EFFECTS OF FALLOUT ON AGRICULTURAL ECOSYSTEMS IN CALIFORNIA

FINAL REPORT
MAY 1972

Contract No. DAHC20-69-C-0294
OCD Work Unit No. 3145C
Prepared for:
OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

UNIVERSITY OF CALIFORNIA
EDUCATION RESEARCH SERVICE
RIVERSIDE

EFFECTS OF FALLOUT ON AGRICULTURAL ECOSYSTEMS IN CALIFORNIA

FINAL REPORT
MAY 1972

By: Vernon M. Stern
Nicholas Toscano

Contract No. DAHC20-69-C-0294
OCD Work Unit No. 3145C
Prepared for:
OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

UNIVERSITY OF CALIFORNIA
EDUCATION RESEARCH SERVICE
RIVERSIDE

OCD Review Notice
This report has been reviewed by the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) DEPARTMENT OF ENTOMOLOGY University of California Riverside, California 92502	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

EFFECTS OF FALLOUT ON AGRICULTURAL ECOSYSTEMS IN CALIFORNIA

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

STERN, Vernon M.
Professor of Entomology

Nicholas Toscano
Research Assistant

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1972	90	22

8a. CONTRACT OR GRANT NO. DAHC20-69-C-0294 b. PROJECT NO. OCD Work Unit No. 3145C c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

"Approved for public release; distribution unlimited."

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Civil Defense Department of the Army Washington, D.C. 20310

13. ABSTRACT

A survey was made of the major food crops grown in California and the areas where these crops are grown. The mobility of the major insect and mite pests attacking these crops was used as a basis for predicting their reinvasion potentials, i.e., the ability of insects to repopulate an area in which they had been eradicated.

The data of elapsed time for recolonization after theoretical elimination from fallout, indicate that most pest insects will be capable of continuing competition with man for food crops following nuclear disaster. The data clearly indicate that the arthropods, by their resistance to radiation; diverse life cycles; and dispersal habits, can be expected to survive in large numbers and rapidly reinvade disturbed areas.

Radiation from fallout by the detonation of nuclear weapons on potential targets in California could destroy many insects and crops in large parts of the central and southern agricultural areas. The distribution of the fallout from even very heavy attacks is believed to be such that areas of low fallout occur throughout the state, and in them reservoirs of surviving insect pests will exist. Upon resumption of agriculture, reinfestation by these pests will cause significant losses of potential food production if pesticides are not available or if other insect control measures are restricted.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Arthropod Pests						
Severity of Pests						
Dispersion of Pests						
California Vegetable Crops						
California Tree Crops						
California Field Crops						
Marketing Standards						
Pesticides						
Pesticides and Radiation						
Fallout Effects on Arthropods						

TABLE OF CONTENTS

INTRODUCTION

The possible disruption from nuclear attack to food production in California is of vital concern to many public agencies. This concern is particularly important because California produces about ten percent of the United States total agricultural production in terms of cash receipts. This accounts for about six percent of the livestock and fourteen percent of the crop value.

One question related to California food production is whether a nuclear disaster is likely to produce conditions that favor outbreaksof ravaging mite and insect pests. Stern (1) suggested that the available data indicate this may well happen. However, he noted that pest outbreaks would not be directly caused by radioactive fallout. The reason for damaging pest numbers would be the removal or curtailment of constraints which are now used to suppress pest arthropod species. That is, year after year, a wide variety of pests are held below damaging numbers by insecticides and cultural methods. If for some reason, pesticides were not available or farm equipment could not be used efficiently, it can be expected that many pest species would rise above their economic threshold and could cause severe crop injury.

Moreover, there are many indications that pest problems are far more severe today than they were a decade ago. One reason for this is that the widespread and often indiscriminate use of insecticides has eliminated or suppressed severely large numbers of predators and parasites that help regulate the population density of pest species. With natural enemies of pests present in low numbers combined with a possible restriction on the availability of pesticides, pest species could increase rapidly to high numbers and cause severe crop damage before predator and parasite populations could overtake their hosts.

An increase in some pest populations could also occur if normal agricultural practices such as early planting or plowing of crops, destroying insect infested material and general field sanitation are restricted by lack of fuel or residual fallout radiation. Under these conditions some pest species could increase to high numbers, whereas under ordinary circumstances many overwintering forms are killed by efficient farming operations.

Research Plan

A survey was made of the major food crops grown in California and the areas where these crops are grown. The mobility or flight characteristics of the major insect and mite pests attacking these crops were used as a basis for predicting their reinvasion potentials, i.e., the ability of insects to repopulate an area in which they previously been erradicated.

General Summary

The data of elapsed time for recolonization after theoretical elimination from fallout, indicate that most pest insects will be capable of continuing competition with man for food crops following nuclear disaster. The data clearly indicate that the arthropods, by the nature of their resistance to radiation, their diverse life cycles and ecology, and because of their migration and dispersal habits, can be expected to survive in large numbers and rapidly reinvade disturbed areas.

Radiation from fallout created by the detonation of nuclear weapons on potential targets in California could destroy many insects and crops in large parts of the central and southern agricultural areas. The distribution of the fallout from even very heavy attacks is believed to be such that areas of low fallout occur throughout the state and in them reservoirs of surviving insect pests may exist. Upon resumption of agriculture, reinfestation by these pests will cause significant losses of potential food production if pesticides are not available or if other insect control measures are restricted.

TERMINOLOGY *

To clarify the discussion in other parts of this paper some definitions and explanations of terms are here given:

BIOLOGICAL CONTROL. The action on parasites, predators, or pathogens on a host or prey population which produces a lower general equilibrium position than would prevail in the absence of these agents. Biological control is a part of natural control (q.v.) and in many cases it may be the key mechanism governing the population levels within the framework set by the environment. If the host or prey population is a pest species, biological control may or may not result in economic control. Biological control may apply to any species whether it is a pest or not, and regardless or whether or not man deliberately introduces, manipulates, or modifies the biological control agents.

ECONOMIC CONTROL. The reduction or maintenance of a pest density below the economic-injury level (q.v.).

ECONOMIC-INJURY LEVEL. The lowest population density that will cause economic damage. Economic damage is the amount of injury which will justify the cost of artificial control measures; consequently, the economic-injury level may vary from area to area, season to season, or with man's changing scale of economic values.

ECONOMIC THRESHOLD. The density at which control measures whould be determined to prevent an increasing pest population from reaching the economic-injury level. The economic

* After Stern, et al. (2)

threshold is lower than the economic-injury level to permit sufficient time for the initiation of control measures and for these measures to take effect before the population reaches the economic-injury level.

ECOSYSTEM. The interacting system comprised of all the living organisms of an area and their nonliving environment. The size of the area must be extensive enough to permit the paths and rates of exchange of matter and energy which are characteristic of any ecosystem.

GENERAL EQUILIBRIUM POSITION. The average density of a population over a period of time (usually lengthy) in the absence of permanent environmental change. The size of the area involved and the length of the period of time will vary with the species under consideration. Temporary artificial modifications of the environment may produce a termporary alteration of the general equilibrium position (i.e., a temporary equilibrium).

GOVERNING MECHANISM. The actions of environmental factors, collectively or singly, which so intensify as the population density increases and relax as this density falls that population increase beyond a characteristic high level is prevented and decrease to extinction made unlikely. The governing mechanisms operate within the framework or potential set by the other environmental elements.

NATURAL CONTROL. The maintenance of a more or less fluctuating population density within certain definable upper

<u>and lower limits over a period of time by the combined actions of abiotic and biotic elements of the environment</u>. Natural control involves all aspects of the environm , not just those immediate or direct factors producing premature mortality, retarded development, or reduced fecundity; but remote or indirect factors as well. For most situations, governing mechanisms (q.v.) are present and determine the population levels within the framework or potential set by the other environmenta elements. In the case of a pest population, natural control may or may not be sufficient to provide economic control.

ARTHROPOD PESTS

There are a number of arthropods that have been pests of man for eons of time. The most important are those of medical importance such as the mosquito vectors of malaria. In years of devastating outbreak, the plague grasshoppers could also be considered in this category when they denuded huge areas occupied by nomadic tribesmen. There were of course other species that fed on parts of plants eaten by man; but in natural undisturbed communities, rarely do arthropods devastate the plant environment (Huffaker 3, Doutt 4).

As early man began to congregate in the most rudimentary forms of society and divisions of labor evolved, man became dependent on certain plant species and a number of arthropod species began to increase to pest status. The increase to pest status of a particular species may be the result of a single factor or a combination of factors (Stern 1, and Stern et al. 2).

First, by changing or manipulating the environment, man has created conditions that permit certain species to increase their population densities (Ullyett, 5). As mentioned, this occurred in many cases when man began to select special types of food plants and grow them on progressively larger acreages. A recent example is the rise of the Colorado potato beetle, <u>Leptinotarsa decemlineata</u> (Say) to pest status. Prior to 1850, this obscure beetle apparently existed along the Eastern slopes of the Rocky Mountains and was of no importance to anyone. However, when the potato, as well as other solanaceous plants, was brought under widespread cultivation in the United States, a change favorable to the beetle occurred in the environment which enabled this insect to become very quickly an important pest. Similarly, when alfalfa, Medicago sativa L., was introduced into California about 1850, the alfalfa butterfly, Colias eurytheme Boisduval, which had previously occurred in low numbers on native legumes, found a widespread and favorable new host plant in its environment, and it subsequently became an economic pest (Smith and Allen 6).

