents have shown promise as control programs. Considerable success has also been achieved by the use of pest pathogens (bacteria and virus) in controlling economic pests.

Table G-8 Insect Pest and their Parasites and Predators Successfully Colonized in Continental United States [53]

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FRUIT INSECTS	
Aphids, several species, Family Aphidae (see Field and Garden Insects)	Florida citrus and papaya areas	Leis dimidiata 15-spilota (Hope)
Apple mealybug, Phenacoccus aceris (Signoret)	Oregon, and Maine to Vermont	Allotropa utilis Mues.
Black scale, Saissetia oleae (Bern.)	California	Aphycus helvolus Comp. Aphycus lounsburyi How. Aphycus stanleyi (Comp.) Coccophagus capensis Comp. Coccophagus cowperi Gir. Coccophagus pulvinariae Comp. Coccophagus rusti Comp. Coccophagus trifasciatus Comp. Diversinervus elegans Silv. Lecaniobius utilis Comp. Quaylea whittieri (Gir.) Rhizobius debilis Blackb. Rhizobius ventralis (Er.) Scutellista cyanea Mots.
California red scale, Aonidiella aurantii (Mask.)	Chiefly California, Arizona, and Texas	Aphytis lingnanensis Comp. Aphytis melinus DeBach Chilocorus kuwanae Silv. Comperiella fasciata How. (red scale strain) Cybocephalus sp. Habrolepis rouxi Comp. Lindorus lophantae (Blaisd.) Orcus chalybeus (Boisd.) Prospaltella perniciosi Tower (red scale strain)
Citrophilus mealybug, Pseudococcus gahani Green (see Tree and Shrub Insects)	California	Cleodiplosis koebelei (Felt) Coccophagus gurneyi Comp. Scymnus binaevatus (Muls.) Tetracnemus pretiosus Timb.
Citrus mealybug, Pseudococcus citri (Risso) (See Tree and Shrub Insects)	California and Florida	Allotropa citri Mues. Cryptolaemus montrouzieri Muls. Leptomastidea abnormis (Gir.) Pauridia peregrina Timb.

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FRUIT INSECTS.--Continued.	
Coconut scale, *Aspidiotus destructor* Sign.	Florida	*Azya trinitatis* Mshll. *Cryptognatha nodiceps* Mshll.
Comstock mealybug, *Pseudococcus comstocki* (Kuw.)	Eastern apple regions	*Allotropa burrelli* Mues. *Pseudaphycus malinus* Gahan
Cottony-cushion scale, *Icerya purchasi* Mask.	California, Arizona, and Southeastern seaboard	*Cryptochaetum iceryae* (Will.) *Rodolia cardinalis* (Muls.)
Florida red scale, *Chrysomphalus aonidum* (L.)	Florida, Mississippi, Louisiana, California	*Aphytis holoxanthus* DeBach
Gypsy moth, *Porthetria dispar* (L.) (see Tree and Shrub Insects)	New England, New York, New Jersey and Pennsylvania	*Anastatus disparis* Ruschka *Apanteles melanoscelus* (Ratz.) *Blepharipa scutellata* R.-D. *Calosoma sycophanta* (L.) *Carabus auratus* L. *Compsilura concinnata* (Meig.) *Exorista larvarum* (L.) *Monodontomerus aereus* Wlkr. *Ooencyrtus kuwanai* (How.) *Parasetigena agilis* (R.-D.) *Phobocampe disparis* (Vier.)
Japanese beetle, *Popillia japonica* Newm. (See Field and Garden Insects and Tree and Shrub Insects)	The East	*Dexilla ventralis* (Ald.) *Hyperecteina aldrichi* Mesnil *Prosena siberita* (F.) *Tiphia popilliavora* Roh. *Tiphia vernalis* Roh.
Long-tailed mealybug, *Pseudococcus adonidum* (L.) (See Tree and Shrub Insects)	California	*Anagyrus fusciventris* (Gir.) *Anarhopus sydeyensis* Timb. *Tetracnemus peregrinus* Comp.
Olive scale, *Parlatoria oleae* (Colvée) (See Tree and Shrub Insects)	California and Maryland	*Aphytis maculicornis* (Masi) (Egyptian strain) (Indian strain) (Persian strain) (Spanish strain) *Aspidiotiphagus* sp. *Chilocorus bipustulatus* (L.)

TABLE G-8 (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FRUIT INSECTS.--Continued.	
Oriental fruit moth, Grapholitha molesta (Busck)	The East California, and scattered elsewhere	Agathis diversa (Mues.) Agathis festiva Mues.
Pineapple mealybug, Pseudococcus brevipes (Ckll.)	South Florida and Hawaii	Hambletonia pseudococcina Comp.
Purple scale, Lepidosaphes beckii (Newm.)	California, Florida to Texas	Aphytis lepidosaphes Comp. Physcus fulvus C. & A.
Scales, several species, Family Coccidae (see Tree and Shrub Insects)	General in fruit areas	Chilocorus sp. near distigma (Klug) Exochomus quadripustulatus (L.)
Walnut aphid, Chromaphis juglandicola (Kalt.) (see Tree and Shrub Insects)	Pacific Coast States, Utah and Idaho	Trioxys pallidus Hal.
Western grape leaf skeletonizer, Harrisina brillians B. & McD.	Southwest, Utah Colorado	Apanteles harrisinae Mues. Sturmia harrisinae Coq.
Woolly apple aphid Eriosoma lanigerum (Hausm.)	General	Aphelinus mali (Hald.) Exochomus quadripustulatus (L.)
Yellow scale, Aonidiella citrina (Coq.)	California, Texas and Florida	Comperiella bifasciata How
	FIELD AND GARDEN INSECTS	
Alfalfa weevil, Hypera postica (Gyll.)	General	Anaphes pratensis (Foerst.) Bathyplectes curculionis (Thoms.) Microtonus aethiops (Nees.) Tetrastichus incertus Ratz.
Aphids, several species, Family Aphidae (see Fruit Insects)	General	
Asiatic garden beetle, Maladera castanea (Arrow)	The East	Tiphia asericae A. & J.
Clover leaf weevil Hypera punctata (F.)	General	Biolysia tristis (Grav.)

TABLE G-8 (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	FIELD AND GARDEN INSECTS.--Continued	
European corn borer, <u>Ostrinia nubilalis</u> (Hbn.)	The East and the Midwest	<u>Chelonus annulipes</u> Wesm. <u>Horogenes punctorius</u> (Roman) <u>Lydella thompsoni</u> Herting <u>Macrocentrus gifuensis</u> Ashm. <u>Phaeogenes nigridens</u> Wesm. <u>Sympiesis viridula</u> (Thoms.)
European wheat stem sawfly, <u>Cephus pygmaeus</u> (L.)	Eastern wheat areas and North Dakota	<u>Collyria calcitrator</u> (Grav.)
Greenbug, <u>Schizaphis graminum</u> (Rondani)	General	<u>Aphidus testaceipes</u> (Cresson) <u>Hippodamia convergens</u> Guer.
Hessian fly, <u>Phytophaga destructor</u> (Say)	All small-grain areas	<u>Pedobius metalicus</u> (Nees)
Imported cabbageworm, <u>Pieris rapae</u> (L.)	General	<u>Apanteles glomeratus</u> (L.)
Japanese beetle, <u>Popillia japonica</u> Newm. (see Fruit Insects and Tree and Shrub Insects)	The East	
Pea aphid, <u>Acyrthosiphon pisum</u> (Harris)	General	<u>Aphidus smithi</u> S. & A. <u>Hippodamia convergens</u> Guer.
Rhodes grass scale, <u>Antonina graminis</u> (Mask.)	Gulf States, New Mexico, Arizona and California	<u>Anagyrus antoninae</u> Timb. <u>Dusmetia sangwani</u> Rao
Spotted alfalfa aphid, <u>Therioaphis maculata</u> (Buckton)	General	<u>Aphelinus semiflavus</u> How. <u>Praon palitans</u> Mues.
Sugarcane borer, <u>Diatraea saccharalis</u> (F.)	Gulf States	<u>Agathis stigmatera</u> (Cress.) <u>Lixophaga diatraeae</u> (Tns.) <u>Paratheresia claripalpis</u> (V.d.W.)
Yellow clover aphid, <u>Therioaphis trifolii</u> (Monell)	The East	<u>Trioxys utilis</u> Mues.

TABLE G-8 (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	TREE AND SHRUB INSECTS	
Balsam woolly aphid, Chermes piceae Ratz.	East and West Coasts	Aphidoletes thompsoni Mohn. Cremifania nigrocellulata Cz. Laricobius erichsonii Rosen. Leucopis obscura Hal. Scymnus impexus Muls.
Barnacle scale, Ceroplastes cirripediformis Comst.	Southern coastal areas, California, and Hawaii	Scutellista cyanea Mots.
Birch leaf-mining sawfly, Heterarthrus nemoratus (Fall.)	Northern New England	Chrysocharis laricinellae (Ratz.) Phanomeris phyllotomae Mues.
Browntail moth, Nygmia phaeorrhoea (Donov.)	New England	Apanteles lacteicolor Vier Carabus auratus L. Carcelia laxifrons Vill. Eupteromalus nidulans (Thoms.)
Browntail moth,--Cont. Nygmia phaeorrhoea (Donov.)	New England	Exorista larvarum (L.) Meteorus versicolor (Wesm.) Monodontomerus aereus Wlkr. Townsendicellomyia nidicola (Tns.)
Citrophilus mealybug, Pseudococcus gahani Green (see Fruit Insects)	California	
Citrus mealybug, Pseudococcus citri (Risso) (see Fruit Insects)	California	
Elm leaf beetle, Galerucella xanthomelaena (Schr.)	Pacific States and the East	Erynniopsis rondanii Tns. Tetrastichus brevistigma Gahan
European earwig, Forficula auricularia L. (also general-nuisance pest)	Eastern Seaboard and the West	Bigonicheta spihipennis (Meigen)
European elm scale, Gossyparia spuria (Mod.)	The East and California	Coccophagus insidiator (Dalm.)
European pine sawfly, Neodiprion sertifer (Geoff.)	New England, New Jersey	Pleoplophus basizonius (Grav.) Dahlbominus fuscipennis (Zett.) Exenterus abruptorius (Thnb.)

