TRC-68-70

INSECT PESTS OF MAJOR FOOD CROPS, THEIR REINVASION POTENTIAL AND THE EFFECTS OF RADIATION ON ARTHROPODS

FINAL REPORT
JUNE 1969

Contract No. N0022868C0157
OCD Work Unit No. 3145B

Prepared for:
OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310

UNIVERSITY OF CALIFORNIA
EDUCATION RESEARCH SERVICE
RIVERSIDE

210

TRC-68-70

INSECT PESTS OF MAJOR FOOD CROPS, THEIR REINVASION POTENTIAL AND THE EFFECTS OF RADIATION ON ARTHROPODS

FINAL REPORT
JUNE 1969

By: Vernon M. Stern
Professor of Entomology

Contract No. N0022868C0157
OCD Work Unit No. 3145B
Prepared for:
OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON, D.C. 20310
Through:
TECHNICAL PLANNING AND
MANAGEMENT OFFICE
NAVAL RADIOLOGICAL DEFENSE LABORATORY
SAN FRANCISCO, CALIFORNIA 94135

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.

CONTENTS

Contents cont'd

LIST OF TABLES

List of tables cont'd

LIST OF FIGURES

LIST OF FIGURES cont'd.

LIST OF FIGURES cont'd.

INTRODUCTION AND SUMMARY

Introduction: In recent years, a number of public agencies have been concerned about arthropod pests following nuclear attack. There has been some suggestion that ravaging insect epidemics might occur and threaten our entire food supply (Ayers, 1). To a certain extent the available data indicate that this may well happen. However, 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 we now use to suppress pest species. That is, year after year, a wide variety of pests are held below damaging numbers by insecticides. If these were no longer available it can be expected that many pest species would rise above their economic threshold and cause severe crop injury.

In addition, there is some indication that pest problems are far more severe today than they were a decade ago. One reason for this is that the widespread and sometimes indiscriminate use of pesticides has eliminated or decreased large numbers of natural enemies that help to govern the population density of pest species. With natural enemies present in low numbers combined with a possible restriction in the availability of pesticides, pest species could suddenly flare to high densities and cause widespread crop damage before natural enemy populations could respond.

A further possible reason for an increase in some pest populations could be restrictions in human activity that might inhibit early planting or plowing of crops, burning contaminated material, general field sanitation and so forth. Or, with restricted transportation in moving fuels, farm equipment may sit idle and this might also permit some pest species to survive and increase to high numbers whereas under ordinary circumstances many overwintering forms are killed by efficient farming operations.

This study was conducted for the Office of Civil Defense to gain more knowledge of the effects of nuclear war on insect pest populations.

Research Plan: A survey was made of insecticide application and insect control literature. This was compiled and analyzed to try to construct population fluctuation models where different insect species had been essentially eliminated and then repopulated the t eated area. The idea was to try to predict the elapsed time of insect recolonization into an area after their elimination by insecticide applications. These data were to be correlated with predicted dose and pattern of radioactive fallout from varying MT yield surface bursts that might occur in different ecosystems.

Finally, certain inferences from predicted fallout effects were to be combined with the available data relating to biological effects from gamma and beta radiation on arthropods.

General Summary: After reviewing the pesticide application literature it was impossible to obtain sufficient data to rely solely on pest control to construct population fluctuation models which would give accurate predicted rates of insect recolonization. The reason for this is that there are very few examples reported in the literature where insecticides have been applied over a continuous 100 or 1000 square mile area such as might occur in heavy radioactive fallout.

Thus, the authors used other types of empirical data to predict rates of reinvasion into an area where the species had been eliminated. These included the nature of the Class Insecta; its excellent mobile and high reproductive capacity, and the biology and ecology of each pest species mentioned in this report.

The data of elapsed time for recolonization after theoretical elimination from fallout, indicate that most insects will be capable of continuing competition with man for food crops following nuclear disaster.

The extent to which fallout may differentially affect beneficial or natural enemies of pest species of insects is unknown. It seems likely that the arthropods, by the nature of their cell division, their diverse life cycles and ecology, and because of their migration and dispersal habits, may be expected to survive in large numbers and rapidly reinvade disturbed areas.

There were only a few references relating to effects of beta rays on insects. It is impossible to draw any sound biological conclusions from the very limited data.

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 of 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 should be determined to prevent an increasing pest population from reaching the economic-injury level. The economic 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.

* After Stern, et al.,2.

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 temporary 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 and lower limits over a period of time by the combined actions of abiotic and biotic elements of the environment. Natural control involves all aspects of the environment, 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 environmental elements. In the case of a pest population, natural control may or may not be sufficient to provide economic control.

NATURAL REDUCTION. Deaths or other losses to the population caused by naturally existing abiotic and biotic elements of the environment in a given period of time.

POPULATION. <u>A group of individuals of the same species that occupies a given area</u>. A population must have at least a minimum size and occupy an area containing all its ecological requisites to display fully such characteristics as growth, dispersion, fluctuation, turnover, dispersal, genetic variability, and continuity in time. The minimum population and the requisites in occupied area will vary from species to species.

POPULATION DISPERSION. <u>The pattern of spacing shown by members of a population within its occupied habitat and the total area over which the given population may be spread</u>.