A second way in which arthropods have risen to pest status has been through their transportation across geographical barriers while leaving their specific predators, parasites and diseases behind. The increase in importance through such transportation can be illustrated by the cottony cushion scale, Icerya purchasi Maskell.

This scale insect was introduced into California from Australia on acacia in 1868. Within the following two decades, it increased in abundance to the point where it threatened economic disaster to the entire citrus industry in California. Fortunately, the timely importation and establishment of two of its natural enemies, Rodolia cardinalis (Mulsant) and Cryptochaetum iceryae (Williston), resulted in the complete suppression of I. purchasi as a citrus pest (Doutt, 7).

A third cause for the increasing number of pest arthropods has been the establishment of progressively lower economic thresholds (see page 4). This can be illustrated by lygus bugs (Lygus spp.) on lima beans. Not too many years ago, the blotches caused by lygus bugs feeding on an occasional lima bean were of little concern, and lygus bugs were considered a minor pest on this crop. However, with the emphasis on product appearance in the frozen-food industry, a demand was created for a near-perfect bean. For this reason, economic injury thresholds were established and lygus bugs are now considered serious pests of lima beans.

A fourth way that insects can rise to pest status is by the elimination of natural enemies that hold a potential pest in check. For example, during the height of the emergency chemical campaign against the exotic spotted alfalfa aphid, Therioaphis trifolii (Monell), in 1955 through 1957 in southern and central California, there were unprecendented numbers of a leaf miner, Liriomyza sp.; spider mites, Tetranychus spp.; pea aphid, Acyrthosiphon pisum (Harris); beet armyworm, Spodoptera exiqua (Hubner); and a leaf roller, Platynota stultana Walsingham, causing damage in alfalfa. Circumstantially, at least, these pest upsurges seemed to have been correlated with the widespread and repeated use of the broadly toxic pesticides, parathion and malathion (van den Bosch and Stern, 8). Certain of these pests caused considerable damage to alfalfa and one, P. stultana, spread to cotton where, for the first time, it caused serious damage to this crop in southern California (Atkins, et al., 9, 10).

When the emergency parathion and malathion spray campaign gave way to more sophisticated methods of pest control where low dosages of Demeton were used selectively, these species subsided to minor pest status in alfalfa and cotton.

Other examples include the present outbreak of the beet armyworm, S. exiqua; cabbage looper, Trichoplusia ni (Hubner); and bollworm, Heliothis zea (Boddie) following widespread treatments of Azodrin® and Bidrin® for lygus bug control in cotton fields on the west side of the San Joaquin Valley, California. The 1969 outbreak of the cotton leaf perforator, Bucculatrix thurberiella Busek, following widespread chemical treatments for control of the pink bollworm, Pectinophora gossypiella (Saunders). in the Imperial Valley, California is another example.

THE SEVERITY OF PESTS IN RELATION TO THEIR GENERAL EQUILIBRIUM POSITION AND ECONOMIC THRESHOLD

In order to determine the relative economic importance of pest species, both the economic threshold and general equilibrium position of the pests must be considered. It is the general equilibrium position and its relation to the economic threshold, in conjunction with the frequency and amplitude of fluctuations about the general equilibrium position, that determine the severity of a particular pest problem.

In the absence of permanent modification in the composition of the environment, the density of a species tends to fluctuate about the general equilibrium position as changes occur in the biotic and abiotic components of the environment. As the population density increases, the density-governing factors respond with greater and greater intensity to check the increase; as the population density decreases, these factors relax in their effects. The general equilibrium position is thus determined by the interaction of the species population, these governing mechanisms, and the other natural control factors of the environment. A permanent alteration of any factor of the environment, either abiotic or biotic, or the introduction of new factors may alter the general equilibrium position.

The economic threshold of a pest species can be at any level above or below the general equilibrium position or it can be at the same level. Some phytophagous species may utilize our crops as a food source but even at their highest attainable density are of little or no significance to man. Such species can be found associated with nearly every crop of commercial concern.

Populations of other arthropods rarely exceed the economic threshold and these consequently are occasional pests. Only at their highest population densities will chemical control be necessary.

When the general equilibrium position is close to the economic threshold, the population density will frequently reach the economic threshold. In some cases, the general equilibrium position and the economic threshold are at essentially the same level. Thus, each time the population fluctuates up to the level of the general equilibrium position, insecticidal treatment is necessary. In such species the frequency of chemical treatments is determined by the fluctuation rate about the general equilibrium position, which in some cases necessitates almost continuous treatment.

Finally, there are pest species in which the economic threshold lies below the general equilibrium position; these constitute the most severe pest problems in entomology.

The economic threshold may be lower than the level of the lowest population depression caused by the physical and biotic factors of the environment, e. g., many insect vectors of viruses. In such cases, particularly where human health is concerned, there is a widespread and almost constant need for chemical control.

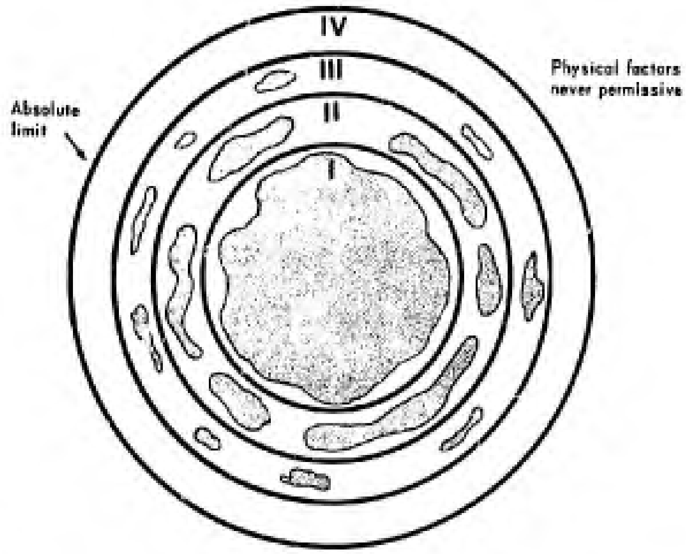
DISPERSION OF PEST SPECIES

A species population is not static. It is undergoing constant change within the limits imposed upon it by its genetic constitution and the characteristics of its environment. When the species is of greatest numerical abundance, it also has its widest distributional range and is of maximum economic status. When the species is at its lowest abundance, it is generally restricted in geographical range and is of only minor economic concern.

Figure 1 schematically illustrates the relationship between the geographic distribution of a species and the interrelatedness of physical and biotic factors in the environment. Each circle (zone) of the concentric series represents a type of environment. The irregular patches in each zone represent localized areas of relatively permanent favorability in regard to physical conditions and the interspaces represent the degree of waxing and waning of such areas in time.

The relative sizes of these zones as shown here have no significance. One species, such as the bollworm, Heliothis zea, may range over large areas encompassing several states, while another species may be restricted to a small area within a single state.

The environment of Zone 1 has nearly optimal climatic conditions, at least during a certain part of the year and permits an increase in numbers. In the environment of Zone 1, essentially the total area is represented by maximum favorability in the physical framework of the environment; hence, there is little room for physical conditions to alter population potential.



Zone I Stable zone of permanent occupancy. Most nearly optimal physical conditions.

Zone II Intermediate zone of permanent occupancy. Physical conditions intermediate.

Zone III Marginal zone of permanent occupancy. Physical conditions rigorous, mostly unfavorable, at very limited places permanently permissive.

Zone IV Zone of only temporary occupancy. Physical conditions only temporarily permissive anywhere. Dependant on immigration.

Fig. 1. The geographic distribution of a species population and the interrelation of conditioning and regulating forces. (After DeBach, (11.)

In the environment of Zone 3, permanently favorable localized habitats are greatly reduced. Thus, the waxing and waning of population potentials is a dominant feature relative to climatic factors causing population change.

In the environment of Zone 4, migrants from the more favorable areas are necessary to populate this area when favorability is temporarily permitted.

If any part of the species is eliminated in part of its range by pesticides, radioactive fallout, use of sterile males, unfavorable heat or cold, elimination of food and so forth, the survivors in the adjoining areas will repopulate the disturbed area once the unfavorable factor has disappeared. The rate of reinvasion will depend on prevailing physical factors and on the flight habits, behavior and ecology of the species involved.

MAJOR VEGETABLE, FRUIT AND NUT AND FIELD CROPS IN CALIFORNIA, THEIR DISTRIBUTION: THE MAJOR ARTHROPOD PESTS ATTACKING THESE CROPS AND A RATING OF THE REINVASION POTENTIAL OF THE PEST SPECIES AFTER POSSIBLE ELIMINATION FROM CERTAIN AREAS BY RADIOACTIVE FALLOUT.

The major crops of California include cotton, alfalfa hay, sugar beets, barley, wheat, rice, field corn and sorghum, safflower, beans, peas, potatoes, tomatoes, cucurbits (cucumbers, squash, pumpkins), various melons, artichokes, asparagus, cabbage, cauliflower, broccoli, brussels sprouts, lettuce, celery, sweet corn, carrots, table beets, sweet potatoes, turnips and radishes, vegetable seed crops, grapes, plums, prunes, nectarines, peaches, apricots, cherries, apples, pears, lemons, oranges, grapefruit, walnuts and almonds.