TABLE G-8 (Continued)

PEST	WHERE FOUND	PARASITE OR PREDATOR
	TREE AND SHRUB INSECTS.--Continued	
European pine shoot moth, Rhyacionia buoliana (Schiff.)	Northeast, North Central States, and Washington	Temelucha interruptor Grav. Orgilus obscurator (Nees) Tetrastichus turionum (Htg.)
European spruce sawfly, Diprion hercyniae (Htg.)	Upper New England	Dahlbominus fuscipennis (Zett.)
Gypsy moth, Porthetria dispar (L.) (see Fruit Insects)	New England, New York, New Jersey, and Pennsylvania	
Japanese beetle, Popillia japonica Newm. (see Fruit Insects and Field and Garden Insects)	The East	
Larch casebearer, Colephora laricella (Hbn.)	Eastern half of U.S.	Agathis pumila (Ratz.) Chrysocharis laricinellae (Ratz)
Long-tailed mealybug, Pseudococcus adonidum (L.) (see Fruit Insects)	Citrus-growing areas	
Nigra scale, Saissetia nigra (Nietn.)	California	Aphycus helvolus Comp.
Olive scale, Parlatoria oleae (Colvée) (See Fruit Insects)	California	
Oriental moth, Cnidocampa flavescens (Wlkr.)	Massachusetts	Chaetexorista javana B. & B.
Satin moth, Stilpnotia salicis (L.)	New England Washington, and Oregon	Apanteles solitarius (Ratz.) Meteorus versicolor (Wesm.)
Walnut aphid, Chromaphis juglandicola (Kalt.) (see Fruit Insects)	Pacific Coast States, Utah, and Idaho	

Source: Agricultural Research Service, U.S.D.A. (Modified).

6. Sterility Approach to Insect Control

The use of insect sterilization to control and eradicate pest populations is one of the revolutionary departures of modern entomology.[54-57] There are two ways by which the sterility principle might be used to help control or eradicate insects. One involves rearing, sterilization and release into the natural population so that the sterile members will compete with normal ones and thus lower the reproduction rate. Early experiments in sterilizing insects employed x-rays, but the first attempts at sterilizing insects as a control measure utilized irradiation with gamma rays from a cobalt-60 source. A theoretical model involving such a release procedure is given in Table G-9. It is assumed that the natural population exists in an isolated area containing a stable population of 2 million insects with a 1:1 ratio of males to females in equilibrium with the environment and with the biotic potential canceled out by environmental resistance. Each generation, 2 million sterile males would be released in this area to compete equally for mates. By the fourth generation, the ratio of sterile to fertile males competing for each virgin female would be 1, 807 to 1; with equal competition 99.95% of these matings would be sterile.[54]

The other method is to treat and sterilize insects in the natural population to reduce reproduction. The chemical compounds which reduce or entirely eliminate the reproductive capacity are called chemosterilants. Chemosterilants may affect only one sex (male sterilants, female sterilant) or both sexes (male-female sterilants). United States Department of Agriculture entomologists and chemists have screened 3, 000 materials and have found that at least 50 of them produce sterility in insects. Apholate and Aphoxide are among the most active chemosterilants currently under

Table G-9 Theoretical Population Decline in Each Subsequent Generation When a Constant Number of Sterile Males Are Released Among a Natural Population of 1 Million Females and 1 Million Males[54]

Generation	Number of virgin females in the area	Number of sterile males released each generation	Ratio of sterile to fertile males competing for each virgin female	Percentage of females mated to sterile males	Theoretical population of fertile females each subsequent generation
F1	1,000,000	2,000,000	2 : 1	66.7	333,333
F2	333,333	2,000,000	6 : 1	85.7	47,619
F3	47,619	2,000,000	42 : 1	97.7	1,107
F4	1,107	2,000,000	1,807 : 1	99.95	Less than 1

Source: Knipling, E. F.

investigation.[55] When administered orally or by contact these compounds produce irreversible sterility without apparent adverse effects on the mating behavior and length of life of the insects.

Insects on which sterility information is available[57] and which are ready for field testing are listed in Table G-10.

a. Eradication Program of the Screw Worm Fly in the Southeastern States

Screw worms were brought to the vanishing point by the release of 100 sterile males per square mile per week on Sanibel Island near Fort Myers, Florida, but eradication could not be proved because the test area was not sufficiently isolated to prevent immigration of a few fertilized females from nearby untreated areas. The other experiment was performed on the island of Curacao[56] where eradication was achieved on that isolated 170 square mile island. The apparent eradication of the screw worms from Curacao supported the theory that screw worms could be eradicated from the southeastern states by by releasing sterilized flies. In July 1958, a huge sterilized fly production facility was completed at Sebring, Florida. This establishment produced 50 million sterilized flies per week, which were distributed over all infested areas in the Southeast (Florida, Georgia, Alabama, Mississippi, South Carolina, North Carolina). By 1958, the screw-worm had been eliminated from the Southeastern states, the major part of the Continental United States in which this pest can overwinter, and no infestations of screw worms have since occurred.[58]

The screw worms were irradicated with gamma-rays using a cobalt 60 source.[59] The 7500 roentgens dose was adopted as standard for eradication programs. In laboratory experiments, the radiation-induced sterility was permanent and the sterilized males were competitive with normal males in cage-mating experiments.

TABLE G-10 Insects on which sterility information is available and which are ready for field testing.[57]

Scientific Name	Common Name
Anastrepha ludens (Loew)	Mexican fruit fly
Ceratitis capitata (Wied)	Mediterranean fruit fly
Dacus cucurbitae Coq.	Melon fly
Dacus dorsalis (Hendel)	Oriental fruit fly
Anastrepha suspensa	Carribean fruit fly
Anastrepha fraterculus Wied.	South American fruit fly
Dacus tryoni (Froyg.)	Queensland fruit fly
Drosophila spp.	Vinegar flies
Dacus oleae (Gmelin)	Olive fly
Glossina morsitans (Westwood)	Tsetse fly
Glossina austeni (Newstead)	Tsetse fly
Hylemya antiqua (Meig)	Onion fly
Aedes aegypti	Yellow fever mosquito
Aedes scutellaris	Vector of filariasis (mosquito)
Culex pipiens fatigans Wied.	Vector of filariasis (mosquito)
Anopheles gambiae	Vector of malaris (mosquito)
Dermatobia hominis (Linnaeus)	Torsalo, human bot fly
Haematobia irritans (Linnaeus)	Hornfly
Musca domestica (Linnaeus)	House fly
Authonomus grandis (Bol.)	Boll weevil
Oryctes rhinoceros L.	Rhinoceros beetle
Acanthoscelides obtectus Say	Bean weevil
Melolontha vulgaris F.	Cockchafer
Carpocapsa pomonella L.	Codling moth
Diatraea saccharalis (F.)	Sugar cane borer
Leucoptera coffeella	Coffee leaf miner
Heliothio virescens (F.)	Tobacco budworm
Heliothio zeae (Boddie)	Cotton bollworm
Chilo suppressalis Walker	Rice-stem borer
Pectinophera gonypiella (Saunders)	Pink bollworm
Dysdercus peruvianus C.	Cotton red stainer
Popillia japonica (Newm.)	Japanese beetle
Protoparce sexta (Ich.)	Hornworm
Trichoplusia ni	Cabbage looper

Source: International Atomic Energy Agency (Modified).

Further applications of the same techniques are now being tried with other pests. These are being combined with chemosterilants and genetic male sterile forms.

b. Eradication of the Cotton Bollworm From St. Croix, U. S. Virgin Islands

Eradication of the cotton bollworm, Heliothis zea (Boddie), from St. Croix, U. S. Virgin Islands, was attempted in 1968 and 1969, using the sterile-male release method.[60] Although both attempts failed in the primary objective of eradicating the species, the reasons were the high ratios of sterile to natural males which caused the elimination of oviposition, and high degree of locking between the released population and the native females.

c. *Eradication of Cotton Boll Weevil in the Southeast*

A truly effective chemosterilant for the boll weevil has not yet been discovered. Some of the aziridinyl compounds, particularly apholate, induce a rather high degree of sterility in the males, but the mortality of treated insects is high and their competitiveness is reduced.[61] During 1962, Apholate sterilized male boll weevils Anthonomus grandis, normal males and virgin untreated females were released in three experimental one acre plots of cotton in Virginia, Tennessee, and Louisiana in the ratio of 20:1:1 in each of five uniformly distributed points. A total of 8, 850 sterile males released over an eight week period, prevented matings between the ensuing F_1, males and females. On the seventeenth week of the experiment, no egg or feeding punctures were found in two examinations of all the squares and bolls on plants in the field. Only in the Louisiana experiment was eradication of the population achieved.[62] The successful eradication in 1962 of an artificially induced infestation of boll weevils prompted further studies. From June 17 through August 26, 1964, eleven weekly releases of apholate sterilized male boll weevils were made in nine cotton fields that had been treated with insecticides in the fall of 1963, to reduce the population of diapausing weevils. An average of 8, 200 males were released per acre. This was done in Baldwin County, east of Mobile, Alabama. This release program reduced the number of oviposition punctured squares. Also, the percentage of infertile eggs, the number of live immature and adult weevils per acre in fruit, numbers of over-wintered adults and the levels of infestation during the second year were considerably lower in the release zone than in the zone treated intensively with insecticides.

Effectiveness of apholate in decreasing the sperm viability of the male boll weevil was determined[63] in Mississippi by allowing the weevils to feed on a diet containing from 0.001 to 0.020 percent of the chemosterilant and on plants sprayed with 0.5 and 2.5 percent solutions. After both treatments, virgin females mated to treated males oviposited eggs with decreased hatchability and emergence of the F_1, progeny. At the higher levels of treatment, longevity of males was reduced. Repeated spray applications of the chemosterilant to plants, especially at the higher levels, caused phytotoxicity manifested by leaf necrosis, stunting of growth and cessation of square production. The male boll weevil can also be sterilized with TEPA, either by feeding 1, 500 ppm in the diet for two days or by an injection of 3.5 mg.[64] Lower levels of TEPA produced transitory sterilization. At the effective levels, mortality was significant.

d. Control of House Flies with Chemosterilant Baits in Florida

Three compounds, aphoxide, aphomide, and apholate caused sterility in male and female house flies at concentrations of 1 percent to 0.5 percent in food given to the adults.[65] Of 97 percent compounds administered in granulated sugar or in fly food tested in Florida, only 27 percent caused sterility in adult house filies, Musca domestica L.[66]

Corn meal baits containing 0.5 percent of aphoxide (1-Aziridinyl Phosphine Oxide), a chemosterilant, were applied on an isolated refuse dump in the Florida Keys for the control of house flies, Musca domestica L. Applications were made each day during the second week. House fly populations were reduced from 47 per grid to zero within four weeks and the percent hatch among all eggs laid was reduced to one percent within five weeks.[67] House fly baits containing 0.5 percent of metepa (methaphoxide tris-(2-methyl-1-aziridinyl) phosphine oxide) were applied to the droppings in a poultry house in the suburbs of Orlando, Florida, for the control of house flies. Applications were first made at weekly intervals for nine weeks, then semi-weekly. Granular baits with corn meal as a carrier were the most effective and vermiculite granules, were unsatisfactory.[68]

A corn bait containing 0.75 percent of Apholate was applied on a dump at Pine Island, Florida for the control of house flies. Applications were made over a week for seven consecutive weeks, then five times each week for seven consecutive weeks, then five time each week for five weeks. The fly population decreased from 68 per grid to 5 to 20 during the first seven weeks and remained between 0 and 3 per grid the following five weeks.[69]

e. Preliminary Work with Chemosterilants for Important Noctuids in Georgia

The corn earworm, Heliothis zea (Boddie); the armyworm, Pseudaletia unipuncta (Haworth); and the granulate cutworm, Feltia subterranea (F.), can be sterilized with TEPA. Males of each species are sterilized when they are fed 53 mg of TEPA in a 10 percent sucrose solution. A dose in excess of 106 mg is required to sterilize female corn earworms and a dose of more than 53 mg to sterilize female army worms and granulate cutworms.[70] Sterilization of the fall armyworm by a apholate and TEPA has also been reported.[71]

Insect sterility, a new technique is offering promise for many major agricultural pests of southeastern U. S. including the boll weevil, bollworm, budworm, and pink bollworm. Much research and field experiments must be conducted on each pest problem to determine if this approach will be useful in an expanded practical control program.