TEMPORARY EQUILIBRIUM POSITION. <u>The average density of a population over a large area temporarily modified by a procedure such as continued use of insecticides</u>. The modified average density of the population will revert to the previous or normal density level when the modifying agent is removed or expended (cf. "general equilibrium position").

INSECT PESTS

All organisms are subjected to the physical and biotic pressures of the environments in which they live and these factors together with the genetic make-up of the species, determine their abundance and existence in any given area. Without natural control, a species which reproduces more than the parent stock could increase to infinite numbers. Man is subjected to environmental pressures just as other forms of life are, and he competes with other organisms for food and space.

Utilizing the traits that sharply differentiate him from other species, man has developed a technology permitting him to modify environments to meet his needs. Over the past several centuries, the competition has been almost completely in favor of man, as is attested by decimation of vast vertebrate populations, as well as populations of other forms of life (Thomas, 3). But while eliminating many species as he changed the environment of various regions to fit his needs for food and space, a number of species, particularly among the Arthropoda, became his direct competitors. Thus, when he subsisted as a huntsman or foraged for food from uncultivated sources, early man was largely content to share his subsistence and habitat with the lower organisms. Today, by contrast, as his population continues to increase and his civilization to advance, he numbers his arthropod enemies in the thousands of species.

The increase to pest status of a particular species may be the result of a single factor or a combination of factors.

First, by changing or manipulating the environment, man has created conditions that permit certain species to increase their population densities (Ullyett, 4). The rise of the Colorado potato beetle, Leptinotarsa decemlineata (Say), to pest status occurred in this manner (Fig. 1). When the potato, as well as other solanaceous plants,

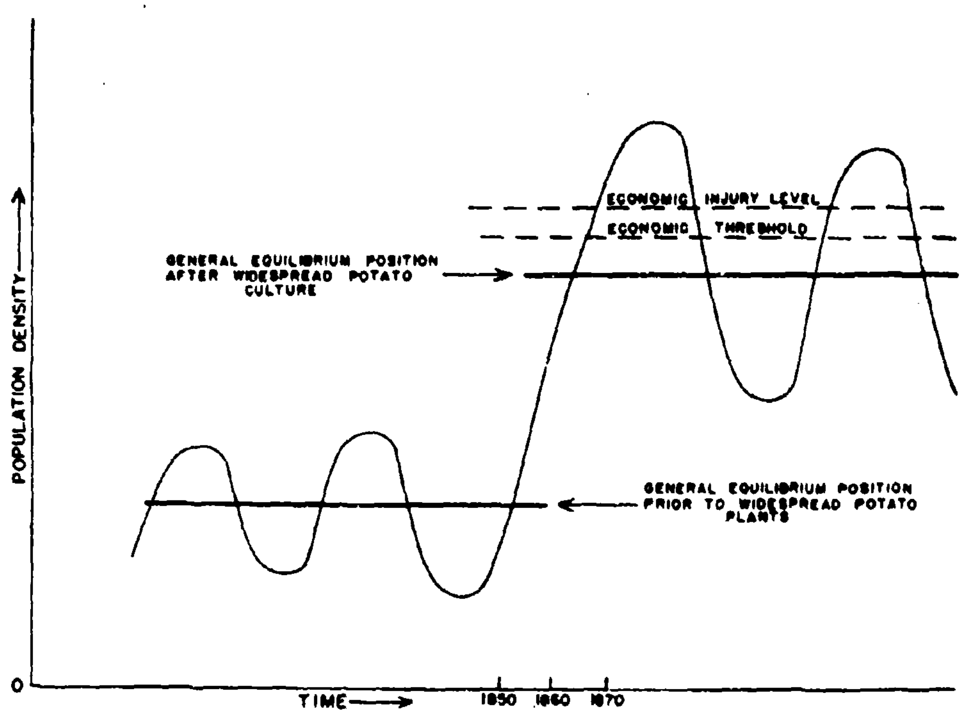

Fig. 1. Schematic graph of the change in general equilibrium position of the Colorado potato beetle, Leptinotarsa decemlineata, following the development of widespread potato culture in the United States. For a discussion of the significance of economic-injury levels and economic thresholds in relation to the general equilibrium position, see page 10. (After Stern, et al., 2)

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, 5).

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 (Smith, 6). The increase in importance through such transportation is illustrated by the cottony cushion scale, Icerya purchasi Maskell (Fig. 2). 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).

The cottony cushion scale again achieved the status of a major pest when the widespread use of DDT on citrus in the San Joaquin Valley eliminated the vedalia (Ewart and DeBach, 8).