Identification of the major insect and mite pests attacking these crops was obtained from Faculty Specialists in the Departments of Entomology at Davis and Riverside, the Department of Entomology and Parasitology, Berkeley and the Agricultural Extension Service of the University of California. The data on flight habits of each pest species was also obtained from these Specialists in order to predict the reinvasion potential of the pest after elimination from an area. Supplementary data to support these predictions were obtained from literature and knowledge on the general flight habits of the various insect orders. In this analysis, reinvasion potential indices were established to reflect only the flight and dispersal or migratory capabilities of the species in question. A more perfect index would include a reestablishment potential. Such factors as biotic potential, feeding habits, food availability, reproductive rates, longevity and the economic threshold of each pest would be combined with the reinvasion potential to give an estimation of the ability of a species to return to pest status after elimination from a given area. However, the data needed for the formation of such an index for all pests listed herein is not available in the literature. This will require a thorough study of the population dynamics of the pest species concerned along with similar studies on their parasites and predators.

The references to the reinvasion potential (=R.P.) of the pest species attacking the crops in tables 2-12; 14-18 and 20-27 are discussed below. The migration time intervals refer to the probable time it would take a representative pest to travel 30-50 miles from one direction during the favorable season.

(1) ===those arthropod pests that do not have wings and whose body size is too large to be carried long distances by wind currents; elapsed time, 1 or more years.

(2) ===those species that are capable of flying but for various reasons are poor fliers or can migrate moderate distances without flight; elapsed time, entire growing season.

(3) ===those species that are considered average fliers; elapsed time, 1 to 3 months.

(4) ===those species that are considered very good fliers and can disperse many miles in a short period of time; elapsed time, a few days to 1 to 2 weeks.

(5) ===those species that may or may not have wings, but are transported by wind currents, man and animals, water, and so forth. All mite species are wingless but many of them are transported by wind currents because of special habits of dropping into the air by silken filaments and then being transported or carried away; elapsed time, 3 months to an entire growing season. For scale insects in

which only the males have wings, elapsed time would be at least 1 or more entire growing seasons. Pests in this category that have wings can become airborne and may then be carried long distances with the help of air currents, such as aphids, leafhoppers, etc.; elapsed time, 1 week with favorable winds to an entire growing season. Occasionally, favorable winds may assist the movement of species in categories 2, 3, and 4 above.

CALIFORNIA VEGETABLE CROPS

There are over 800,000 acres of vegetables grown in California each year. There are also about 90-100,000 acres of potatoes grown in the State. This amounts to nearly 1 billion dollars in total value. The major vegetables include artichokes, asparagus, beans, broccoli, brussels sprouts, cabbage, cantaloupes and other melons, carrots, cauliflower, celery, sweet corn, cucumbers, garlic, lettuce, onions, green peas, peppers, potatoes, sweet potatoes, spinach, strawberries, tomatoes, watermelons, and a wide variety of miscellaneous vegetables. California accounts for 38 percent of the Nation's total production of the 27 principal fresh market crops and 43 percent of the total production of the ten major processing crops.

California produces 100 percent of the Nation's artichokes, garlic and market green peas, 89% - brussels sprouts, 85% - broccoli, 84% - honeydew melons, 70% - processing tomatoes, 67% - cauliflower, 65% - cantaloupes and lettuce, 59% - celery, 55% - strawberries, 50% - processing spinach, 48% - processing lima beans, 46% - asparagus, 43% - carrots and 32% - fresh market tomatoes.

Vegetable crops are grown in all areas of the State except the mountain regions. (Fig. 2, Table 1).

Fig. 2. Distribution of areas of major fresh market vegetables (Anon. 12). (California Vegetable Crops, 1967-68). Table 1 gives an explanation of these regions and the major crops produced in each region.

Table 1. CALIFORNIA'S MAJOR FRESH MARKET VEGETABLE PRODUCING DISTRICTS

REGION

1. <u>Tulelake-Butte Valley</u>: Onions, potatoes
2. <u>Sacramento Valley</u>: Honeydews, persians, other melons, tomatoes, watermelons
3. <u>Delta</u>: Asparagus, sweet corn, onions, peas, potatoes, tomatoes
4. <u>Brentwood-Tracy</u>: Sweet corn, lettuce, tomatoes
5. <u>Santa Cruz-San Mateo Coast</u>: Artichokes, brussels sprouts, broccoli, cauliflower
6. <u>Fremont-San Jose</u>: Broccoli, cauliflower, celery, sweet corn, lettuce, onions, peas, peppers, strawberries, tomatoes
7. <u>Patterson-Newman</u>: Cantaloups, honeydews, other melons, sweet corn, lettuce, tomatoes, peppers
8. <u>Modesto-Turlock</u>: Carrots, honeydews, other melons strawberries, sweet potatoes, tomatoes, watermelons
9. <u>Salinas-Watsonville</u>: Artichokes, snap beans, broccoli, cabbage, carrots, cauliflower, celery, garlic, lettuce, onions, peas, spinach, potatoes, strawberries, tomatoes
10. <u>Gilroy-Hollister</u>: Sweet corn, garlic, lettuce, onions, potatoes, peppers, peas, tomatoes
11. <u>West Side</u>: Cantaloups, honeydews, lettuce, persians, tomatoes
12. <u>Merced-Atwater</u>: Peppers, sweet potatoes, tomatoes, watermelons
13. <u>Kingsburg-Dinuba</u>: Sweet potatoes, watermelons
14. <u>Cutler-Orosi</u>: Tomatoes, other spring vegetables
15. <u>Kern-Tulare</u>: Sweet corn, cantaloups, garlic, honeydews, lettuce, onions, peas, potatoes, sweet potatoes, watermelons

REGION

16. Santa Maria-Oceano: Artichokes, snap beans, broccoli, cabbage, carrots, cauliflower, celery, lettuce, peas, potatoes, strawberries

17. Oxnard: Broccoli, cabbage, carrots, cauliflower, celery, lettuce, strawberries, tomatoes

18. Antelope Valley: Cantaloups, onions, potatoes

19. Los Angeles-Orange County: Asparagus, snap beans, cabbage, carrots, celery, cauliflower, sweet corn, lettuce, peppers, strawberries, tomatoes

20. Chino-Ontario: Sweet corn, onions, potatoes, sweet potatoes

21. Perris-Hemet: Cantaloups, other melons, onions, potatoes, sweet potatoes, watermelons

22. Oceanside-San Luis Rey: Snap beans, cabbage, lettuce, peppers, strawberries, tomatoes

23. Coachella Valley: Asparagus, snap beans, carrots, sweet corn, cantaloups, onions, peppers, tomatoes, watermelons

24. Blythe: Sweet corn, cantaloups, honeydews, lettuce, other melons, onions

25. Chula Vista: Snap beans, cabbage, celery, cucumbers, lettuce, strawberries, peppers, tomatoes

26. Imperial Valley: Asparagus, broccoli, cabbage, cantalopes, carrots, cucumbers, garlic, lettuce, onions, tomatoes, watermelons

GREEN, WHITE AND RED VEGETABLES

These include cucurbits (melons, cucumbers, and squash), cole crops (cabbage, cauliflower, broccoli and brussels sprouts), tomatoes, artichokes and asparagus. There are nearly 480,000 acres of vegetables grown each year, and tomatoes account for 260,000 acres. Vegetables are grown from the upper Sacramento Valley through the Salinas, Santa Maria, San Joaquin Valleys and down through the Imperial Valley (Figure 2, Table 1).

Insect pests: The major pests of vegetable crops are Lepidopterous larvae, aphids, leafhoppers, tree bugs, beetles, thrips, and flies. The aphids and leafhoppers can be very destructive when they become vectors of plant virus pathogens.

Reinvasion potential: Nearly all the Lepidopterous adults represented are excellent fliers as are many of the beetles. With favorable wind currents, the aphids, leafhoppers and thrips are capable of widespread dispersal. It can be expected that nearly all the vegetable crop pests would rapidly reinvade areas where they might be eliminated from fallout.