7. Insect Attractant and Repellants

Many insects find their food, their partners for mating and favorable sites in which to deposit their eggs by means of automatic response to various scent clues. Male moths for example, can smell potential sexual partners at a considerable distance. Not surprisingly, each species tends to have its own distinctive odor which facilitates the meeting of partners capable of mating. The survival and adaptation of many insect species depend on these odors. Frequently they can be attracted by means of a chemical attractant to a trap for pest detection purposes or to a toxicant that destroys them, or to a substance which makes them incapable of fertile mating.[72]

Attractants have been classified into three categories; sex, food, and oviposition lures. The type of lure is inferred or deduced from insect behavior and the designation given to such response is frequently uncertain. If exposure to a chemical causes a male insect to assume a mating posture, the chemical is probably a sex attractant, even if it is a synthetic and unrelated to any natural lure. Some entomologists believe that methyleugenol, the attractant for the oriental fruit fly (Dacus dorsolis Hendel), is a sex attractant because the chemical attracts only the male.

However, it appears to be a food lure, because the flies avidly devour the chemical.[73] The insects in which female lures male and conversely, males lure or excite the females are presented in Table G-11 and Table G-12 respectively.[74]

The use of food-based or fermenting lures has a definite place in control operations. Disadvantages include lack of specificity (traps fill with many kinds of insects), attraction over only a short distance, rapid deterioration (especially of fermenting lures), and frequently inconsistent performance. In regard to oviposition lures, females have been induced to lay their eggs on, or in the vicinity of, certain chemicals. Materials that release ammonia are known to encourage oviposition in house flies. The apple maggot is attracted to decomposing proteins, such as egg albumin.[73]

Chemical attractants and associated agents, such as stimulants and assertants have been widely used for many years in studies of insect behavior. They have served many useful purposes as lures in traps, for example:

- To sample insect populations, to determine relative densities from time to time and from place to place.
- To trace the movement of marked insects in dispersion and migration studies.
- To study survival of insects in their natural environments.
- To study behavior associated with the search for mates and ovipositions sites.

In the search for selective methods of insect control, many entomiologists and plant protection personnel are seeking chemicals which elicit repellence. A repellent is a chemical that causes an insect to make oriented movements away from its source.[8] The distance the insect need move, however, is usually much shorter than the distance it does move in response to an attractant. Ordinarily, it need only leave or avoid a treated surface or at most move a few centimeters out of the effective concentration of repellent vapor. Less use has been made of repellents

TABLE G-11 INSECTS IN WHICH FEMALES LURE THE MALES [74]

Order	Scientific Name	Common Name
Orthoptera	Blaberus craniifer (Burmeister)	Giant death's head roach
	Blaberus giganteus (L.)	
	Byrsotria fumigata (Guèrin)	Cockroach
	Leucophaea maderae (F.)	Cockroach
	Mantis religiosa (L.)	Praying mantis
	Nauphoeta cinerea (Olivier)	Cockroach
	Periplaneta americana (L.)	American cockroach
	Periplaneta australasiae (Fabricius)	Australian cockroach
	Periplaneta brunnea (Burmeister)	
	Periplaneta fuliginosa (Serville)	
Lepidoptera	Achroea grisella (Fabricius)	Lesser wax moth
	Achroea sp.	
	Acronicta psi (L.)	
	Actias caja (L.)	Garden tiger moth
	Actias selene (Hübner)	
	Actias villica (L.)	Cream-spot tiger moth
	Agathymus baueri (Stallings & Turner)	
	Agathymus polingi (Skinner)	
	Aglia tau (L.)	Nailspot
	Agrotis fimbria (L.)	
	Agrotis ypsilon (Hufnagel)	Black cutworm
	Antheraea pernyi (Guèrin-Mèneville)	
	Antheraea (Telea) polyphemus (Cramer)	Polyphemus moth
	Aphomia gularis (Zeller)	
	Argynnis adippe (L.)	
	Argynnis euphrosyne (L.)	Pearl-bordered fritillary
	Argynnis latonia (L.)	
	Argynnis paphia (L.)	Emperor's cloak

TABLE G-11 (Continued)

Order	Scientific Name	Common Name
Lepidopetra (Contd.)	Autographa californica (Speyer)	Alfalfa looper
	Bombyx mori (L.)	Silkworm moth
	Cacoecia murinana (Hb.)	
	Caligula japonica (Butler)	
	Callimorpha dominula (L.)	Scarlet tiger moth
	Callimorpha dominula persona (Hbn.)	
	Callosamia promethea (Drury)	Promethea moth
	Carpocapsa pomonella (L.)	Codling moth
	Celaena haworthii (Curtis)	Haworth's minor
	Chaerocampa elpenor (L.)	
	Clysia ambiguella (Hubner)	Grape berry moth
	Colocasia coryli (L.)	
	Colotois pennaria (L.)	
	Cossus robiniae (Pek.)	
	Cucullia argentea (Hufnagel)	Silver monk
	Cucullia verbasci (L.)	Brown monk
	Dasychira fascelina (L.)	
	Dasychira horsfieldi (Saund.)	
	Dasychira pudibunda (L.)	Pale tussock moth
	Dendrolinus pini (L.)	
	Diatrae saccharalis (F.)	Sugarcane borer
	Endromis versicolora (L.)	Kentish glory moth
	Ephestia cautella (Walker)	Almond moth
	Ephestia elutella (Hubner)	Tobacco moth
	Ephestia kühniella (Zeller)	Mediterranean flour moth
	Eumeta crameri (Westw.)	
	Euproctis chrysorrhoea (L.)	Gold tail moth
	Eupterotida fabia (Cram.)	
	Eupterotida undulata (Blanch.)	
	Galleria mellonella (L.)	Greater wax moth
	Graphotitha molesta (Busck)	Oriental fruit moth
	Harrisima brillians (B. & McD.)	Western grape leaf skeletonizer
	Heliothis virescens (F.)	Tobacco budworm

TABLE G-11 (Continued)

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	Heliothis zea (Boddie)	Bollworm, corn earworm, tomato fruitworm
	Heterusia cingala (Moore)	
	Hyalophora cecropia (L.)	Cecropia moth
	Hyalophora colleta	
	Hyalophora euryalus (Boisduval)	Ceanothus silk Moth
	Hypocrita jacobaeae (L.)	Cinnabar moth
	Hypogymna morio (L.)	
	Laphygma frugiperda (J. E. Smith)	Fall armyworm
	Lasiocampa quercus (L.)	Oak eggar moth
	Lasiocampa trifolii (Schiff.)	Grass eggar moth
	Lobesia (Polychrosis) Botrana (Schiff.)	
	Lymantria ampla (Walker)	
	Mahasena graminivora (Hampson)	Bagworm
	Malacosoma neustria (L.)	Lackey moth
	Metopsilus porcellus (L.)	
	Micropteryx spp.	
	Orgyia antiqua (L.)	Vapourer moth, rusty tussock moth
	Orgyia ericae (Germ.)	
	Orgyia gonostigma (Fabricius)	
	Parasemia plantaginis (L.)	Wood tiger moth
	Pectinophora gossypiella (Saunders)	Pink bollworm moth
	Phalera bucephala (L.)	Moonspot
	Plodia interpunctella (Hübner)	Indian meal moth
	Porthesia similis (Fuessly)	
	Porthetria (Lymantria) dispar (L.)	Gypsy moth
	Porthetria dispar japonica (Motsch)	Gypsy moth
	Porthetria (Lymantria) monacha (L.)	Nun moth

TABLE G-11 (Continued)

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	Prodenia litura (Fabricius)	Egyptian cotton leaf worm
	Prodenia ornithogalli (Guenée)	Yellow-striped armyworm
	Protoparce sexta (Johannson)	Tobacco hornworm
	Pierostoma palpina (L.)	Snout spinner
	Ptilophora plumigera (Schiff.)	
	Pygaera curtula (L.)	
	Pygaera pigra (Hufn.)	
	Rhyacionia buoliana (Schiff.)	Pine shoot moth
	Rhyacionia frustrana (Comstock)	Nantucket pine tip moth
	Rothschildia orizaba (Westwood)	Orizaba silk moth
	Samia cynthia (Drury)	Cynthia moth
	Sanninoidea exitosa (Say)	Peach tree borer
	Saturnia carpini (Schiff.)	
	Saturnia pavonia (L.)	Emperor moth, peacock moth
	Saturnia pavonia minor (L.)	Lesser peacock moth
	Saturnia pyri (L.)	
	Smerinthus ocellatus (L.)	Eyed hawk moth
	Solenobia fumosella (Hein.)	
	Solenobia lichenella (L.)	
	Solenobia seileri (Sauter)	
	Solenobia triquetrella (Hbn.)	
	Sphinx ligustri (L.)	Privet hawk moth
	Spilosoma lutea (Hufn.)	Buff ermine moth
	Spodoptera exigua (Hübner)	Beet armyworm
	Stilpnotia salicis (L.)	Satin moth
	Synanthedon pictipes (Grote & Robinson)	Lesser peach tree borer
	Tineola bisselliella (Hummel)	Webbing clothes moth
	Trabala vishnu (Lef.)	
	Trichoplusia ni (Hübner)	Cabbage looper