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

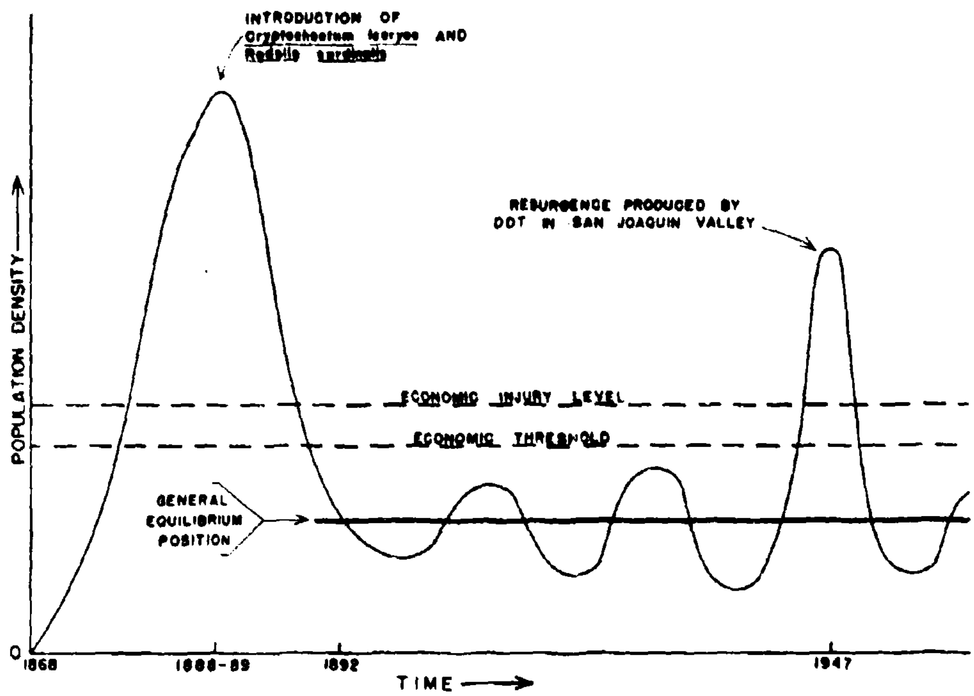

Fig. 2. Schematic graph of the fluctuations in population density of the cottony cushion scale, Icerya purchasi, on citrus from the time of its introduction into California in 1868. Following the successful introduction of two of its natural enemies in 1888, this scale was reduced to noneconomic status except for a local resurgence produced by DDT treatments. (After Stern, et al., 2)

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.

Of course in a nuclear disaster, insects in this category would not be considered pests since they generally do little to injure or destroy the food product. However, in terms of all the pest species attacking food and forage crops in theUnited States, those in this category are relatively small in number.

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 unprecedented numbers of a leaf miner, Liriomyza sp.; spider mites, Tetranychus spp.; pea aphid, Acyrthosiphon pisum (Harris); beet armyworm, Spodoptera exigua (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, 9). 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., 10, 11).

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. exigua; 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.

These outbreaks are of special interest in relation to radioactive fallout. At present, there are no data to indicate whether gamma or beta radiation might act differentially on the beneficial arthropod parasites and predators in comparison to their host pest species. One reason for the lack of information is that most of the applied research, other than genetic studies, has been aimed at the male sterilization technique as a means of controlling pest species and no one appears to be studying the effects of radiation on beneficial species.

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 density-governing factors, and the other natural 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 (Fig. 3). 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 (Fig. 4).

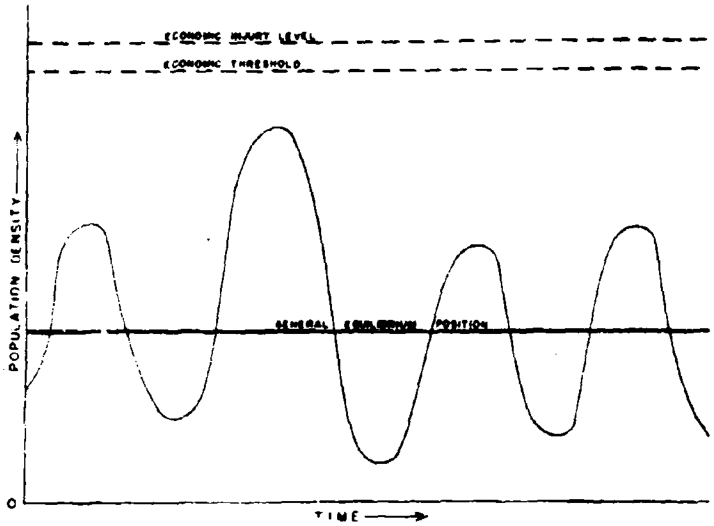

Fig. 3. Non-economic population whose general equilibrium position and highest fluctuations are below the economic threshold, e.g., Aphis medicajinis Koch on alfalfa in California. (After Stern, et al.,2).

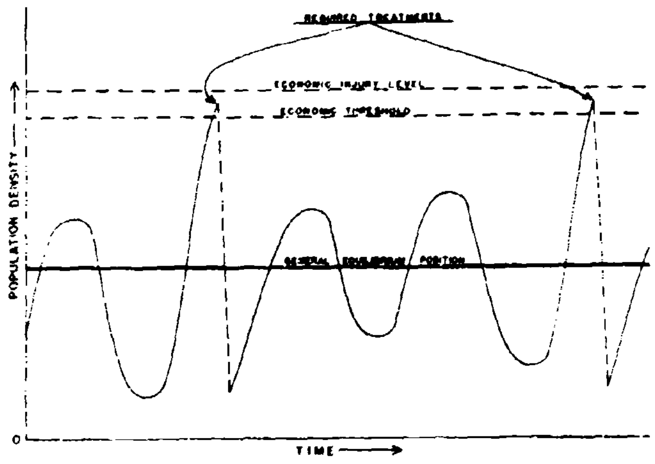

Fig. 4. Occasional pest whose general equilibrium position is below the economic threshold but whose highest population fluctuations exceed the economic threshold, e.g., Grapholitha molesta Busek on peaches in California. (After Stern, et al.,2).