Table 2. Major pests of cucurbits (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Provenus mindara Rough-skinned antworms	High	4
Cutworms (Non-specific)	High	4
Trichoplusia ni Cabbage looper	Moderate	4
HOMOPTERA		
Leafhoppers (Non-specific)	High	5
Aphids (Non-specific)	High	5
COLEOPTERA		
Dibrotica U. undecimpumactata	Moderate	4
DIPTARA		
Agromyza spp.	Moderate	4
Melanagromyza Spp. Leafminers	Moderate	4
THYSONOPTERA		
Thrips (Non-specific)	Moderate	5

Table 3. Major pests of cole crops (by orders); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Trichoplusia ni Cabbage looper	High	4
Plutella maculipennis Diamondback moth	Moderate	4
Cutworms (Non-specific)	High	4
Pieris rapae Imported cabbageworm	Moderate	4
DIPTERA		
Hylemya brassicae Cabbage maggot	Moderate	4
HOMOPTERA		
Myzus persicae Green peach aphid	High	5
Brevicoryne brassicae Cabbage aphid	High	5

Table 4. Major pests of tomatoes (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Manduca sexta Tobacco hornworm	High	4
M. guenquemoculata Tomato hornworm	Moderate	4
Keiferia lycopersicella Tomato pinworm	High	4
Heliothis zea Tomato fruitworm	High	4
Phthorimaea operculella Potato tuberworm	High	4
Cutworms (Non-specific)	High	4
HOMOPTERA		
Circulifer tanellus Beet leafhopper	High	5
Aphids (Non-specific)	Moderate	5
DIPTERA		
Drosaphila melanogaster Drosaphila	High	3

Table 5. Major pests of artichokes and asparagus (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Platyptilia carduidactyla Artichoke plume moth	High	4
Oeobia rubigalis Celery leaf tier	Moderate	4
HOMOPTERA		
Aphids (Non-specific)	High	5
DIPTERA		
Agromyza spp.	Moderate	4
Melanagromyza spp. Leafminers	Low	4
ACARINA		
Tetranychus urticae Two-spotted spider mite	High	5

VEGETABLE ROOT CROPS

These include turnips, sweet potatoes, beets and carrots. Most of the acreage can be found in the Sacramento and Salinas Valleys, and carrot production in the San Joaquin and Imperials Valleys (Fig. 2, Regions 9, 12, 13, 15, 16, 17, 19, 20, 21, 23, 26).

Insect pests: The major pests of vegetable root crops are lepidopterous larvae, aphids beetles, and flies. Some of these pests feed on the foliage, while others feed on the roots. The aphids are very important because they transmit plant virus diseases.

Reinvasion potential: Nearly all the lepidopterous adults and beetles are excellent fliers and are capable of rapid reinfestation into an area from which they were eliminated. As previously mentioned, aphids, mites and thrips are capable of rapid dispersal in favorable wind currents. Mites cannot fly, but are able to produce a long threadlike filament which carries them by the wind. All the vegetable root crop insect pests will have a very high reinvasion potential (Table 6).

Table 6. Major pests of root crops (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTEROUS		
Peridroma sancia Variegated antworm	High (all crops, seedling stages)	4
Trichophusia ni Cabbage Looper	Moderate (turnips)	4
Armyworms (Non-specific)	Moderate (turnips)	4
Bedellia somnulentella Morning glory leafminer	Moderate (sweet potatoes)	4
COLEOPTERA		
Listroderes costirostris obliquus Vegetable Weevil	Moderate (turnips)	
Wireworms (Non-specific)	High	3
Flea Beetles (Non-specific)	Moderate	2
Darling Beetles (Non-specific)	Moderate	3
HOMOPTERA		
Myzus persicae Green peach aphid	High	5
HOMOPTERA		
Rusty Banded aphid	High (carrots)	5
Tulip aphid	High (carrots)	5
HEMIPTERA		
Lygus hesperus *Lygus elisus* Lygus bugs	High (Seed crops carrots)	
DIPTERA		
Hylemya brassicae Cabbage maggot	Moderate	4
Hylemya platura Seed corn maggot	Moderate	4
ACARINA		
Petrobia latens Petrobia mites	High (carrots)	5

VEGETABLE SEED CROPS

(Cabbage, broccoli, cauliflower, brussels sprouts, mustard, turnips and collards)

California produces the major portion of vegetable seed crops because it has a dry summer climate which increases seed set and improves harvestability of the seed. The dry climate also reduces the incidence of plant disease (i.e. bacteria and fungus) (Fig. 2, Regions 5, 6, 9, 14, 16, 17, 19, 22, 25, 26).

Insect pests: Insects from five different orders are pests of the seed vegetables.

Reinvasion potential: The lepidopterous adults are generally good fliers, as are the Hemipterous pests. The thrips and aphids are capable of long range dispersal when wind currents are favorable. All these insects would rapidly reinvade areas from which they were eliminated (Table 7).

Table 7. Major pests of vegetable seed crops (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Trichoplusia ni Cabbage looper	Moderate	4
HEMIPTERA		
Lygus hesperus *L. elisus* Lygus bugs	High	4
HOMOPTERA		
Myzus persicae Green peach aphid	High	5
Brevicoryne brassicae Cabbage aphid	High	5
THYSONOPTERA		
Thrips tabaci Thrips	Moderate	5
COLEOPTERA		
Centorhynchus assimilis Cabbage seed pot weevil	Low	2

POTATOES

There are about 91,000 acres of potatoes grown in California each year. The majority of these potatoes are grown in Kern County and in the Santa Maria Valley (Fig. 2, Regions 1, 3, 9, 10, 15, 16, 18, 20, 21).

Insect pests: These are species in the Orders Coleoptera Homoptera, and Lepidoptera. The beetles and lepidopterous pests (aphids, leafhoppers) feed on the foliage. The homopterous pests (aphids, leafhoppers) feed on the foliage and may cause severe damage because they transmit virus diseases.

Reinvasion potential: The flight characteristics of most potato pests are very good. With favorable wind currents, aphids can disperse rapidly. Nearly all pests of potatoes would soon reinvade a disturbed area where they may have been eliminated by fallout (Table 8).

Table 8. Major pest of potatoes (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Phthorimaea operculella Potato tuberworm	High	3
Cutworms (Non-specific)	Moderate	4
HOMOPTERA		
Eupoasea fabae Potato leafhopper	High (Virus transmission)	5
Aphids (Non-specific)	High (Virus transmission)	5
Myzus persicae Green peach aphid	High (Virus transmission)	5
COLEOPTERA		
Wireworms (Non-specific)	Moderate	3

BEANS AND PEAS, SNAP AND LIMA BEANS

There are approximately 50,000 acres of beans and 14,000 acres of peas produced throughout the state (Fig. 2 Regions 3, 9, 10, 15, 16, 19, 22, 23, 25).

Insect pests: A number of Lepidopterous larvae, aphids leafhoppers, beetles, true bugs, and flies are pests of beans and peas.

Reinvasion potential: The Lepidopterous adult are generally considered good to excellent fliers and are capable of far-reaching dispersal. The aphid, and leafhoppers are rather poor fliers and are depondent, for the most part, on passive dispersal by favorable wind currents. The beetles, true bugs and fly pests for these two crops are regarded as excellent fliers and capable of long dispersal. It is assumed that for all of the insects mentioned, that they would all be capable of rapid reinvasion into a devastated area after disipation of the radiation contaminants (Table 9).

Table 9. Major pests of beans and peas (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea Corn earworm	High	4
Cutworms (Non-specific)	High	4
Loopers (Non-specific)	High	4
HOMOPTERA		
Acyrthosiphon pisum Pea aphid	Moderate	5
Leafhoppers (Non-specific)	High	5
Aphids (Non-specific)	High	5
Trialenrodes spp. Whitefly	Moderate	5
HEMIPTERA		
Lygus hesperus *L. elisus* Lygus bugs	High	4
COLEOPTERA		
Bruchus rufimanus Broadbean weevil	Moderate	4
Diabrotica U. undecimpunitata Western spotted cucumber beetle	Low	4
DIPTERA		
Hylemya platura Seed corn maggot	High	4
Agromyza Spp.	Moderate	4
Melanagromyza Spp. Leafminers	Moderate	4

LETTUCE AND CELERY

There are approximately 132,800 acres of lettuce and 16,400 acres of celery grown in California. These crops are grown in the Sacramento Delta, Santa Maria, Kern County and Imperial Valleys (Fig.2, Regions 4, 6, 7, 9, 10, 11, 15 16,17,19,22, 24, 25, 26).

Insect pests: These crops are attacked mainly by lepidopterous larvae, beetles and aphids.

Reinvasion potential: The lepidopterous adults are excellent fliers and with favorable wind currents the aphids and mites are capable of extensive dispersal. Most of the pests of lettuce and celery would be capable of rapid re-invasion into and area after elimination by radioactive fallout (Table 10).

Table 10. Major pests of lettuce and celery (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA Anagrapha falcifera Celery looper	Low	4
Trichoplusia ni Cabbage looper	High	4
Estigmene acrea Salt Marsh caterpillar	Moderate	4
Spodoptera exigna Beet armyworm	High	4
Hiliothis zea Corn earworm	High	4
Cutworms (Non-specific)	Moderate	4
Armyworms (Non-specific)	Moderate	4
Oeobia rubigalis Celery leaf tier	Moderate	4
Papilio polyxenes Celery caterpillar	Low	4
HOMOPTERA Pemphigus gursorius Lettuce root aphid	Moderate	5
HOMOPTERA Aphids (Non-specific)	High	5
COLEOPTERA Darkling Beetles (Non-specific)	Moderate	3
Listroderes costirostris obliquus Vegetable weevil	Moderate	2
ACARINA Tetromychus telarius Red spider mite	Moderate	5

SWEET CORN

Sweet corn is grown in the southern part of the San Joaquin and in the Coachella Valley (Fig. 2, Regions 3,4,6, 7,10,15,19,20,23,24).

Insect pests: The major pests attacking sweet corn are beetles, lepidopterous larvae, seed-corn maggot and grasshoppers.

Reinvasion potential: The beetles are moderate fliers while the lepidopterous adults are generally excellent fliers. The seed-corn maggot adult and grasshopper also have excellent flight characteristics. Most of the species attacking sweet corn in California could rapidly reinvade an area where they had been eliminated (Table 11).