TABLE G-11 (Continued)

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	Vanessa uritcae (L.)	
	Zygaena filipendulae (L.)	Six-spot burnet moth
Coleoptera	Agriotes ferrugineipennis (LeConte)	Click beetle
	Ctenicera destructor (Brown)	Click beetle
	Ctenicera sylvatica (Van dyke)	Click beetle
	Diabrotica balteata (LeConte)	Banded cucumber beetle
	Dytiscus marginalis (L.)	
	Hemicrepidius morio (Leconte)	
	Hylecoetus dermestoides (L.)	
	Limonius californicus (Mann.)	Sugar-beet wire worm
	Limonius sp.	Wireworm
	Melolontha vulgaris (Fabricius)	
	Pachypus cornutus (Olivier)	
	Phyllophaga lanceolata (Say)	June beetle
	Rhopaea magnicornis (Blackburn)	
	Rhopaea verreauxi (Blanchard)	
	Telephorus rufa (L.)	
	Tenebrio molitor (L.)	Yellow mealworm
Hymenoptera	Apis mellifera (L.)	Honey bee
	Bracon hebetor (Say) (=Habrobracon juglandis)	Wasp
	Crabro cribrarius (L.)	Wasp
	Dasymutilla spp.	Velvet ant
	Diprion similis (Hartig)	Introduced pine sawfly
	Gorytes campestris (L.)	Wasp

TABLE G-11 (Continued)

Order	Scientific Name	Common Name
Hymenoptera (Contd.)	*Gorytes mystaceus* (L.)	
	Macrocentrus ancylivora (Rohwer)	
	Macrocentrus gifuensis (Ashmead)	
	Macropis labiata (Fabricius)	
	Megarhyssa atrata (Fabricius)	
	Megarhyssa inquisitor (Say)	
	Megarhyssa lunator (L.)	
	Neodiprion lecontei (Fitch)	Red-headed pine sawfly
	Neodiprion pratti pratti (Dyar)	Virginia-pine sawfly
	Praon palitans (Muesebeck)	
	Pristiphora conjugata (Dahlb.)	Sawfly
Diptera	*Culiseta inornata* (Williston)	Mosquito
	Drosophila melanogaster (Meigen)	
	Musca domestica (L.)	House fly
	Phytophaga destructor (Say)	Hessian fly
Isoptera	*Reticulitermes arenincola* (Coellner)	Termite
	Reticulitermes flavipes (Kollar)	Eastern subterranean termite

Source: Jacobson, M.

TABLE G-12. INSECTS IN WHICH MALES LURE OR EXCITE THE FEMALES.[74]

Order	Scientific Name	Common Name
Orthoptera	Byrsotria fumigata (Guèrin)	Cockroach
	Eurycotis floridana (Walker)	
	Leucophaea maderae (F.)	Cockroach
Hemiptera	Lethocerus indicus (Lepetier & Serville) (=Belostoma indica)	Giant water bug
	Rhoecocoris sulciventris (Stal.)	Bronze orange bug
Lepidoptera	Achevontia atropos (L.)	
	Achroca grisella (Fabricius)	Lesser wax moth
	Aphomia gularis (Zeller)	
	Argynnis adippe (L)	
	Argynnis aglaja (L.)	
	Argynnis paphia (L.)	Emperor's cloak
	Caligo arisbe (Hbn.)	
	Colias edusa (Fabricius)	
	Danaus plexippus (L.)	Monarch butterfly
	Elymnias undularis (Dru.)	
	Ephestia cautella (Walker)	Almond moth
	Ephestia elutella (Hübner)	Tobacco moth
	Erynnis tages (L.)	
	Eumenis semele (L.)	
	Euploca phaenareta (Schall.)	
	Euploca sp.	
	Eurytides protesilaus (L).	
	Galleria mellonella (L.)	Greater wax moth
	Hepialus behrensi (Stretch.)	
	Hepialus hectus (L.)	
	Hipparchia semele (L.)	Grayling butterfly
	Lethe rohria (F.)	
	Lycaena spp.	
	Mycalesis suaveolens (W.-M. & N.)	
	Opsiphanes invirae isagoras (Fruhst.)	
	Otosema odorata (L.)	
	Panlymnas chrysippus (L.)	
	Papilio aristolochiae (F.)	
	Pechipogon barbalis (CL.)	
	Phassus schamyl (Chr.)	
	Phlogophora meticulosa (L.)	Angleshade moth
	Pieris napi (L.)	Mustard white
	Pieris rapae (L.)	Imported cabbage worm
	Plodia interpunctella (Hübner)	Indian meal moth
	Sphinx ligustri (L.)	Privet hawk moth

TABLE G-12 Continued.

Order	Scientific Name	Common Name
Lepidoptera (Contd.)	Stichophthalma camadeva (Westw.)	
	Syrichtus malvae (L.)	
	Terias hecabe fimbriata (Wall.)	
	Tineola bisselliella (Hummel)	Webbing clothes moth
	Xylophasia monoglypha (Hufn.)	Dark arch moth
Coleoptera	Anthonomus grandis (Boheman)	Boll weevil Malachiidae bettles
Hymenoptera	Bombus terrestris (L.)	Bumble bee
Diptera	Ceratitis capitata (Wied.)	Mediterranean fruit fly
	Drosophila melanogaster (Meigen)	
	Drosophila victoria (Sturtevant)	
Mecoptera	Harpobittacus australis (Klug)	Scorpion fly
	Harpobittacus nigriceps (Selys)	Scorpion fly
Neuroptera	Osmylus chrysops (L.)	

Source: Jacobson, M.

for the protection of animals and plants than for the protection of man. For humans these have been skin repellents, systemic repellents, and repellents for clothing treatment.

Ultimately the best attractants (based on laboratory findings) must be tested in the field where they must prove effective despite a multitude of natural odors, colors, light conditions, and weather.[73, 75, 76] Examples of some potent synthetic attractants are listed in Table G-13

a. Use of Synthetic Attractants in Control and Eradication of the Mediterranean Fruit Fly in Florida

In 1956, the Mediterranean fruit fly (med-fly) reappeared in Florida after an absence of 26 years. Following its initial eradication in 1929-30, the on-tree annual value of the citrus crop had climbed to about 250 million dollars and that of all other commercial hosts of this pest was many million dollars more.[77] It was estimated that if these flies were not eradicated the combined annual cost of control efforts, fumigation of exported fruit, and maintenance of quarantine and road blocks would approximate 20 million dollars exclusive of crop losses and decrease of consumer acceptance of the state's citrus products.

Quick action by state and federal agencies (Plant Pest Control and Entomology Research Branch, U. S. Department of Agriculture) and industry, along with good public support, made it possible to establish effective curtailment and eradication programs in a minimum of time. The eradication effort was a complete success (Table G-14).

The general plan for state-wide eradication was to apply aerial sprays to known infested areas and strips one-half mile adjacent to these areas. The spray contained 1 lb. of protein hydrolysate and 2 lbs. of 25% malathion per acre. The spray was applied on a 10-day schedule, but later the coverage was on at a 7-day schedule because of rainy conditions.

Lures and detection methods comprised of angelica oil, Siglure and esters of cyclohexene carboxylic acid on cotton dental roll wicks with 3% DDVP (another phosphorus insecticide). A 25% lindane and 40% chlordane wettable powder was applied bi-weekly at 1/4 teaspoon per trap to prevent ant and spider depredation and to assist in fly kill. The traps were placed at the rate of 10 to 40 per square miles preferably in med-fly hosts. The number of traps was increased after a larval or adult find. The trap servicing was done on two to three weeks schedules. Traps aided in determining the effectiveness of the bait spray.

The cost of the program was $11 million. Among the most important results of this research were the development:

- Of highly effective lures for use in bait traps. These served as indicators of the presence of the flies in a given location and as a measure of the progress toward eradication.
- Of attractive materials which could be combined with insecticides in bait sprays.

TABLE G-13 Potent Attractants Made Synthetically.[73]

Common Name	Species Attracted	Other Species Attracted
Methyleugenol[a]	Oriental fruit fly (Dacus dorsalis)	Dacus umbrosus
Anisylacetone	Melon fly (Dacus cucurbitae)	Queensland fruit fly (D. tryoni) (D. ocbrosiae)
Cue-lure[a]	Melon fly (Dacus cucurbitae)	Queensland fruit fly (D. tryoni) (D. ocbrosiae)
	Melon fly (Dacus cucurbitae)	
Siglure	Mediterranean fruit fly (Ceratitis capitata)	Walnut husk fly (Rhagoletis completa)
Medlure	Mediterranean fruit fly (Ceratitis capitata)	
Frontalure	Southern pine beetle (Dendroctrotonus frontalis)	Western pine beetle (D. brevicomis) Douglad fir (D. pseudotsuge)
Trimedlure[a]	Mediterranean fluit fly (Ceratitis capitata)	Natal fruit fly (Pterandrus rosa)
Natural lure of gypsy moth[a]	Gypsy moth (Porthetria dispar)	- -
Gyplure	Gypsy moth (Porthetria dispar)	- -
Bombykol	Silkworm worth (Bombyx mori)	- -
Butyl sorbate[a]	European chafer (Amphimallon majalis)	- -
Methyl linolenate[a]	Bark beetles (Ips typographus) (Hylurgops glabratus)	- -

TABLE G-13 (Continued)

Common Name	Species Attracted	Other Species Attracted
Grandlure	Cotton boll weevil *Anthnomous grandis Boheman*	- -

[a]Most effective lure for insect under "Species Attracted" column.

Source: Beroza, M. and Green, N. (Modified).

Table G-14. Status of Bait-Spray and Trap Operations for Eradication of the Mediterranean fruit fly in Florida.[77]

Date or Period Ending	Counties Being Sprayed	Acres Sprayed by Air: Currently	Acres Sprayed by Air: Cumulative Coverage	No. of Traps In use	Flies Per 1,000 Trap-Days
1956					
June 30	19	328,309	495,541	4,000	122,500
July 31	24	602,381	1,996,000	17,000	7,490
Aug. 31	23	239,646	3,321,091	18,100	3,780
Sept. 30	19	215,506	4,022,141	34,157	0,882
Oct. 31	16	168,485	4,921,715	39,503	0,475
Nov. 30[a]	14	106,820	5,510,613	45,060	0,161
Dec. 31[b]	14	38,055	5,787,193	45,801	0,027
1957					
Feb. 28	11	24,580	6,168,696	45,026	0,037
Apr. 30	5	11,530	6,324,529	47,810	0,051
June 30[c]	6	31,100	6,572,925	48,760	0,033
Aug. 31	2	3,500	6,723,052	36,978	0,002
Oct. 31	1	1,400	6,747,592	27,757	0,001
Dec. 31	1	4,600	6,787,653	23,722	0,004
1958					
Feb. 28	0	0	6,805,000	25,197	0

[a]Hernado (last county found infested) added.