When the general equilibrium position is close to the economic threshold, the population density will frequently reach the economic threshold (Fig. 5). 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 (Fig. 6). 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. This produces conditions favorable for development of insecticide resistance and other problems associated with heavy treatments.

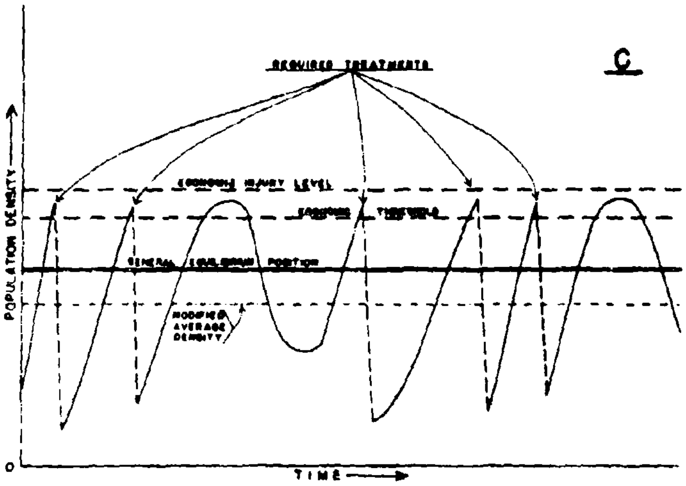

Fig. 5. Perennial pest whose general equilibrium position is below the economic threshold but whose population fluctuations frequently exceed the economic threshold, e.g., Lygus spp. on alfalfa seed in the western United States. (After Stern, et al.,2).

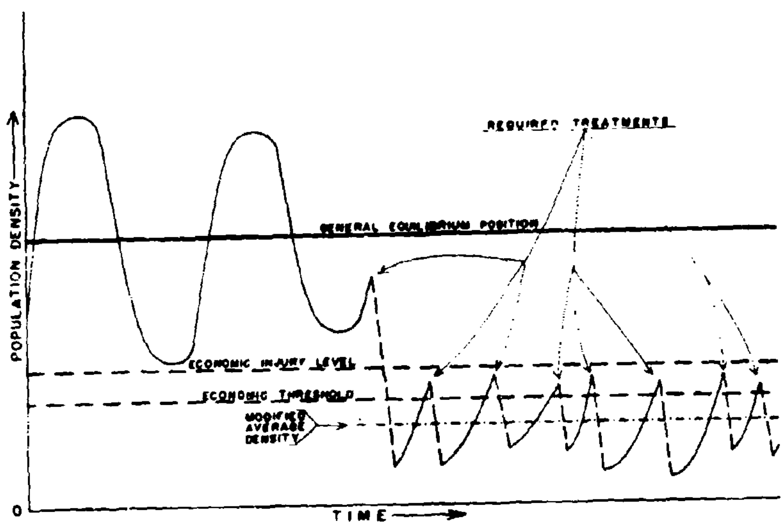

Fig. 6. Severe pest whose general equilibrium position is above the economic threshold and for which frequent and often widespread use of insecticides is required to prevent economic damage, e.g., Musca domestica in Grade A milking sheds. (After Stern, et al.,2).

DISPERSION OF PEST SPECIES

A species population is plastic and is undergoing constant change within the limits imposed upon it by its genetic constitution and the characteristics of its environment. Typical fluctuations in population dispersion are shown in Figure 7. The population dispersions shown at the three points in time: A, B, and C, are not static but rather are instantaneous phases of a continuously changing dispersion.

Thus at point A, when the population is of greatest numerical abundance, it also has its widest distributional range (as depicted by the maximum diameter of the base of the model), and is of maximum economic status (as depicted by the number and magnitude of the blackened pinnacles representing penetrations of the economic threshold). At point B, on the other hand, when the species population is at its lowest numerical abundance, it is generally most restricted in geographical range and is of only minor economic status. Point C represents an intermediate condition between points A and B.

Figure 8 is related to Figure 7 and 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 regards 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 thousands of square miles while another species may be restricted to one or two states or even less.

The environment of Zone 1 has nearly optimal climatic conditions, at least during a certain part of the year and

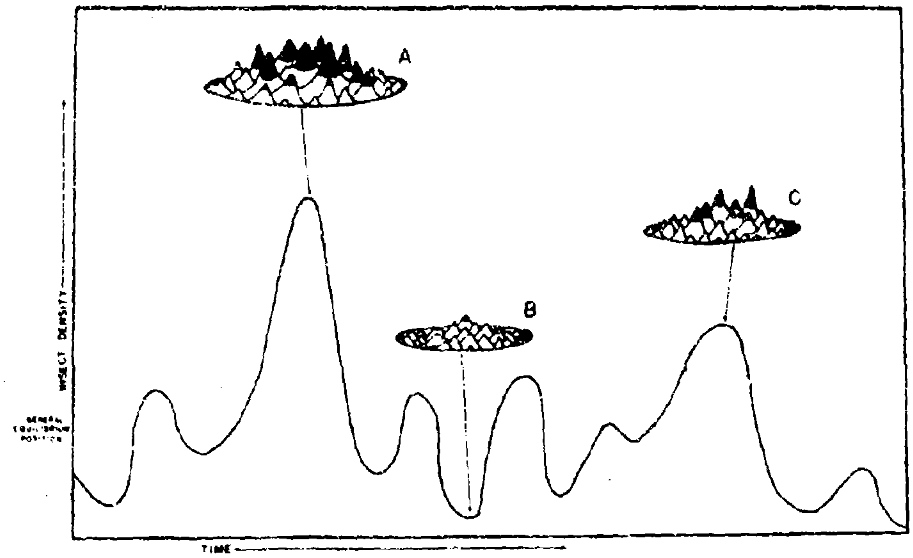

Fig. 7. Schematic graph of the population dispersion of a pest species over a long period of time. (After Stern, et al.,2).