Table 11. Major pests of sweet corn (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea Corn earworm	High	4
Armyworms (Non-specific)	Moderate	4
Cutworms (Non-specific)	Moderate	4
COLEOPTERA		
Chaetocnema pulicaria Corn flea beetle	Low	2,5
ORTHOPTERA		
Grasshoppers (Non-specific)	High (cyclical)	4
DIPTERA		
Hylemya platura Seed-corn maggot	High	4

STRAWBERRIES

There are about 8,600 acres of strawberries grown in California. This acreage produces 144,000 tons of strawberries for, canning, freezing and fresh market. (Fig. 2, Regions 6, 8, 16, 17, 19, 22, 25).

Insect pests: The major pests of strawberries are lepidopterous larvae, true bugs, aphids and mites. Strawberries are a high value crop, and consequently require rather extensive pest control measures.

Reinvasion potential: The lepidopterous species and the true bug are generally excellent fliers and therefore, have a high capability of reinvasion. The aphids, although they are winged and the mite species which are not, would have a high reinvasion potential with favorable wind current for passive dispersal.

Table 12. Major pests of strawberries (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Cutworms (Non-specific)	High	4
HOMOPTERA		
Chaetosiphon fragaefolii aphid	High	5
HEMIPTERA		
Lygus hesperus Lygus bug	High	4
Lygus elisus Lygus bug	High	4
ACARINA		
Tetranychus urticae Two-spotted spider mite	High	5

CALIFORNIA TREE FRUITS, TREE NUTS, AND GRAPES

There are about 1,331,110 acres of deciduous tree fruits, grapes, tree nuts, semitropical tree fruits and citrus fruits grown in California. The yearly total value of production is slightly less than 1 billion dollars. California essentially produces all of the avocados, almonds and walnuts, figs, prunes, raisins and in other ways accounts for about 90 percent of the grape production in the United States. Citrus production amounts for nearly 20 percent of that grown in the Nation, with Florida producing nearly 80 percent.

Fig. 3 Distribution of areas of majcr fruit and nut crops of California (Anon. 13). (California Fruit and Nut Statistics, 1968-69). Table 13 gives an explanation of these regions and the crops produced in each region.

Table 13. CALIFORNIA FRUIT AND NUT CROPS

MAJOR PRODUCING DISTRICTS

REGION

1. Sacramento Valley: Almonds, apricots, grapes, olives, peaches, pears, plums, prunes, walnuts
2. Sierra Mountains: Apples, grapes, peaches, pears, plums
3. North Coast: Apples, grapes, pears, prunes, walnuts
4. Central Coast: Almonds, apples, apricots, cherries, grapes, pears, plums, prunes, walnuts.
5. San Joaquin Valley: Almonds, apricots, cherries, figs, grapes, lemons, nectarines, olives, oranges, peaches, persimmons, plums, pomegranates, prunes, walnuts
6. Southern California: Almonds, apples, apricots, avocados, dates, grapes, grapefruit, lemons, oranges, olives, walnuts.

FRUITS

Pome Fruits; apples and pears

Stone Fruits; peaches, plums, apricots, nectarines, prunes.

These crops are grown throughout the state except for the far northern and desert counties (Fig. 3, Table 12, Regions 1-6).

Insect pests: The major pests of these crops include mites, Lepidopterous larvae, and Homopterans. Most fruit crops require a number of insecticide treatments each year to prevent crop damage.

Reinvasion potential: With the exception of the scale insects, nearly all of these pests are capable of rapid dispersal. Therefore, it is very likely that these insects would rapidly reinvade areas when they were eliminated from by radioactive fallout (Tables 14, 15).

Table 14. Major pests of pome fruits (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Archips argyrospila Fruit tree leafroller	Low	4
Carpocapsa pomonella Codling moth	High	4
HOMOPTERA		
Dysaphis plantoginea Rosy apple aphid	Moderate	5
Aphis pomi Green apple aphid	Moderate	5
Aspidiotus perniciosus San Jose scale	Low	5
Psylla pyricola Pear psylla	Moderate	5
Mealybugs (Non-specific)	Moderate	5
ACARINA		
Panonychus ulmi European Red mite	High	5
Tetranychus urticae Two-spotted mite	High	5
Eriophyes pyri Pear leaf Blister mite	Moderate	5
Tetranychus mcdanieli McDaniel Spider mite	Moderate	5

Table 15. Major pests of stone fruits (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Anarsia lineatella Peach twig borer	High	4
Grapholitha molesta Oriental fruit moth	Moderate	4
HOMOPTERA		
Typhlocyba pronicola Leafhopper	Moderate	5
Hyalopterus pruni Mealy Plum aphid	Low	5
Aspidiotus perniciosus San Jose scale	Moderate	5
Parlatoria oleae Parlatoria olive scale	Low	5
ACARINA		
Bryobia arborea Brown mite	Moderate	5
Tetranychus urticae Two-spotted mite	High	5

GRAPES

There are 457,270 acres of grapes grown in California, making them almost the number one acreage crop (Fig. 3, Regions 1-6).

Insect pests: The major pests of grapes include mites, Lepidopterous larvae, leafhopper, beetles and thrips. Grapes are usually sulfured every year which helps reduce some pest species.

Reinvasion potential: The Lepidoptera and Coleoptera generally have good to excellent flight characteristics and are capable of rapid dispersal. The Homoptera and Thysanoptera are usually dependent on favorable wind currents for their dispersal. All the pest species would be able to rapidly reinvade an area from which they had been eliminated. (Table 16).

Table 16. Major pests of grapes (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Platynota stultana Omnivorous leafroller	Moderate	4
HOMOPTERA		
Pseudococcus naritimus Grape mealybug	Moderate	5
Erythroneuia variabilis Variegated grape leafhopper	High	5
COLEOPTERA		
Bud beetles (Non-specific)	Low	4
THYSANOPTERA		
Drepanothrips reuteri Grape thrips	High	5
ACARINA		
Tetranychus sacificus Pacific mite	High	5
Telranychus willamettei Willametti spider mite	Moderate	5

CITRUS

Citrus is produced in central and southern California.

Insect pests: The major pests of citrus include mites, aphids, scales and mealybugs (Fig. 3, Regions 5, 6).

Reinvasion potential: The Homopteran insects, although usually winged at some stage in their life cycles, are moderately strong fliers at best and very limited as to distance without the help of favorable wind currents. The mites are wingless, and therefore dependent on the wind for dispersal. Given suitable meteorological conditions, many of these species would reinvade a devastated area after the effects of radiation had disipated (Table 17).

Table 17. Major pests of citrus (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Argyrotaenia citrana Orange tortrix	High	4
Archips argyrospilus Fruit tree leafroller	Moderate	4
HOMOPTERA		
Aonidiella aurantii California red scale	High	5
Saissetia oleae Blash scale	High	5
Coccus pseudomagnoliarum Citricola scale	High	5
Citrus aphid (Non-specific)	High	5
ORTHOPTERA		
Scudderia furcata Katydid	Low	2
Microcentrum retinerve Katydid	Low	2
THYSANAPTERA		
Seirtothrips citri Citrus thrips	Moderate	5

WALNUTS AND ALMONDS

There are approximately 276,000 acres of walnuts and almonds produced in California each year. The growing areas are from the upper Sacramento Valley through the San Joaquin Valley, with a few acres of nuts in southern California (Fig. 3, Regions 1, 3, 6).

Insect pests: The pest of these crops are principally from four orders: Lepidoptera, Homoptera, Diptera and Acarina. Almonds and walnuts are treated every year with dormant oils as a prophylactive measure.

Reinvasion potential: The Lepidopterous and Dipteran species are generally considered to be excellent fliers, capable of far reaching dispersal. The mite species are highly dependent on wind currents for passive dispersal. With favorable wind condition it is assumed that these pests would soon reinvade a given area from which they were eliminated (Table 18).

Table 18. Major pests of walnuts and almonds (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Anarsia lineatella Peach twig borer	High (almonds)	4
Paramyelois transitella Navel orangeworm	High (almonds)	4
Carpocapsa pomonella Codling moth	High (almonds)	4
HOMOPTERA		
Lecanium pruinosum Frosted scale	High (walnuts)	5
DIPTERA		
Rhagoletis completa Walnut husk fly	High	4
ACARINA		
Tetranychus urticae Two-spotted spider mite	High (Walnuts, almonds)	5
Tetranychus pacificus Pacific spider mite	High (Walnuts, almonds)	5
Bryobia arborea Brown mite	High (almonds)	5

CALIFORNIA FIELD CROPS

There are 6.4 million acres of field crops grown in California at a production value of 1 billion dollars. The largest acreage (1.8 million acres) is planted in forage hay, mostly alfalfa, for an overall value of about $200 million. Alfalfa is the second most important crop in the State and is only exceeded by grapes, the No. 1 cash value crop. There are 1.4 million acres of barley, 276 thousand acres of field corn and 374 thousand acres of sorghum, all used for animal feed. There are 700 thousand acres of cotton with the cottonseed by-products used for cooking oil and the meal for beef cattle supplement feed.

The other important field crops include, about 400 thousand acres of both rice and wheat, 260 thousand acres of sugar beets, 220 thousand acres of dry beans, and 165 thousand acres of safflower, all grown primarily for human consumption. There are about 100 thousand acres each of alfalfa seed, potatoes and oats. Miscellaneous field crops are various legume seed crops, hops and sweet potatoes (16).