[b]Insecticide applications completed in all eastern and southern counties.

[c]Final eradication in all counties except Hillsboro, Lake, Manatee, Orange, Pasco, Pinellas, and Polk.

Source: Steiner, L. E. et al.

The bait sprays greatly suppressed house flies and mosquitoes also. Some species of tropical fish in very shallow water were susceptible to the small amounts of malathion in the bait spray. Apart from this drawback, the eradication program was relatively safe compared to conventional aerial sprays, and was very effective.[77]

b. Synthetic Pheromone of the Boll Weevil

Two terpene alcohols and two terpene aldehydes from male boll weevils, Anthonomous grandis Boheman, were isolated and identified at the Mississippi State University in 1969.[78] These compounds are the components of the pheromone to which only female boll weevils respond in laboratory tests. In bioassays, mixtures containing all four compounds elicited a response by females equivalent to or better than that elicited by live males.[79] Absence of either alcohols or the two aldehydes from the mixture resulted in almost complete lack of response. The response to mixtures of synthetic compounds was identified to that obtained from corresponding mixtures of natural compounds. The extract of fecal material of boll weevils (both male and mixed sexes) produced a material highly attractive to females but not to males.

The synthesized pheromone was names Grandlure. This compound, however, had a very short life. Polyethylene glycol increased its life. This stable product became a tool in surveying boll weevil infestation.[80]

c. Virgin Female Traps for Introduced Pine Sawfly

The Pine Sawfly (Diprion similis) is a pest of eastern white pine. Once it was observed that large numbers of males swarmed toward females. Investigations were conducted to determine whether a sex attractant was involved. The wooden traps used consisted of a box (12 X 6 X 1 inches) with a 2 1/2-inch screened opening in the center. A virgin female was placed in the screened portion and Tanglefoot was spread over the wooden portion. The traps were suspended from trees in infested areas. An average of 1,000 males were attracted in each of the eight traps. Large numbers of males also fell to the ground. Some females did not attract males for an unknown reason. The male response was rapid. Many approached within 30 seconds after the traps were set-up. Traps set-up at an angle of 90 degrees to the wind direction at the edge of the woods were consistently more attractive than those set in dense woods. Greatest activity took place from midmorning to sunset. One trap with a virgin female exposed from 11 a.m. to 4 p.m. attracted more than 7,000 males. She continued attracting males at approximately 1,000 per day until she died on the fifth day, after which small numbers were caught for the next three days. Males were lured 200 feet from the forest over an open field. Chemosterilant-attractant mixtures can be effective in reducing or eradicating a field population of this insect.[74]

d. Sex Pheromones of the Southern Pine Beetle and Other Bark Beetles

Epidemics of the southern pine beetle, Dendrochonus frontalis Zimm., have occurred periodically throughout the outheast and in parts of Texas. The standard procedure developed in response to this problem involved aerial detection of infested pines over intervals of several weeks, followed by confirmation on the ground and actual control. The control techniques consisted of cutting and spraying infested trees with benzene hexachloride (BHC) in water or oil. The trees most recently infested were cut and sprayed first. This was to interrupt the otherwise continuing aggregation of the southern pine beetle population in response to the attractants emanating from such standing, freshly attacked trees. The control effect on individual infestations appeared satisfactory but research revealed that although the southern pine beetles did not aggregate on sprayed and felled timbers, their predators did. Despite very diligent and persistant efforts the BHC-control failed to affect the overall population level. The results of further research suggested that the prescribed control method was in fact, more effective against predators, parasites and competitors of the souther pine beetle than the target insect; so BHC-control was largely abandoned in early 1969. The subsequent rapid decline of the southern pine beetle epidemic undoubtedly had a complex cause. The elimination of insecticides may account for subsequent resurgence of predators.

A method presently being tried uses Frontalure [1, 5-dimethyl-6, 8-dioxabicyclo (3. 2. 1) octane, the sex pheromone and 2 parts of d-pinene] to aggregate southern pine beetle populations on the trees to be harvested and/or treated with cacodylic acid, which checked brood development but does not harm non-target insects. In fact, the simultaneous aggregation and survival of predators and competitors has become an integral part of this method.

The new method depends, like prior measures, on aerial survey detection of southern pine beetle activity. Infestations, however, can be treated immediately by the crew performing the ground check. Few tools are needed and the amount of chemicals deployed does not surpass gram quantities per acre. The reduction in labor in comparison with former control measures is considerable and environmental pollution is avoided. The recommended technique involves the following steps:

- The cause, extent of damage, and the number of pines containing an active brood of southern pine beetle are determined.
- Two to ten non-infested pine trees, near the most recently attacked trees in active infestations, are selected for baiting with Frontalure. Two pines seem to be adequate for small infestations, but at large spots of infestations, up to ten trees are baited. Six caps containing 1 ml. of Frontalure are attached on each tree around the circumference at a convenient height. The large trees are preferred.
- The brood is destroyed by injecting cacodylic acid into baited trees and the adjacent trees within 15 to 25 ft., provided these are 6" or more in size (Diameter at breast height of DBH). Cacodylic acid is applied in closely spaced frills made with an ax, at least one foot above the ground. The total number of trees present in the spot.
- This treatment is followed after two or three weeks with either salvage of the treated and infested timber or re-check of the infestation, and repetition of the procedure where necessary.

This 'ground-checking control' is a typical example of the point application of population attractants and especially suits the forestry practices of the large pulpwood industry in southeast.[81]

Attractants and related agents may be used in several ways for controlling insects, as well as for gathering fundamental information about pest population, which might lead to their control. By their use in practical control programs, insects may be lured into traps and then killed by an insecticide or by adhesive, etc., or a culture of pathogens may be mixed with an attractant or feeding stimulant to destroy the pest. A chemical may also be used to attract large numbers of insects that can be sterilized and released among the native population to reduce pest numbers. Attractants are increasingly finding such uses.

8. Insect Hormones

Scientists are looking for new chemicals to control pests. These should be specific to only a given pest species, non-toxic to man and domestic animals, biodegradable, and of such a nature that pests will not be able to develop resistance.

One approach involves our rapidly expanding knowledge of how insects rely upon hormones to regulate their growth, feeding, mating, reproduction and diapause or over-wintering.[76] The primary candidate is the Juvenile hormone that all insects secrete at certain stages in their lives.[82] Therefore, the potential utilization of this information for insect control depends upon the ingenuity with which man can supply a Juvenile hormone to the insect at an unfavorable stage. The contact of a last-stage nymph, larva or pupa with a Juvenile hormone induces morphogentic damage. This results in the development of intermediates or monsters which are unable to mature and die in a short time.

Subsequent investigations have revealed other important function of the Juvenile hormone in insects such as, diapause, reproduction, embryogenesis, sex attractant production, and lipid metabolism.[76]

The synthetic Juvenile hormone analogue, Trans, Trans 10, 11-Epoxy farnesenic acid methyl ester successfully terminated adult diapause in several species of Hemiptera, including the box elder bug and the red linden bug.[83] Juvenile hormones are unquestionably deeply involved in the regulation of diapause and the possibility exists that more research may result in the development of antihormones which can prevent or even induce diapause.

A male pyrrhocoris treated topically with 1 mg of dichloride compound, synthetic Juvenile hormone, is able to transfer enough of this chemical to females by contact during mating to induce sterility.[84] This novel method of transmitting sterility should have interesting field applications if similar chemicals affecting insects other than Pyrrhocoris are developed.

Williams[82] believes that synthetic Juvenile hormone eventually will prove to be most effective as an egg killer (ovicide).

Ecdysone is another insect hormone which has the potential of becoming a selective insecticide. This substance initiates ecdysis (shedding of skin) or metamorphosis from one stage to another in the larval or nymphal development of insects. Overstimulation with ecdysone results in repeated metamorphosis without sufficient time for the accumulation of food reserves so that eventually the larva or nymph becomes exhausted and dies.

From the foregoing it is obvious that the application of morphogenetic compounds to immature insects can kill them by upsetting their development. The practical utilization of these compounds becomes attractive with the realization that these hormonal effects are specific to insects. In addition, these chemicals have no effect on other forms of life.[76, 82] A further advantage is that insects cannot develop immunity against the compounds for if they did, they would become immune to the hormone that is essential to part of their life cycle. Since this discipline of pest control is still little explored, specific case studies are not available.

9. Integrated Control

Integrated control combines several agronomic practices and pest control methods. The total effect of these combined methods is synergistic rather than additive; not only does it reduce the pesticide pollution problem, but the control obtained is more effective. Integrated control is predicated on fundamental ecological principles.[85] The concept includes appropriate combinations of pesticides, natural enemies, insect pathogens, and cultural treatments, etc.[29]

The first principle emphasizes the ecosystem which includes the complex of organisms, the culture of the crop or animal and the environment. The second principle stresses economic levels. It concerns the population levels at which the pest species cause harm, damage or constitute a nuisance, and measures directed to keep them below detrimental economic levels. The third principle emphasizes the importance of avoiding disruptive actions. Measures must be designed to give adequate control in a manner which does not upset some other part of the ecosystem.[86]

a. Integrated Control of Cotton Boll Weevil in Southeastern States

A large scale experiment is currently underway to eradicate the cotton boll weevil, a meanacing and costly pest of cotton, in the southeast. The test area is 150 miles in diameter and is located around Gulfport, Mississippi. This two-year study runs to July 1, 1973. At that time researchers will have determined if eradication is feasible, and what the cost will be. Presently it is estimated that the total cost of eradication might be about $275 million.