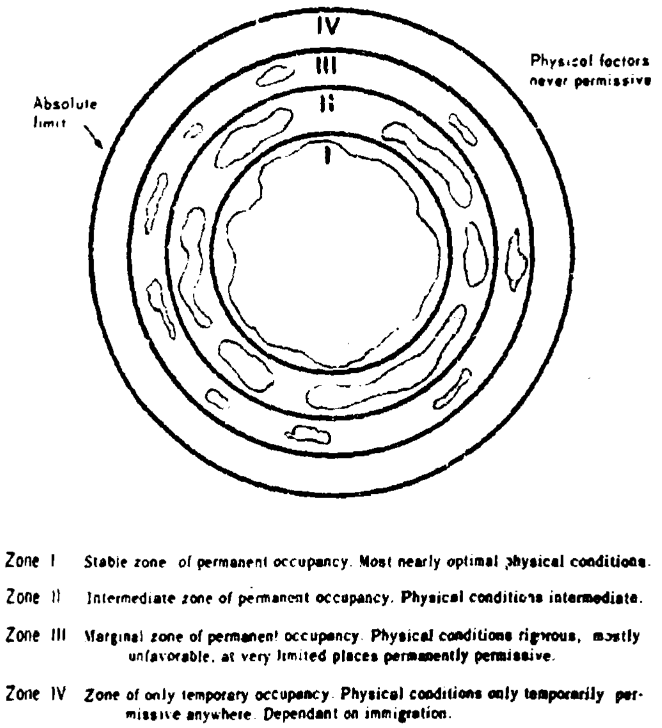

Fig. 8. The geographic distribution of a species population and the interrelation of conditioning and regulating forces. (After DeBach (ed.),12).

permits an increase in numbers generation after generation. In the environment of Zone 4, at the other extreme, only temporary existence is possible. If any part of the species population 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 re-invasion will depend on prevailing physical factors and on the flight habits, behavior and ecology of the species involved.

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 the changing physical conditions to alter population potential.

In the environment of Zone 3, on the other hand, 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. However, the role of physical forces and natural enemies are still the same as in the environments of Zones 1 and 2. In the environment of Zone 4, migrants from the more favorable areas are necessary to populate this area when favorability is temporarily permitted.

EMPIRICAL EVIDENCE FOR RAPID INSECT
REINVASION OF AREAS AFTER ELIMINATION BY RADIOACTIVE FALLOUT

A. MOBILITY: During biological evolution only four groups of organisms have at some time during their history developed the power of true flight. These include reptiles, birds, mammals and insects. Of all the tremendous numbers and varieties of invertebrates, only insects can fly.

Wings evolved but once and early in the evolution of this diverse group. It seems certain that wings were a part of the ancestral pattern which gave rise to the vast majority of present day forms and has contributed much to the biological success of insects.

The presence of wings has certainly influenced success in meeting their requirements for food, protection, reproduction and species radiation. Their ability to rapidly move from one area to another gives them a great flexibility and advantage in selecting suitable environments for survival, growth and reproduction.

In addition to wings for mobility, most pest species have a high reproductive potential and produce several generations per year. This often permits them to rapidly increase in numbers under favorable environmental conditions.

Rather than present an extensive review of the literature on the migration and dispersal habits of insects a number of pertinent papers can be cited that will help document a general conclusion of the author and his colleagues at the University of California that pest species will rapidly reinvade an area disturbed by radioactive fallout.*

---

*Elton, 14; Glick, 15; Gressitt, 16; Hardy & Milne, 17, 18, 19; Hocking, 20; Holzapfel & Harrell, 21; Huffaker, 22; Hurd, 23; Johnson, 24; Kettle, 25; Lutz, 26; Muller, 27; Profft, 28; Schneider, 29; South, 30; Tutt, 31; Uvarov, 32; Wellington, 33; Wester, 34; Williams, 35, 36, 37, 38; Wolfenbarger, 39.

In addition, figures 13 and 14 which were taken from the Third Quarterly Report on "Contamination of Human Food Following Nuclear Attack", (Benson, et al., 13) indicate that there would be certain areas with little or no fallout. It can be expected that insect survivors from these areas will provide a source for reinvasion into areas where they had been eliminated.

B. EXAMPLES OF REINVASION AFTER NEAR ELIMINATION BY PESTICIDES:

I. The spruce budworm, Choristoneura fumiferana is a forest pest in all Canadian Provinces and Territories, and in the northeast, midwest and northwestern United States. It is by far the most destructive insect affecting the extensive balsam fir-spruce forest types in Ontario, Quebec, the Maritime Provinces and Maine.

In northern and central New Brunswick and adjacent parts of Quebec and northern Maine this insect reaches its most critical economic importance. The reason for this is because of a high preponderance of the most susceptible and vulnerable host, balsam fir, and a heavy dependence of this tree to the local forest industry.