Fig. 4. Distribution of areas of major field crop of California (Anon. 14). (California Field Crop Statistics, 1969) Area boundaries are approximate only. Table 19 gives an explanation of these regions and the crops produced in each region.

Table 19. CALIFORNIA'S MAJOR FIELD CROP AREAS

REGION

1. Northeastern Interior: Hay, potatoes, small grains
2. Sacramento Valley: Alfalfa seed, corn, dry beans, hay, hops, ladino clover, rice, safflower, small grains, sugar beets.
3. North Coast: Hay, small grains
4. Central Coast: Dry beans, hay, potatoes, small grains, sugar beets
5. San Joaquin Valley: Alfalfa seed, cotton, corn, dry beans, hay, potatoes, rice, small grains, safflower, sugar beets, sweet potatoes
6. South Coast: Dry beans, alfalfa, potatoes, small grains, sugar beets
7. Southeastern Interior: Alfalfa, cotton, small grains, sugar beets

ALFALFA HAY

In California, there are about 6,000,000 tons of alfalfa produced on 1,152,000 acres each year (Fig. 4, Table 18, Regions 1-6).

Insect pests: The pests of alfalfa hay are mainly from three orders: Lepidoptera, Homoptera and Coleoptera. Often the entire crop may be defoliated when insecticides are not used to eliminate the destructive pests.

Reinvasion potential: The lepidopterous adults are considered excellent fliers, with a high reinvasion potential. Aphids can fly fairly well, but are generally dependent on wind for passive dispersal. The alfalfa weevils are very poor fliers and not capable of very efficient reinvasion into an area from which they were eliminated (Table 20).

Table 20. Major pests of alfalfa hay (by orders); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Prodenia praefica		
Western yellow-striped armyworm	High	4
Colias eurytheme		
Alfalfa caterpillar	Moderate	4
Spodoptera exigua		
Beet armyworm	Moderate	4
HOMOPTERA		
Therioaphis trifolii		
Spotted alfalfa aphid	High	5
Acyrthosiphon pisum		
Pea aphid	High	5
COLEOPTERA		
Hypera brunneipennis		
Egyptian alfalfa weevil	High	2

ALFALFA SEED

There are approximately 100,000 acres of alfalfa seed grown in California each year (Fig. 4; Regions 2,5,7). This is an important crop because California, Washington, Idaho and Utah produce nearly 100 percent of the alfalfa seed produced in the United States.

Insect pests: The major pests of this crop are lygus bugs, mites and aphids. Very little alfalfa seed can be grown without repeated lygus bug treatments and nearly all the seed varieties grown are susceptible to the spotted alfalfa aphid which requires additional pesticides.

Reinvasion potential: The lygus bugs are excellent fliers and capable of rapid reinvasion into areas where they may have been eliminated. Mites are wingless and generally dependent on favorable wind conditions for dispersal. The spotted alfalfa aphid also spreads more rapidly under favorable wind conditions.

Table 21. Major pests of alfalfa seed (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
HEMIPTERA		
Lygus hesperus Lygus bugs	High	4
Lygus elisus Lygus bug	High (early season)	4
HOMOPTERA		
Therioaphis trifolii Spotted alfalfa aphid	High	5
ACARINA		
Tetranychus pacificus Pacific spider mite	High	5
Tetranychus atlanticus Atlantic spider mite	High	5

LADINO CLOVER

In California, there are about 13,000 acres of Ladino clover grown for seed each year (Fig. 4, Region 2).

Insect pests: The major pests of this crop are Lepidopterous larvae, true bugs, aphids and mites.

Reinvasion potential: The Lepidopterous adults and the true bugs are generally considered to have excellent flight characteristics. The aphids which are winged are able to fly fairly well, and the mites which are wingless, are dependent on favorable wind conditions for long range passive dispersal. It is assumed that all these pest species would be capable of reinvasion into an area from which they had previously been eliminated by radioactive contamination (Table 22).

Table 22. Major pests of Ladino clover (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Prodenia praefica Yellow striped armyworm	High	4
HEMIPTERA		
Lygus hesperus Lygus bug	High	4
Lygus elisus Lygus bug	Low	4
HOMOPTERA		
Acyrthosiphon pisum Pea aphid	High	5
ACARINA		
Tetranychus urticae Two-spotted spider mite	High	5

COTTON

Cotton is grown in the southern half of the San Joaquin Valley and in the Imperial, Palo Verde and Coachella Valleys. In California, there are approximately 687,000 acres of cotton planted each year (Fig. 4, Regions 5,7).

Insect pests: The major economic pests of cotton are Lepidopterous larvae, Hemopterous insects, Acarina and Hemopterans.

Reinvasion potential: The Lepidopterous insects are generally considered to be excellent fliers with a high reinvasion potential. The Hemopterans are also good fliers with the ability to rapidly reinvade an area from which they were eliminated. The Homopterans are dependent largely on favorable wind currents for their dispersal (Table 23).

Table 23. Major pests of cotton (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea		
Cotton bollworm	High	4
Pectinophora gosseypiella		
Pink bollworm	High (Imperial only)	4
Bucculatrix thurberiella		
Cotton leaf perforator	High (Imperial and Coachella only)	4
LEPIDOPTERA		
Trichoplusia ni		
Cabbage looper	Moderate	4
HEMIPTERA		
Lygus hesperus	High	4
Lygus elisus		
Lygus bugs	High (early season)	
HOMOPTERA		
Empoasca solana		
Southern garden leafhopper	Moderate (Imperial only)	5
ACARINA		
Spider mites		
(Non-specific)	High	5
LEPIDOPTERA		
Spodoptera exigna		
Beet armyworm	Moderate	4

FIELD CORN AND SORGHUM

In California, sorghum and a little field corn is grown (Fig. 4, Regions 1-7).

Insect pest: The majority of pest attacking these crops are the same as for sweet corn, except for greenbug, wireworms and spider mites.

Reinvasion potential: Mite pests are wingless and require wind for rapid dispersal. A certain percentage of the adult aphids attacking these crops have wings but they are dependent on wind currents for passive dispersal (Table 24).

Table 24. Major pests of field corn and sorghums (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea Corn earworm	High (corn) Moderate (milo)	4
Cutworms (Non-specific)	Moderate (seedlings)	4
Armyworm (Non-specific)	Moderate	4
HOMOPTERA		
Schizaphis graminum Greenbug	High	5
COLEOPTERA		
Metaponium spp. *Blapstinus* spp. Darkling beetles	Low	3
Cutworms (Non-specific)	Moderate	3
ACARINA		
Spider mites (Non-specific)	High	5
DIPTERA		
Hylemya platura Seed corn maggot	Low	4

RICE

Rice is grown mainly in the northern Sacramento Valley and in the northern region of the San Joaquin Valley, California. (Fig. 4, Regions 2, 5).

Insect pests: Insects from three orders attack this crop mainly through boring or puncturing action. A crustacean representative (tadpole shrimp) is also a serious pest in the northern areas. When conditions are favorable in northern California, the rice leaf miner can be a serious pest and destroy the crop unless chemical treatment is used.

Reinvasion potential: The major insect pests of this crop are regarded as moderately strong fliers, and therefore have the potential of rapid re-entry after the major effects of radiation have disappeared.

The tadpole shrimp is an obligatory aquatic organism and a very slow dispersing form in the adult and larval stage. However, eggs of this organism are usually desiccated during dry periods of the year and are readily dispersed by other animals and wind (Table 25).

Table 25. Major pests of rice (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
COLEOPTERA Lissorhoptrus oryzophilus Rice water weevil	High	2
DIPTERA Hydrellia griscola Rice leafminer	High	2
CRUSTACAE Triops longicaudatus Tadpole shrimp	Moderate	1
LEPIDOPTERA Armyworms (non-specific)	Moderate	3

BARLEY AND WHEAT

These two crops are grown in most areas of California. The major portion of the 300,000 acres of wheat are the winter varieties (Fig. 4, Regions 1-7). The two crops are usually planted in the late fall and harvested early in the following summer.

Insect pests: Insects from two orders attack these crops with aphids being the single most damaging pest.

Reinvasion potential: The adult stage of these insects are generally considered to be good fliers or light enough to be effectively carried by wind currents. If eliminated from an area by radioactive fallout, it is reasonable to expect that they would readily reinvade the disturbed areas after the major effects of radiation had disappeared.

All species attacking these crops can and do exist on other host plants including a number of wild hosts. This feature adds greatly to their ability to become established when migrants reinvade a disturbed area. In the case of aphids, a single female can reinvade and start a new colony, since they are capable of reproduction without males (i.e. parthenogenic reproduction)(Table 26).

Table 26. Major pests of wheat, barley and (by order) damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
HOMOPTERA		
Rhapalosipum podi *Rhapalosipum maides*	High	5
HEMIPTERA		
Euschistus conspersus Stink bug	Low (Cyclical)	2 or 3

SUGAR BEETS

Sugar beets production is distributed throughout the state (Fig. 4, Regions 2-7).

Insect pests: These include aphids, leafhoppers, and lepidopterous larvae. Aphids and leafhoppers are of special importance because of virus transmission.

Reinvasion potential: Under adequate wind conditions, the aphids and leafhoppers can disperse long distances. The flight characteristics of the remaining pests range from fair to excellent. Most of these pests would soon reinvade an area where they were eliminated (Table 27).