For the first time treatment involves at least six simultaneous operations. These include in-season spray as needed; a series of reproduction - diapause sprays in the fall to prevent overwintering; defoliation; stalk shredding; and pheromone traps for males to prevent reproduction by surviving males. In addition, continued experiements with Frego-bract weevil resistant cotton, and temik systemic insecticide will be part of the research. The chief weapon will be diapause control by a series of up to seven fall sprays applied mainly by five helicopters in the core zone, Columbia, Mississippi, and the first buffer zone, spilling over slightly into Alabama and Louisiana. Properly timed, this treatment can kill up to 99 percent of weevils entering hibemation. Chemicals used will be ultra-low-volume Guthion or Malathion, depending upon the environmental hazard involved. Next spring, adhesive-coated traps baited with Grandlure will be placed on fencelines. These traps should catch about 80 percent of emerging weevils. A single application of insecticide before square drop should kill about half of the surviving weevils, without permanently suppressing beneficial insect popullations. The sterile males will then be released at 50 to 200 per acre for several generations, and theoretically should reduce the native population by 98 percent with each generation.[4,87] If the eradication of the boll weevil should eventually be possible at a cost comparable to the annual losses for just 1 year, such a program w uld be one of the best investments the cotton industry could make. Perhaps even more important, the elimination of this insect would be the greatest single contribution that could be made in the foreseeable future toward the goal of reducing environmental pollution caused by the use of broad spectrum insecticides.

b. Integrated Control of Heliothis

Recent theoretical studies not yet published suggest that the mass production and programmed releases of one or more species of selective Heliothis larval parasites could also provide an effective and highly selective means of managing Heliothis populations. Relatively little is known about the numerical relationship between parasites and their hosts. However, based on a theoretical appraisal, there is good reason to believe that it is well within the realm of feasibility to mass produce and release sufficient selective parasites to truly manage insect populations like the Heliothis species. This system of insect population management should have its maximum efficiency when the host insect population is high and should have diminished efficiency when it is low. This is just the reverse of the potential efficiency of the genetic approach. Therefore, the parasite release technique and the genetic technique may eventually prove to be highly complementary when they are integrated into one system of suppression.[4] Insect pathologists are making considerable progress in developing microbial agents which may further strengthen their integrated approach.

c. Integrated Control System for Tobacco Horn
North Carolina

Control of Hornworms on Tobacco, Protoparce sexta (Hohan), and P. quinquemaculata, with insecticides is not completely satisfactory in North Carolina. When Polistes wasps were induced to nest in shelters erected around the field, populations of fifth-instar hornworms were reduced by about 60 percent and damage by 76 percent. One-fifth the recommended rate of insecticides TDE or Endrin, applied as top sprays gave reliable and adequate control of both hornworms and budworms. This was true whether applied every two weeks on a preventive schedule or only when counts indicate treatment was needed.[88] Such an integrated program would be more economical than present systems and would reduce residues to a fraction of the present levels.

d. Integrated Control of Muscid Flies in Poultry Houses in
Kentucky

Control of the house fly, Musca domestica l., and little house fly, Fannia canicularis (L.), in poultry houses was studied in an integrated control system in Kentucky employing the predator mites, Macrocheles musaedoemsticae (Scopoli) and Fuscuropoda vegetans (De Geer), fly larvicides and fly poisoned baits. Baccilus thuringiensis Berliner was the most harmless to the mites. Diazinon gave consistent reduction of fly larvae and was relatively harmless to the mite populations. A parasite nematode, Neoplectana carpocapsae Weiser, was ineffective largely because of its succeptibility to desiccation. Adult flies were effectively controlled with the use of liquid poisoned diazinon baits.[89]

e. Integrated Biological and Chemical Control of Aquatic Weeds in Florida

The introduction of the beetle (Agasicles sp.) as a biological control agent has been an added deterrent to the growth of alligatorweed (Althernanthera philoxeroides Mart. Griseb.) through the Atlantic Coast states. However, floating mats have been controlled in only very small local areas where herbicides have not been used. The recommended chemical control of alligatorweed is 2 or more treatments of silvex [2-(2, 4, 5-trichlorophenoxy) propionic acid] at 8 lb/A. Alligatorweed may be controlled with less herbicide in the presence of large populations of alligatorweed flea beetles. A dense mat of alligatorweed was treated with 6 lb/A of silvex and a beetle population of one adult per 2-sq ft of mat was introduced when regrowth was 2 to 5" high. The beetles showed a feeding preference for the young regrowth over the more mature nontreated alligatorweed and maintained sufficient feeding pressure to eliminate the floating mat growth.[90]

Integrated control today has acquired a wider interpretation than was proposed 15 years ago. Broadly, it refers to integration of all crop protection procedures. The acceptance of such an approach of pest control is widely accepted by agriculturists and environmentalists.

Integrated control programs in general required a higher level of scientific background when compared to chemical control. At least a minimum level of information is usually needed regarding the following points: the general biology, distribution and behavior of the key pests; an approximation of the pest population levels that can be tolerated without significant crop loss; a rough evaluation of the times and places of occurrence, and the significance of the major predators, parasites, and pathogens present; information on the impact of the use of pesticides, insecticides, herbicides, and fungicides, as well as other control measures on natural enemies, and on natural and agroecosystems.

10. Miscellaneous Methods

a. Seed Laws

One of the methods by which weeds spread is through their inclusion with crop seeds. As early as 1821, Connecticut passed a law prohibiting the sale of grass seed containing Canada thistle and other weeds. The earliest vegetable seed laws were adopted by Florida in 1889. By 1941 all 48 states had seed laws. The federal seed act[91] requires in part that the following information be provided on seed labels in interstate commerce: percentage of pure seed of the named crop, percentage of other crop seeds, percentage of weed seeds, and the rate of their occurrence. Crop seeds cannot be sold for seeding purposes in most states if they contain noxious weeds in exceed of a specified percent by weight of weed seeds, generally two or three percent.

The model state seed law, used as a guideline for legislation by many states, provides a typical example of state regulations. Noxious-weed seeds are separated into two classes: prohibited (generally annuals) and restricted (seeds of perennial weeds).

Seed laws at state and federal levels have been important in reducing the spread of weed species and in improving seed quality.[91]

b. Seed Certification

Seed certification is the system used to keep pedigree records for crop varieties and to make available sources of genetically pure, disease-free seeds and propagating material for general distribution. Without such a system, seeds tend to become contaminated and mixed and lose identity. Certified seeds contain relatively fewer weed seeds.

Drill-box surveys of the quality of field crop seeds planted by farmers has indicated that seed suppliers have not kept pace wi th the strides that have been made in developing better seed-cleaning machinery and knowledge of seed processing. Only about five percent of seeds were certified and they were found to contain 1.2 weed seeds per pound, in comparison with 160 weed seed per pound for non-certified seeds purchased from dealers or taken from farmers bins. Although seed certification programs have direct control over only a small percentage of the small grain that is planted, their beneficial effect on quality of seeds planted by farmers will grow through continuing seed certification and educational program.[92, 7]

c. Disease Control through Virus-free Stock

There are at present no practical and economical treatments to cure virus-infected plants in the fields. Methods of control, therefore, are generally directed toward preventing infection by eliminating the source of inoculum, by preventing spread of virus, or by developing varieties immune to the virus or immune to disease they cause. The production abd distribution of "virus-free" propagating material has proved highly successful in controlling virus diseases in many crops. The term virus-free can be defined as free from the known and specified viruses for which tests have been conducted.

The tactics of virus control depend upon integration of several distinct activities:

- The recognition and characterization of the virus diseases in each crop
- The development of reliable indexing methods to retrieve any existing healthy stock, to sort plants that have been treated to eliminate virus, and to detect any symptomless carriers

- The development of techniques to rid a few selected plants of virus and establish clones of virus-free foundation stocks where no healthy material is found.
- The enactment of measures such as certification program to maintain the health of foundation stocks, and to secure effective distribution of their progeny to growers and nurserymen.

In the United States certification programs are individual state functions. A certification program for virus-free citrus stocks is presently used in Florida. Such programs tend to keep a control on the known viruses of crops propagated from vegetative stocks.[18]

d. Quarantine and Regulatory Controls

In agriculture, quarantine refers to the restraints or restrictions placed upon the transportation of animals, livestock, poultry, plants, fruits and vegetables, plant and animal products or other materials which are suspected of being carriers of agricultural pests. Such precautions are necessary as many of the worst plant pests came from other countries and thrieved here because of abundant food and few natural enemies. The tempo of international travel has greatly increased and with it the danger of spreading pests has greatly increased. Quarantine system is, as such, a necessary element of overall national preventive pest control programs.[93]

Domestic quarantines between states, combined with treatment programs , have eliminated several pests from the United States. For example Japanese beetle, Popillia japonica Newman has been under continuous regulation in the United States since 1919. Established infestation still doesn't exist west of the Mississippi River, and occurs only in siolated areas in the southeast. Control and quarantine programs have confined the gypsy moth, Prothetria dispar (Linn.) to a few north-eastern states although there are some 100 million acres west of the Mississippi River known to be susceptible to attack.[8]

Publicly supported regulatory programs are an essential part of the overall effort to protect crops and livestock from pests. Various methods are used in eradication, containment and suppression programs; there include chemical, cultural and biological measures. Greater merit is indicated for large scale alternative control programs as compared to region-wide chemical spraying. Many of the alternative techniques of pest control are employed on larger areas than individual farms. Programs of state and federal agencies in cooperation with private agencies and farmers will be required in pest control.

e. Pest Surveillance

The detection of pests and surveys of their distribution and abundance are essential prerequisites to rational control programs. The first principle of pest detection and surveys as related to control is that no control measures should be undertaken against a pest unless it is known that the pest is actually present. In many instances, this principle is not followed. Many farmers often follow a strict schedule without bothering to determine whether the pest is actually present. This is partly attributed to the lack of appreciation of the merits of pest assessment. The second principle of pest detection is that no control measures should be undertaken unless it is known that the pest is present in sufficient numbers to cause economic loss.

In 1971, cotton insect scouting programs have been conducted in ten states (Alabama, Arkansas, Georgia, Mississippi, Missouri, North Carolina, South Carolina, Texas and Louisiana). A total of 628 scouts were trained. They scouted 877,225 acres out of 10,421,000 acres under cultivation. Scouting programs have been in operation for nine years in Alabama. Scouted cotton fields have averaged 200 more pounds of lint per acre than fields not scouted. A scout who has received special training by an extension service entomologist can keep growers informed of the following:

- When the infestation count is great enough to warrant starting a control program
- When to expect hatchout of boll weevils or bollworms
- How long to continue the control program into the fall

Scouts give farmers weekly written insect reports and also send infestation reports to county extension chairmen and to extension entomologists. Each week, reports are summarized and a copy sent to all county extension chairmen and other agriculturists in the state.[94] Although no data are available about the actual percent reduction in the pesticide used, it is estimated that a considerable number of unnecessary pesticide applications can be avoided without loss in economic returns. This can only be effective if large areas are brought under surveillance. Sufficient understanding of pest ecology and biology exists so that such programs can be initiated now. Extension services and agricultural universities can play an important role in such activities.

f. Genetic Manipulations

The first attempt at control by the application of genetics to decrease fitness involved the tsetse flies, Glossina sp. Interspecific crosses were made of Glossina swynnertoni and the reproductively but not sexually isolated G. morsitans. Viable but sterile offspring were obtained from such crosses, which competed with normal individual for survival in the environment.[57]

Many lethal genes exist in populations of insect species that have been subjected to genetic analyses. Deleterious genes need not be lethal nor act immediately for effective control. Drastic reductions in insect numbers can be obtained theoretically by constant low-level mortality factors superimposed on populations already exposed to the stress of adverse environmental conditions as, for example, low temperature during hibernation. Three requirements are essential to the success of control measures utilizing the release of strains carrying unfavorable genetic characters: the factors must not prevent rearing under laboratory conditions; they must not interfere with mating ability; and they should act at particular times, such as during hibernation or immature stages. It has been postulated on theoretical grounds that the eradication of the boll weevil, Anthonomus grandis, could be achieved in a few years if males carrying two lethal genes were repeatedly released into field populations. It should be considered that such additional release of pests could temporarily increase the loss of the crop until lethal genes are inherited and come into effect.