During the late 1940's and by 1951 it appeared that extensive tree mortality was imminent in an area of about 10,000 sq. miles in New Brunswick (Fig.9). The most serious infestation covered about 7,000 sq. miles. In order to preserve valuable pulpwood forests, the application of DDT from aircraft was tested over part of this area in 1952 and aerial spraying was greatly expanded during the subsequent years of the outbreak. Morris (40) has given an extensive report on the research and activities in combating the spruce budworm.

Aerial forest spraying against the spruce budworm was begun in New Brunswick in 1952, with the treatment of nearly 200,000 acres at the headwaters of the Southeast Upsalquitch River in the north-central highlands of the province (Fig. 10).

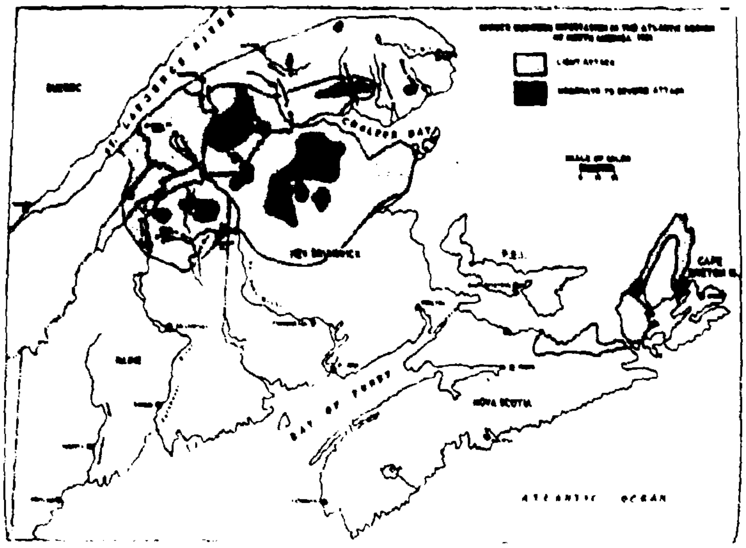

Fig. 9. Spruce budworm infestation in the Atlantic Region of North America, 1951. (After Webb, et al., 41)

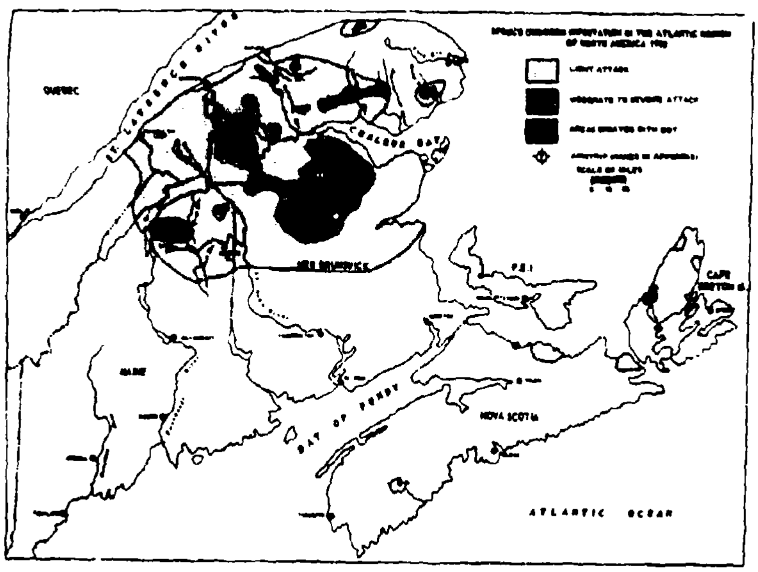

Fig. 10. Spruce budworm infestation in the Atlantic Region of North America, 1952. (After Webb, et al., 41)

Subsequent operations were carried out annually until the end of severe outbreak conditions in northern parts of the province in 1958. A total of about 6.2 million acres was sprayed one or more times or nearly all of the susceptible forest area in northern and central parts of the province (Fig. 11,12).

Insecticide formulation throughout the operations consisted of one pound technical grade DDT in one U.S. gallon of oil solvent, applied at the average rate, of 1/2 gallon of formulation per acre.

In some cases the percent population reduction in the treated area was as high as 99.9 percent. However this was an example of very good control and more often there was about 95 percent control in the treated areas.

All adult males and those females that have laid some eggs are active fliers and under the proper weather conditions (passage of a cold front) may be borne aloft and transported many miles. Consequently, the most drastic influence on the population trend of the spruce budworm in a given area may occur during the adult stage as the result of moth dispersal.

Normal flight activity may also result in dispersal and such dispersal is restricted to short distances because of the brief time active flight can be maintained. Moths in normal flight above the forest canopy may be swept away by air currents and transported several miles. It is only under circumstances of population pressure that long-range dispersal takes on any voluntary aspect. In heavily populated centers, where foliage is depleted, females may become more active in their search for oviposition sites.