Table 27. Major pest of sugar beets (by order); damage potential and reinvasion potential.

PEST SPECIES	DAMAGE POTENTIAL	REINVASION POTENTIAL
LEPIDOPTERA		
Spodoptera exigua Beet armyworm	Moderate	4
HOMOPTERA		
Circulifer tenellus Beet leafhopper	High	5
Empoasia solana Southern garden leafhopper	High	5
Myzus persicae Green peach aphid	High	5

MARKETING STANDARDS

The primary purpose of grading and standardization of agricultural products is to ensure high quality human food. However, in some cases these standards may have little to do with nutrition because competitive marketing, shipping and storage life of the product and commodity appearance can also effect commodity grading.

Standards have also been established with regard to the amount of insect damage and the number of arthropod fragments permissible in a sample of the commodity. These Federal and State marketing standards usually refer to the entire class Insecta rather than a given species.

For example, the California State Department of Agriculture has established marketing standards on over 60 different fruit and vegetable commodities grown in the State. In most cases, the regulations define that the product shall be free of live insects (pupa, larvae, or adults) or that no portion of the skin of the commodity shall be penetrated by insects.

The governing factor for quality control standards is that the agricultural industry has the technological methods available through entomology, pesticide chemistry, plant pathology, agronomy, nematology and so forth that help produce high quality food products. If pesticides are not readily available when pests reach damaging numbers the quality of many agricultural products would decrease below the minimum standard grades. These would not be acceptable

The existing regulations are strickly enforced by examination of the product when it is harvested or shipped to market. If the product cannot pass inspection, it cannot be sold for human consumption. These rigid regulations and enforcement by state and county officials often establishes a zero tolerance on many fruit and vegetable products as far as arthropod injury is concerned.

In addition, the Federal Government has established marketing standards on a large number of other products grown in one state and sold in another. These include the number of insect fragments permitted in cereal grains for human consumption as well as any commodity which is processed in cans or packaged for interstate shipment.

If warranted by postattack food demands, temporary relaxation of standards for quality control and restrictions on pesticide residues could be tolerated.

AVAILABILITY OF PESTICIDES

Nearly 50 percent of all the pesticides used in the United States are applied on cotton (15). I. is the opinion of the authors and their colleagues at the University of California that as much as half of this total ($200 million per year) is unnecessary. In an emergency situation, better use of these pesticides could be used on food crops.

The vegetable crops and deciduous fruit crops are the next most heavily treated. A significant fraction of these pesticides are used only to improve appearance of marketability of the produce. In addition, as much as 40-50 percent of the pesticides used on fruit and vegetable crops is applied solely to raise the quality in order to comply with rigid State and Federal standards of food purity (see preceding section on Marketing). In an emergency, the presence of a few insect fragments in food would not impair its nutritional quality and would be acceptable to most people.

With the exception of seed treatments for fungus disease and soil insect pests, only a small portion of the total pesticides used in the United States are applied on crops, such as: wheat, barley, rice, sugar beets, alfalfa hay, soybeans, corn and grain sorghum.

It is well-known that there are those times and places where heavy infestations of insect pests can destroy a crop. However, it is near impossible to obtain an exact figure on the actual need for pesticides on any crop.

The U.S. Department of Agriculture (15) does prepare estimates of crop loss from insects and the cost of insect control. There is no doubt that insects, mites, and insect borne plant diseases take a heavy toll of the potential food production in the United States. The Mrak Commission (Secretary's (HEW) Commission on Pesticides and Their Relationship to Environmental Health) explicitly state that "chemicals, including pesticides used to increase food production, are of such importance in modern life that we must learn to live with them." If pesticides were totally eliminated or if a nuclear disaster were to restrict their use, food production in the United States would decrease markedly.

SIMILARITY OF PESTICIDES AND FALLOUT RADIATION

With the exception of field tests of relatively small size and laboratory radiation studies on 100-200 insect and mite species selected from the 2 million arthropod species, there is little information concerning the effects of fallout radiation on arthropod populations in their natural state. However, some comparisons might be made between the ecologically disruptive effects of widely toxic pesticides and radioactive fallout. To make this comparison, a few comments are necessary concerning the development and nature of commercial pesticides.

One reason for ecological disruption arising from modern pesticides stems from the manner in which these compounds are developed commercially. During their development and in registering these compounds essentially no ecological considerations enter into the search for new compounds. The candidate materials are screened on the basis of maximum kill on 8-12 laboratory cultures of pest species and for phytotoxicity. The basic considerations as to whether or not a particular compound will be developed are: (1) the size of the potential market for the compound; (2) competing products in that market and the company's patent control over the new product and its competitors; (3) the possibilities of recouping development costs and returning a profit; and (4) certain safety factors with respect to residues, application, and human health.

Under this system, the ideal material from the commercial viewpoint is one which can be registered and labelled for use against a very broad spectrum of pests on a wide variety of crops.

It is precisely this type of compound that has a broad toxicity spectrum not only to pest species, but also to beneficial insects (plant pollinators, predators and parasites) and, as a result, a large proportion of these compounds are ecologically disruptive (Stern 16).

When pesticides are used for control, they involve only immediate and temporary reduction of populations and do not contribute to permanent pest density regulation. Theoretically, they are employed to reduce pest species which rise to dangerous levels when natural enemies of the pest and other environmental pressures are inadequate.

On some occasions the pest outbreak and the application of a pesticide for its control may cover a wide area such as the outbreak of the spruce budworm, C. fumiferana in northeastern Canada (17, 18) or lygus bugs, L. hesperus and L. elisus in the San Joaquin Valley, California (19) and so forth. In other instances, damaging numbers of a pest may occur in restricted locations. In either case, these outbreaks occur during the season favorable to the pest with the relaxed environmental pressures occuring sometime before the outbreak. In general, the California agro-ecosystem is one of huge mono-cultures and the environment has been changed to such a degree that the biological controls (parasites and predators) holding pests in check are often too scarce to prevent pest species from reaching damaging numbers.

Since most pest species have wide ranges of distribution (often hundreds of miles and from one state to another) the treated area is always subjected to reinvasion from individuals outside the area or by rapid resurgence from those not destroyed within the treated area (Stern 1).

In some ways, the effects of fallout radiation can be similar to that of insecticides. It is well-known that some insecticides exhibit differential killing effects on various species when applied at commercial dosages. LaChance et al. (20), in discussing insect sterility data, points out that radiation also has differential effects on arthropods. Most dipteran species can be sterilized with radiation doses under 10 kr., but even within this order a threefold difference was noted. The Hymenoptera require about 6-10 kr. and most Coleoptera seem to sterilize at 4-10 kr. On the other hand, the Lepidoptera, where essentially all species are phytophagous and include some of the most ravaging species on earth, require very large doses to cause sterility. Thus, radiation can be similar to insecticides as far as its differential effects on insects are concerned. In both cases, the reasons for these differential effects is not entirely clear.

An example of the distribution of fallout that could result from a large scale nuclear attack on the United States is shown Figure 5. (21). The contour lines are dose rate in r/hr at H + 1. This hypothetical attack assumed a total explosive yield of about 20,000 MT (1 MT-1 million tons of TNT).

The weapons consisted of three sizes; 5, 10 and 20 MT detonated at ground surface. Each dot represents a burst of one of the three size bombs mentioned. The wind pattern was for a typical spring day with a uniform 15 mph wind velocity from 0-80,000 feet. It was assumed that the fission to fusion ratio is unity producing a total of 10,000 MT of fission equivalents. Further it assumed a surface attack, resulting in the deposition of 80 per cent of the fission products as local fallout. The remaining 20 per cent of the fission equivalents are injected into the stratosphere. (Dosage related contour lines may be determined with magnification).

The contours shown in Figure 5 are the theoretical gamma radiation dose rates that would occur if all the fallout arrives within 1 hour of the detonation. To assess the radiation hazard of this attack the time of fallout arrival must be considered. Moreover, the beta dose, which could be an important additional radiation hazard to plants and insects is not included.

A conversion of the computed gamma dose rate contours of Figure 5 to gamma dose contours for the state of California is shown in Figure 6.

Fig. 5. Distribution of fallout from a large-scale nuclear attack on the United States.