Although genetic methods seem to offer promising leads, considerable work is needed before such techniques can be incorporated at a practical level.

g. Development of Safer Pesticides

It is widely accepted that although alternative technology exists, conventional chemicals will remain the chief means of insect pest control for the foreseeable future.[4, 86, 95, 96] An explanation for this lag in the use of alternative methods merits explanation. There has been a growing concern over certain known and potential threats to the quality of our environment because of the use of the broad-spectrum pesticides. This concern however, has not been fully translated into increased commitment of resources toward search, development or large-scale testing of alternative methods. The United States must be prepared to support substantially larger expenditures from its resources if there is to be great progress in correcting or alleviating many pesticidal pollution problems, utilizing and boradening our knowledge of alternative pest control technology and development of safer pesticides. The time factor is also involved as regards ecological aspects, alternatives need to be developed soundly after elaborate trials. It requires several years to perfect these techniques prior to use at a national or regional level. Such practices in a strict sense, must not be considered as alternatives to total pesticide usage, but rather, means for the more effective use of pesticides.

Most of the chemicals widely used for agricultural pest control have been selected on the basis of optimum effectiveness against the pest and for maximum persistence. The original DDT patent of 1939 covered a number of insecticidal analogs.[96] These included methoxychlor, ethoxychlor and methychlor. All of these compounds are persistent insecticides effective against a wide spectrum of insect pests and they are relatively inexpensive. However, DDT is the most stable and has had extensive use, whereas methoxychlor has been used on a modest scale, and ethoxychlor and methylchlor not at all. These DDT-related compounds are rapidly degraded by the multifunction oxidases of higher animals and converted to water soluble compounds. DDT is not. Similarly, the related compounds are less toxic to fish. Ethoxychlor, methychlor and other biodegradable derivaties of DDT merit further investigation as replacements for DDT and other persistent and non-biodegradable chlorinated hydrocarbons. Similar safer analogs (fenthion, ronnel, dicapthon) exist for methyl parathion, the most commonly used organic phosphate insecticide.[96] Attention is being given to the effect on wildlife of pesticides. Further consideration should also be directed toward the effect of these pesticides on the natural enemies of pests.

A questionnaire survey was conducted by the 1970 National Agricultural Chemicals Association.[97] This is a trade organization representing most of the U. S. pesticide industry. When asked to reply in their words as to the most important obstacles to the development of safer, less persistent and more selective pesticides, the following reasons were listed (the number in parehtheses indicating the number of times each item was cited): high cost of research and development in terms of money and time (11); lack of knowledge of basic plant and animal biochemistry (4); competition from existing, non-selective, relatively inexpensive pesticides (4); lack of grower interest, high cost of selective products that grower is unwilling to pay (3); cumbersome government registration procedures, especially slowness and procrastination in handling of petitions (1), unscientific approach (1), and stringent requirements (1); fear of consumer complaints and litigation (1); lack of interest, support, and experience on part of agricultural workers (1).

The next question was also unstructured and asked what steps might be taken to remove the restraints described under the preceding question. The following suggestions were made (the numbers in parentheses again indicating the number of times each item was cited): design better and more efficient screening, testing, and development methods to reduce development time and cost (4); modify registration requirements to reduce development time and cost, speed up processing of registration applications (3); create a less emotional, more objective public attitude toward pesticides (3); provide for a patent life of pesticides more in line with their commercial usefulness, recognizing the long time required for research, development, and initial registration (2); provide economic incentives to manufacturers (2); increase basic physiological, biochemical, and ecological know-how (1); educate agricultural workers, and regulatory agencies that the purpose of pest control is not destruction of pests, but protection of crop yield (1); define levels of pesticide persistence that are necessary and safe (1); limit manufacturers' liability to proven fault in his product (1); cease diverting manpower to the defense establishment (1).[97]

If chemicals are to be used in a harmonious manner in the agro-ecosystem then we must have materials that are inherently selective or we must learn how to use them so that their effects are selective. All pesticides have some selectivity but the range in degree of selectivity is very great. Much effort has been expended in seeking materials with relatively high toxicity to invertebrates and low toxicity to mammals. We must also seek differential toxicity within the arthropods (insects). We do not need the ultimate in specificity that would permit us to prescribe a specific chemical for each pest species. However, we do need materials that are specific for groups of pests such as aphids, locusts, lepidopterous larvae, weevils, and so forth. As shown above, there are some indications that we can have some materials with such specificity and still have them economically feasible from the viewpoint of the chemical industry. Also, there are indications that safer chemicals can be synthesized.[98] Somehow, the imperative need to replace older and obsolescent agents with substances having more desirable properties has not been forecfully transmitted to the agricultural and pest control industries. At least development and widespread use of selective pesticides has not been encouraged. There is an increasingly regrettable tendency to develop and market nonselective insecticides which are more and more toxic to higher animals and man, as well as beneficial and harmful insects.

There is always likely to be a need for some chemical pesticides if we are to provide for the needs of the human society. Risks of their usage must be minimized and supplemented with other pest control methods.

Through greater cooperation between public and private sectors and by legislation of adequate laws, excessive reliance on broad spectrum pesticides can be reduced. Creation of a situation where voluntary information and resource exchange exists can solve the problem of erratic and short term pesticidal control. Only in such an atmosphere can alternative methods be further developed and utilized. As with other pollution problems, solution of pesticidal dilemna will require a carefully chartered course, consolidated effort and a national commitment. The magnitude of this problem should motivate the country toward an intensive action program at the grass-roots level.

11. Conclusions

Cultural methods of control (sanitation, tillage, dates of planting etc.) along with the use of resistant crop varieties is the farmers first line of defense against pests. These practices considerably reduce but do not eliminate the need for other pest control methods. For certain pests, such as many plant viruses and nematodes, chemical treatment is neither feasable nor economical. In such cases, physical, mechanical and regulatory (quarantine and certification) methods are utilized to reduce or prevent pest populations.

Many major economic pests in the United States have been introduced from other countries without their natural parasites and predators. Importation and release of these natural enemies have proved to be effective in suppression of pests in some cases. Broad spectrum pesticide applications have the adverse effect of destroying the natural enemies of insects thus eliminating a natural check on pest populations in agricultural ecosystems.

Efforts toward the development of biological control agents (virus, bacteria, protoza, fungi, nematodes attacking insects) may result in safer and specific pest control practices. Similarly numerous insect hormones (e.g. juvenile and ecdysone) have the potential of being utilized as selective insecticides.

Many insect attractants have been characterized and developed to lure insects into traps containing pesticides, pathogens and chemosterilants. Chemical and electromagnetic radiation (light traps) attractants also provide for early detection and location of insect-infestation. This is an important component in integrated and pest surveillance programs.

Eradication of selected insect species has been achieved by releasing sterile males to compete with the fertile ones in the natural environment. This method of pest eradication is successful only if the natural insect population is low. In such cases, the sterile males "overwhelm" the fertile males. Expanded use of this technique has been restricted by high cost and logistic factors. Sterilization of the natural pest population by chemosterilants could reduce such time and cost factors.

Integrated control is a pest population management system that employs several suitable techniques to reduce pest populations and maintain them at levels below those causing economic injury. This method provides the best solution to a pest problem because all possible controls are first evaluated. This approach requires ecological information, pest threshold and economic injury levels.

To date, public and private efforts in pest control have been directed toward development of pesticides with little effort being directed to alternatives. There is little inducement for industry to develop alternative methods until large-scale pilot studies have been proven successful. Pesticides will continue to be used in the foreseeable future. Alternative methods, if further developed and applied, can reduce excessive dependence on broad spectrum pesticides.

12. Recommendations

1. A set of national priorities must be established by the U. S. Department of Agriculture for developing alternative methods of pest control beginning with those situations which utilize the largest quantities of broad spectrum, persistant pesticides.

2. U. S. Department of Agriculture, through its Extension Service, should expand its role of judicious use of pesticides. A complementary activity and one of the methods which could considerably reduce the amount of pesticides applied is increased crop surveillance.

3. The Agricultural Research Service of U. S. Department of Agriculture should receive greater support for large scale field testing to determine the effectiveness of promising alternative methods of pest control. Successful programs can then be adopted regionally to eradicate, reduce or maintain pest populations below economic injury thresholds. Pest control at the farmer level should be reevaluated in order that part of the pest management programs can be conducted on the entire pest infestation region.

4. Fundamental research should be supported by U. S. Department of Agriculture and the Environmental Protection Agency which elucidates basic life processes. Such understanding is to provide the basis for improved pest management with minimum disruption of the ecosystem.

5. Educational training at the farm level in pest surveillance, integrated control, population dynamics and ecological aspect must be expanded.

6. Federal and state governments must drastically increase their financial support if alternative methods are to emerge as effective methods of control and management.

7. Protocols for safety tests of microbial pesticides and hormones should be defined by the Food and Drug Adminstration so that researcher as well as prospective producers will be guided by common requirements

8. The U. S. Department of Agriculture in conjunction with other governmental agencies and scientific organizations should seek greater international cooperation in minimizing pest migration and in developing biological control and alternatives to pesticides.

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APPENDIX

BRIEF OF
STATE OF NORTH CAROLINA
SCOTLAND COUNTY COURT

State of North Carolina vs. Stanley Svrlin o, 1953

The defendant, Stanley Svrlingo, a resident of the State of Florida, was charged with engaging in the custom application of pesticides within Scotland County, North Carolina without a license issued by the Commissioner of Agriculture as required by North Carolina General Statutes, Chapter 106, Article 4B, Section 65.14. The term, "custom application of pesticides" is defined in the law to mean any application of pesticides by aircraft.