Convectional transport is the movement of segments of a population from one area to another by pre-frontal or air-mass storm centers. Certain weather conditions, pressure, temperature, and light associated with the passage of a storm stir spruce budworm moths into increased activity. The

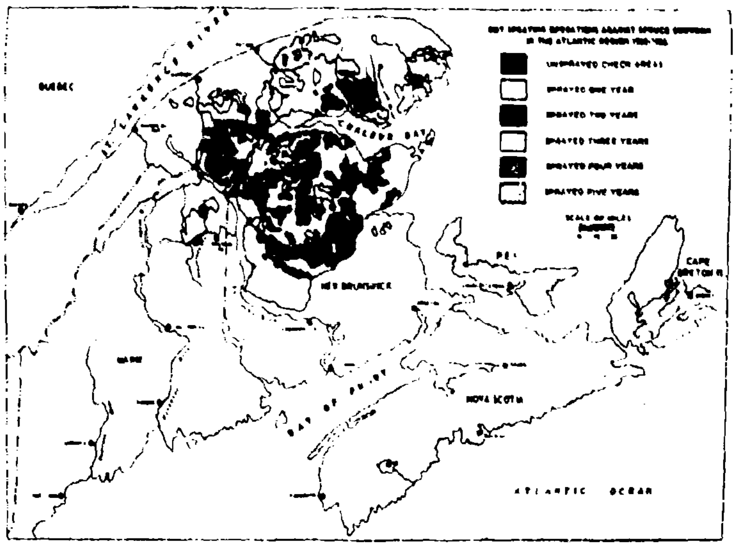

Fig. 11. DDT spraying operations against spruce budworm in the Atlantic Region, 1952-1958. (After Webb, et al., 41)

Synopsis of Area Data — DDT Spraying Operations in New Brunswick, Quebec, and Maine, 1952-1958

	New Brunswick	Quebec	Canadian Total	Maine	Grand Total
Total acres in spray plans	14,027,000	3,781,000	17,808,000	322,000	18,130,000
Total gallons insecticide	7,347,000	1,899,000	9,261,000	323,000	9,584,000
Net area sprayed one or more times	6,161,000	3,152,000	9.313,000	322,000	9,635,000
% of net area sprayed once	26%	84%	46%	94%	48%
% of net area sprayed twice	34	16	28	6	27
% of net area sprayed three times	31	0	20	0	19
% of net area sprayed four times	8	0	5	0	5
% of net area sprayed five times	< 1	0	< 1	0	< 1

Fig. 12. DDT spraying operations for spruce budworm, 1952-1958. (After Webb, et al., 41)

strong up-draughts then carry active moths aloft and transport them over the forest. The moths are subsequently discharged in the central down draught of the storm. This type of transport is generally responsible for the tremendous flights of moths that have suddenly descended upon towns as much as 50 miles from the nearest infestation.

Turbulent wind transport differs from convectional transport in that the moths, rather than being borne aloft by updraughts are swept along in the surface winds. This occurs most commonly on clear or partly cloudy evenings when moths in normal flight activity are caught in the stronger air currents above the tree crowns. In heavily populated areas, this type of dispersal is sometimes spectacular and can be likened only to the tremendous migrations of locusts.

The effect of long-range dispersal of the spruce budworm was clearly evident in 1952 when an area of 300 sq. miles within the heart of the infestation was sprayed with DDT. Budworm larvae there were practically eliminated with survival being less than 1 percent of that in the unsprayed area. Although precautions have been taken to minimize the threat of subsequent invasion by establishing spray boundaries whenever possible at natural buffer zones, which included burned areas, cutover areas, and hardwood stands, the treated area was more or less uniformly reinfested that same summer. Wind dispersal from adjacent unsprayed areas and the convectional transport of females from other centers of infestation brought egg populations up to 48 percent of those in comparable unsprayed areas. In addition, during the study from 1952 through 1956 there was clear evidence of mass invasion during the seasons favorable for dispersal.

It was also evident during the extensive study that the inclusion of species scarce or foreign in the sampling area confirmed the conclusion that the unusual catches represented invading populations rather than local individuals.

II. <u>Lygus</u> <u>hesperus</u> is one of the major pest species in California. In 1967 it was estimated to cause nearly 17 million dollars in crop damage despite the nearly 15 million dollars spent for chemical control. It attacks a variety of crops including cotton, beans, peas, various seed crops and deciduous fruits. Its main breeding areas are in alfalfa hay and safflower. On the west side of the San Joaquin Valley in Kings and Fresno Counties there is essentially no alfalfa hay, but there are about 60-70,000 acres of safflower under cultivation (Stern, et al., 42).

During May most cotton fields are still in the seedling stage and even the very early plantings have not yet begun to produce squares. Cotton in this growth stage is unattractive to <u>Lygus</u> and the bugs do not invade the cotton fields during May. In June, however, when the safflower begins to dry for harvest, the <u>Lygus</u> begin to leave and invade the cotton fields

To prevent an early increase of <u>Lygus</u> in cotton the growers have joined together and treated their safflower and alfalfa seed during April and May. The treated area generally covers the region from Five Points in Fresno County and south to Alpaugh in Kern County. This area is about 45 miles long and 20 miles wide. Often, the safflower may be treated 2 or 3 times during the spring. Since Lygus is not found in barley or on seedling cotton, the greater portion of the population in this area is eliminated by insecticidal treatments. However, quite often high populations of <u>Lygus</u> adults can be found in cotton fields by late June. The adult invaders appear to come from alfalfa hay fields 15 to 20 miles away or from the western foothills of the San Joaquin Valley.

Since lygus bugs are strong fliers there is strong evidence to indicate that if this or similar pest species were to be eliminated from local areas by radioactive fallout they would soon become reestablished after the effects of the radioactivity had disappeared.