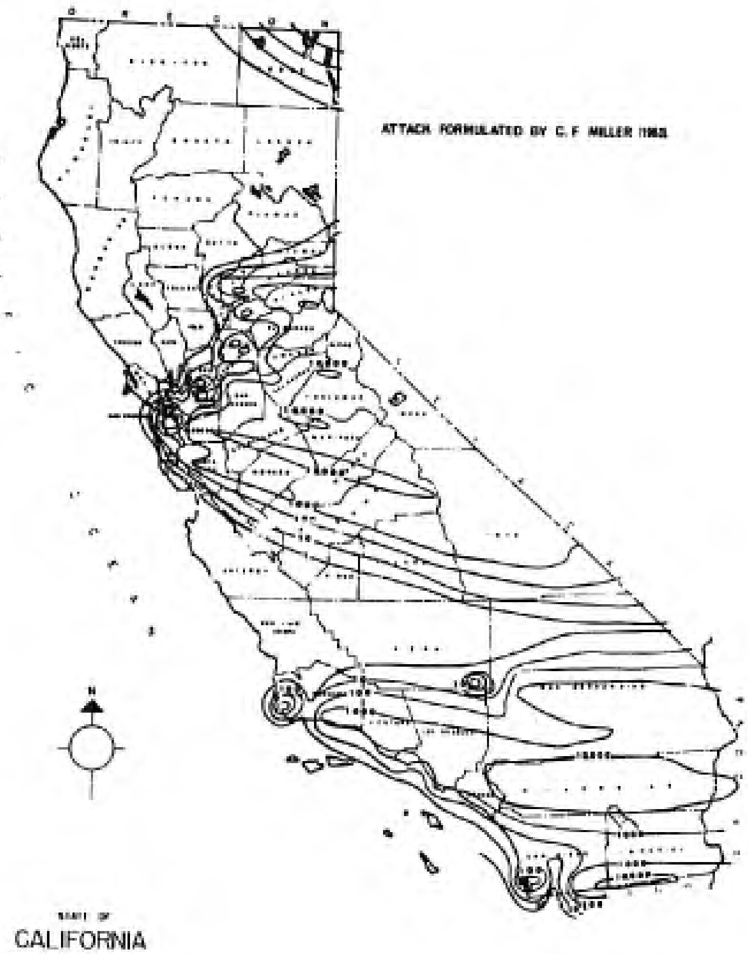


Fig. 6. Fallout gamma radiation dose distribution (The original dose rate contours were converted to dose contours for California by Dr. S. L. Brown, SRI, Palo Alto, California.)

It is obvious that the distribution of fallout from even a massive nuclear attack (see Figure 5 and 6) is such that extensive areas will not receive "lethal" fallout and insect pests will survive.

Fallout radiation would appear to act similarly to an insecticide in its disruptive effects on arthropods. In the case of pesticides, they are usually added to a restricted segment of the environment to eliminate a localized population. Because insecticides and radioactive fallout are non-reproductive, have no searching capacity, and are more or less non-persistent (as far as continuous killing effects are concerned) short term, restricted pressures.

As the fallout radioactivity decays to non-injurious levels, a matter of a few weeks even in high fallout areas, the insects will begin to invade affected areas and the general equilibrium populations existing before the attack will eventually be reestablished. The mobility of insect pest species attacking our major food crops and their reinvasion time after elimination from wide areas was reported previously by Stern (1).

These conclusions are based on (1) empirical evidence that wings have played an important role in the dispersability of insects into new environments and have contributed greatly to the biological success of insects; (2) documentation of the literature on the mobility and reinvasion potential of the pest species of the major food, oil and forage crops grown in the United States; and (3) examples of insect reinvasion after near elimination by pesticides as reported by Stern (1). Thus, by continuous reinvasion, insect pests would eventually become established as soon as plant species were available for food.

EFFECTS OF FALLOUT RADIATION ON ARTHROPOD PESTS

A literature survey conducted by Stern (1) and Teresi and Newcombe (22) indicate a wide variation in radiation sensitivity of arhtropod species. An important feature is that the immature stages are more susceptible to radiation injury than adult stages and the amount of radiation required to cause sterility is much less than the amount needed to cause death or to reduce longevity. However, sterility is equivalent to death as far as the succeeding generation is concerned.

LaChance et al., (20) in discussing insect sterility data, point out that radiation has differential effects on arthropods. Most Dipteran species (flies and mosquitoes) can be sterilized with radiation doses under 10 kr. but within this order a three-fold difference was noted. The Hymenoptera (bees, ants, wasps) require about 6-10 kr. On the other hand, the Lepidoptera (moths and butterflies) where essentially all species are phytophagous and include some of the most ravaging species on earth, require very large doses to produce sterility.

The effects of fallout beta radiation on insects is difficult to assess. The beta radiation dose to insects in contact with fallout may be an order of magnitude or more greater than the gamma dose. However, many insects move up and down plants depending on temperature and wind conditions. Morover, beta radiation is rapidly attenuated by plant biomass and other debris. Thus, insects, many of which are protected by an overstory of plant leaves and branches, could be completely shielded from beta radiation. Immature stages which reside in plant tissue, soil or litter are also well protected.

A somewhat analogous situation occurs in insect pest control. When using pesticides in either dust or liquid formulation by ground equipment or airplane, a major problem is getting the pesticide into the center and lower parts of the plants. Agricultural engineers have worked for years with nozzel size, spray pressure, and dust and liquid volume to accomplish this. Very little pest control could be accomplished by simply permitting a gradual settling of dust on the plant canopy as would occur from fallout.

Most of the insect pests attacking the major food plants in California have excellent flight characteristics and high reinvasion potential. Tables 2-11; 13-18 and 19-25 give the reinvasion potential for the major insect and mite pests for the major crops produced in California. The reinvasion potential in this report and that reported by Stern (1) is based on the time required for a pest to travel 30 to 50 miles in one direction.

With the exception of mite pests which are wingless, the vast majority of insect pests could fly 75 miles distance and become reestablished within a few weeks to a month. Thus, even after possible elimination from certain areas by fallout, it can be expected that insect and mites will continue to compete with man for his food crops.

LITERATURE CITED

1. Stern, V. M. 1969. Insect pests of major food crops, reinvation potential and the effects of radiation on arthropods. OCD Work Unit No. 3145B. University of California, Riverside. 199 p.

2. Stern, V. M., R. F. Smith, R. van den Bosch and K. S. Hagen. 1959. The integration of chemical and biological control of the spotted alfalfa aphid. Part I. The integrated control concept. Hilgardio. 29(2): 81-101.

3. Huffaker, C. B. 1970. Summary of a pest management conference--a critique. Pages 227-242. R. L. Rabb and F. E. Guthrie (eds.). Concepts of pest management. Pub. North Carolina University Press. 242 p.

4. Doutt, R. L. 1967. Chap. I. Biological Control. W. W. Kilgore and Doutt (eds.). Pest Control. Academic Press. N.Y., London. 477 p.

5. Ullyett, G. C. 1951. Insects, man and the environment. Jour. Econ. Entomol., 44(4): 459-464 pp.

6. Smith, R. F. and W. W. Allen. 1954. Insect control and the balance of nature. Sci. Amer. 190(6): 38-42.

7. Doutt, R. L. 1958. Vice, virtue and the vedalia. Entomol. Soc. Amer. Bull. 4(4): 119-23.

8. van den Bosch, R., and V. M. Stern. 1962. The integration of chemical and biological control of arthropod pests. Ann. Rev. Entomol. 7: 367-386.

9. Atkins, E. L., Jr., M. H. Frost, Jr., L. D. Anderson and A. S. Deal. 1957. The omnivorous leaf roller, Playtynota stultana Wlshm., on cotton in California; nomenclature, life history and bionomics (lepidoptera: Tortricidae). Ann. Entomol. Soc. Amer., 50: 251-259.

10. Atkins, E. L., Jr., M. H. Frost, Jr., A. S. Deal and H. T. Reynolds. 1957. The omnivorous leaf roller, Platynota stultana Wlshm., on cotton in California; damage and control. Jour. Econ. Entomol., 50(1): 59-64.

11. DeBach, P. (Ed.), 1964. Biological control of insect pests and weeds. Reinhold Publ. Co., N.Y. 844 p.

12. Anon., California crop and livestock reporting service. August 1969. California vegetable crops 1967-68. California Department of Agriculture. Sacramento, California. 27 p.

13. Anon., California crop and livestock reporting service. 1969. California fruit and nut statistics 1968-69. California Department of Agriculture. Sacramento, California. 11 p.

14. Anon., California crop and livestock reporting service. June 1969. California field crops statistics. 1959-1968. California Department of Agriculture. Sacramento, California. 20 p.

15. U.S. Department of Agriculture. 1965. Losses in Agriculture. Agricultural Handbook No. 291. U.S. Govt. Print. Off., Washington, D. C., 120 p.

16. Stern, V. M. 1971. Insect-induced agro-ecological imbalances as an analog to fallout effects. In Press. Brookhaven Nat. Lab. Symposium. Oct. 1970.

17. Morris, R. F., (ed.). 1963. The dynamics of epidemic spruce budworm populations. Mem. Ent. Soc. Can., No. 31. 435 p.

18. Webb, F. E., J. R. Blais and R. W. Nash. 1961. A cartographic history of spruce budworm outbreaks and aerial forest spraying in the Atlantic region of North America, 1949-1959. Can. Entomol., 93(5): 360-379.

19. Mueller, A. J. 1971. The bionomics of lygus bugs in the safflower-cotton-alfalfa seed cropping system in California. Ph.D. Dissertation, unpublished, Graduate program in Entomology, University of California, Riverside. 141 p.

20. LaChance, L. E., C. H. Schmidt, and R. C. Bushland. 1967. Chap. 4. Raidation-induced sterilization. W. W. Kilgore and R. L. Doutt (eds.). Pest Control. Academic Press, N.Y., London. 477 p.

21. Miller, C. F. 1963. Fallout and radiological countermeasures. Vols. 1 and 2. S.R.I. Project No. 1M-42041 Stanford Research Institute. Menlo Park, California.

22. Teresi, J. D., and C. L. Newcombe. 1966. An estimate of the effects of fallout beta radiation on insects and associated invertebrates. OCD Work Unit No. 3145A. USNRDL-TR-982. 86 p.