The defendant was the operator of a Steerman aircraft. He was warned by the enforcement officer that he could not engage in the custom application of pesticides without a license. The following day the enforcement officer who had warned the defendant personally observed that the aircraft operated by the defendant was dusting a cotton field.

Evidence collected by the State of North Carolina included the eye witness testimony of the enforcement officer, farmers who had contracted for service by the defendant and cancelled checks of farmers who paid earlier for dusting services by the defendant.

Conclusions

A warrant was issued for the arrest of the defendant. Bond in the amount of $25 was set and posted. At the time of the trial, the defendant did not appear. The defendant was observed in North Carolina the following year but the Scotland County solicitor refused to reopen the case.

BRIEF OF
STATE OF NORTH CAROLINA
MARTIN COUNTY COURT

State of North Carolina vs. Walter Ray Griffin, 1956

The defendant, Walter Ray Griffin of RFD Greensboro, North Carolina, was charged with engaging in the custom application of pesticides without a license issued by the Commissioner of Agriculture. The defendant was charged with violating Chapter 106, Article 4B, Section 65.14 of the General Statutes of the State of North Carolina.

Private individuals advised enforcement authorities that an advance agent (spotter) was contacting farmers in Martin County to arrange business contracts for the aerial application of pesticides by the defendant.

Evidence was obtained by subpoena of the advance agent and several farmers. The records of several farmers were obtained which indicated the number of acres sprayed by the defendant using a J-3 Cub aircraft and the amount of dollars paid to the defendant.

Conclusions

The defendant entered a plea of guilty and was convicted. The sentence required the defendant to pay a fine of $100 plus the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
WASHINGTON COUNTY COURT

State of North Carolina vs. Delmar Owens, 1957

The defendant, Delmar Owens of Washington City, North Carolina was charged with violation of Chapter 106, Article 4B, Section 65.14 of the North Carolina General Statutes by operating a J-3 Cub aircraft in Washington County and engaging in the custom application of pesticides without a license from the Commissioner of Agriculture.

The evidence obtained by the enforcement officials included the bills sent by the defendant to several farmers, their cancelled checks and the testimony of several farmers. The defendant was hired by the farmers to apply pesticides to tobacco and soybean crops.

Conclusions

The defendant entered a plea of Guilty. The Clerk of the Court permitted the defendant to satisfy the misdeamor by payment of the court cost only.

BRIEF OF
STATE OF NORTH CAROLINA
ROCKINGHAM COUNTY COURT

State of North Carolina vs. Jack Reynolds, 1958

The defendant, Jack Reynolds, a native of Candor, North Carolina, was charged with violation of Chapter 106, Article 4B, Section 65.14 of the General Statutes of North Carolina. Specifically, he engaged in the custom application of pesticide in Rockingham County by operating a Steerman aircraft in the aerial application of pesticides without the license required by the cited statute.

The defendant was warned of the requirement for a license by enforcement officials several times prior to the indictment. Farmers in the area who had engaged the defendant were subpoenaed by the State. The records of the farmers and their cancelled checks showing payment to the defendant were offered in evidence.

Conclusions

The defendant pleaded Not Guilty. He was convicted of violating the cited statute. The sentence was a fine of $100 plus the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
BEAUFORT COUNTY COURT

State of North Carolina vs. Tom Stancill, 1965

The State of North Carolina indicted Tom Stancill for violation of Chapter 106, Article 4B, Section 65.14 of the General Statutes of North Carolina. The defendant, Mr. Stancill, was charged with engaging in the aerial application of pesticides in Beaufort County, specifically operating a Piper-Pawnee PA18 aircraft.

The defendant was a chronic violator who was warned by enforcement officials numerous times. Mr. Stancill operates a business known as Tom Stancill Flying Service.

Several eye witnesses saw him spraying. On indictment he posted a $200 bond. Evidence included the bills of services rendered from several farmers, photostats of cancelled checks of farmers who paid for the services. The defendant was subsequently involved in an aerial accident during an application flight.

Conclusions

The defendant entered a plea of Guilty with the Clerk of the Court and exercised his right to a waiver of appearance for a misdeamor. The Clerk of the Court accepted settlement of $15 fine plus court cost.

BRIEF OF
STATE OF NORTH CAROLINA
BEAUFORT COUNTY COURT

State of North Carolina vs. Merrill Mayo, 1969

The defendant, Merrill Mayo, was charged with engaging in the custom application of pesticides without a license as required by Chapter 106, Article 4B, Section 65.14 of the General Statutes of North Carolina. Specifically, the defendant as the aircraft owner failed to obtain a license.

The aircraft was found by investigators in Newburn, North Carolina as being without a proper license. Both the defendant and the pilot, Richard Nanney, were informed by the investigators of the law requiring a license. The following day the investigators found the aircraft on a dirt strip in the farming area. A farmer informed the investigator that Mayo's aircraft had sprayed his fields that morning. Again the pilot was instructed. He subsequently engaged in application operations witnessed by the investigator.

Conclusions

The defendant entered a plea of Not Guilty. The eyewitness testimony of the investigator resulted in a conviction. The sentence was a $100 fine plus the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
BEAUFORT COUNTY COURT

State of North Carolina vs. Richard Nanney, 1969

The defendant, Richard Nanney, was charged under Chapter 106, Article 4B, Section 65.14 of the North Carolina General Statutes of operating an aircraft engaged in the custom application of pesticides without a license.

The circumstances and testimony in this case are recorded in the earlier case entitled: State of North Carolina versus Merrill Mayo, 1969.

Conclusions

This case was tried subsequent to the case of Merrill Mayo. The defendant pleaded Guilty. The conviction carried a sentence of a $50 fine plus the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
BEAUFORT COUNTY COURT

State of North Carolina vs. Rodney Godley, 1969

The defendant, Rodney Godley, a native of Beaufort, North Carolina was charged under Chapter 106, Article 4B, Section 65.14 of engaging as a contractor for the custom application of pesticides without a license.

A farmer was prepared to testify that Rodney Godley had contracted for spraying his crops. He had engaged Godley's firm and subsequently witnessed the actual spraying. At the time of arrest, the defendant posted a $200 bond.

Conclusions

The defendant could not be found at the time of trial. The State of North Carolina subsequently elected to nol pros the case.

BRIEF OF
STATE OF NORTH CAROLINA
BEAUFORT COUNTY COURT

State of North Carolina vs. Thomas E. Stancil, Jr., 1969

The defendant, Thomas E. Stancil, Jr., of Beaufort County, doing business as Stancil Flying Service was charged with violation of Chapter 106, Article 4B, Section 65.14 of the North Carolina General Statutes.

Specifically, Mr. Stancil was charged with operating a Cal-Air aircraft in the aerial application of pesticides without a license. The evidence collected by the investigators included bills to farmers submitted by Stancil for services, cancelled checks of farmers paying for the custom application of pesticides. In addition, several farmers were willing to testify that they engage Stancil for custom application services and that he did perform these services.

Conclusions

The defendant entered a plea of Guilty. He was convicted and sentenced to pay a fine of $100 plus the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
HENDERSON COUNTY COURT

State of North Carolina vs. Ernest Marshall, 1969

The defendant, Ernest Marshall, a resident of the State of Florida, was charged with operating an aircraft engaged in the custom application of pesticides without a license from the Commissioner of Agriculture. The statutory authority for the charge was cited as Chapter 106, Article 4B, Section 65.14 of the North Carolina General Statutes.

Mr. Jack Atkinson complained to the state investigators that the defendant did on numerous occasions, spray his land in an intentional discharge from aircraft. These nuisance incidents resulted in an investigation. The defendant operated a Steerman aircraft and engaged without proper license in the custom application of pesticides.

Conclusions

The defendent entered a plea of Guilty. An attorney for the complainant, Jack Atkinson, sat at the trail as a friend of the State. The judgement of the court was six months sentence of imprisonment suspended for five years on the conditions that: (1) the defendant not fly over the property of Jack Atkinson, (2) the defendant not spray within two miles of the City of Hendersonville, North Carolina, (3) the defendant not spray within one mile of Jack Atkinson's property, (4) the defendant not apply any pesticides without a valid license from the Commissioner of Agriculture and (5) the defendant pay the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
BEAUFORT COUNTY COURT

State of North Carolina vs. James Clark, 1969

The defendant, James Clark, a resident of Iowa was charged with operating an aircraft engaged in the custom application of pesticides without a license. The charge was a violation of Chapter 106, Article 4B, Section 65.14 of the North Carolina General Statutes.

A warrant was issued and bond posted in the amount of $200. A farmer testified he had been contacted by Rodney Godley, an advance agent (spotter) and had engaged the services of the firm represented by Godley. He also testified he had witnessed the actual spraying performed by the defendant.

Conclusions

The defendant entered a plea of Guilty. He was convicted. The sentence imposed was a $100 fine plus the court cost.

BRIEF OF
STATE OF NORTH CAROLINA
CLEVELAND COUNTY COURT

State of North Carolina vs. James E. Ellis, 1969

The defendant, James E. Ellis, a native of Cleveland, North Carolina, was charged with violating the General Statutes of North Carolina, specifically Chapter 106, Article 4B, Section 65.14.

Several farmers informed the investigator that the defendant had been engaged by them and did perform the custom application of pesticides. A warrant was issued for the defendant. The case was continued three times. At the time of the trial the first witness expressed a loss of memory. At the suggestion of the prosecutor, the investigator obtained two new warrants. These warrants cited that violation occurred on the particular lands of each of the two farmers.

Conclusions

The case was continued nine times. The State of North Carolina enforcement officials informed the county prosecutors they would appear when the parties were present. Substantial time has passed and the case has since been nol prossed.

BRIEF OF
STATE OF NORTH CAROLINA
PAMLICO COUNTY COURT

State of North Carolina vs. Daniel Emery Jones, 1970

The defendant, Daniel Emery Jones, a pilot was charged with engaging in the custom application of pesticides without a license in violation of Chapter 106, Article 4B, Section 65.14 of the General Statutes of North Carolina.

This charge arose from an incident in which the defendant operated an aircraft for Mr. R. E. King, the aircraft owner. The defendant sprayed a pesticide containing methyl parathion on a field of sweet corn belonging to Sam Jones, a farmer, adjacent to a housing project. It was reported that the spray also landed on several black residents of a family living in the housing project. The residents got sick but would not go to a doctor after the investigator requested them to do so.

Conclusion

The defendant entered a plea of Guilty. The judgement was that the defendant pay the court cost.

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