In addition, one of the host plants of Lygus is Russian thistle which is one of the first plants to appear in denuded or disturbed areas. It can be assumed that this would provide food and oviposition sites for Lygus even before man planted crops in disturbed areas. It seems likely that disturbance plants such as Russian thistle would likely reinvade disturbed areas and provide food and oviposition sites for pest species nearly as rapidly as man would plant his own food plants; or seeds of weed host species that would be more or less protected below the soil surface would germinate at springtime to provide plant hosts for reinvading insect pests.

Even though there are few examples of simultaneous pesticide applications over wide areas there are many cases of extensive treatment schedules against such pests as the bollworm, Heliothis zea on cotton, the codling moth, Carpocapsa pomonella on apples, the alfalfa weevil, Hypera postica on alfalfa, the greenbug, Schizaphis graminum on wheat, grasshoppers and so forth. At best these pesticide programs are shortlived and quite often require repeated applications during a single season.

Admittedly these types of spray programs never cover all the acreage in a 100 sq. mile block. Nevertheless, the general impression is that there are always a few survivors, or individuals entering from the untreated areas, to begin the pest cycle anew.

In addition, the immature stages of many pest species occur below the soil surface, or pupate below the soil or may be partially protected within plant tissue, it would seem likely that some individuals would survive within a fallout area. In addition, Tables 20 and 21 show that arthropods in general are not affected by low dosages of radiation and could thus survive.

THE SIMILARITY OF PESTICIDES AND FALLOUT RADIATION

With certain exceptions the range of distribution of most species covers wide areas. When pesticides are used for control, they involve only immediate and temporary decimation of localized populations and do not contribute to permanent density regulation. They are employed to reduce populations of pest species which rise to dangerous levels when natural enemies of the pest and other environmental pressures are inadequate. On some occasion the pest outbreak and the application of a pesticide for its control may cover a wide area such as occurred in the outbreak of the spruce budworm, Choristoneura fumiferana (Clemens) in the forests in northeastern Canada; or, on lygus bugs, L. hesperus on safflower, or the pink bollworm, P. gossypiella on cotton in California. In other instances, damaging numbers of a pest may occur in very restricted locations. These outbreaks occur during the season favorable to the pest with the relaxed environmental pressures occuring sometime before the outbreak.

In some ways, other than genetic changes, the action of radioactive fallout is similar to that of an insecticide which is always manipulated by man. He applies the pesticide to a restricted segment of the environment to decimate a localized pest population. Because chemical insecticides and radioactive fallout are nonreproductive, have no searching capacity, and are more or less nonpersistent, they constitute short-term, restricted pressures. They cannot permanently change the general equilibrium position of the pest population nor can they restrain an increase in abundance of the pest without repeated applications. Therefore, they must be added to the environment at varying intervals of time.

In certain pest-control programs, the insecticide is applied over extensive geographical areas. In some areas after application, the pest population density may be far below the economic threshold and below its general equilibrium position; but since the insecticide is not a permanent part of the environment, the pest usually returns to a high level when the effects of the insecticide are gone.

Such applications have little influence on the pest in adjoining areas except as localized population depressants.

Other than genetic changes that are likely to affect certain segments of insect populations, radioactive fallout should act similarly to pesticides. That is, in the highest radiation field there could be a total elimination of certain insect species. Away from the high radiation field, there would be less mortality and various types of genetic change. Whether the offspring of these individuals could survive and compete in nature is unknown. However, individuals from outlying areas would be invading the disturbed area even before the radiation had disappeared. By continuous invasion, individuals would eventually become established as soon as plant species were available for food.

ATTACK STUDIES AND AREAS UNAFFECTED BY FALLOUT

Benson, et al., (13) presented certain data that influence the conclusions of this paper. They discussed 3 attacks that assumed 21,340 MT, 4080 MT and 1500 MT bursts on the United States. These attacks were developed by references 52, 53 and 54 respectively. The fallout pattern contour maps of the first two attacks mentioned are taken from Benson, et al., (13) and presented herein in Figures 13 and 14. Further discussion of Fig. 13 is presented by Benson, et al., (55). Even the extremely large scale (21,340 MT) nuclear attack (Fig. 13) indicates that there will be areas that will not be drastically affected or at least will receive fallout that will have a minimum effect on insect pests. The smaller scale attack (4080 MT) shows that while large industrial, transportation, communication and chemical centers (emphasis herein related to pesticide manufacturing centers) will be drastically affected there will be large agricultural areas unaffected.

A large number of pest species in the United States and elsewhere have wide ranges of distribution. In both attacks there will be scattered populations of pest species surviving. The insect survivors in areas not affected and those in areas of minimum fallout can be expected to disperse into the heavy fallout areas. They can become established and feed on whatever host plants may be available, soon after radiation dissipates. Further, when a comparison is made between the total cropland harvested (Fig. 15) and Figures 13 and 14 there is every indication that there will be scattered cultivated and uncultivated areas relatively unaffected. Pest populations from these areas will readily disperse into the heavily disturbed sectors once radiation has dissipated and commercial crops replanted. This may be quite rapid where the pest species feeds on a variety of crops as well as uncultivated plant species.

Fig. 13. Attack formulated by C. F. Miller (52). Values on the contour lines are expressed as r/hr. at h + 1. This attack assumed a total release of about 20,000 MT. The weapons consist of three sizes; 5, 10 and 20 MT. 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.)

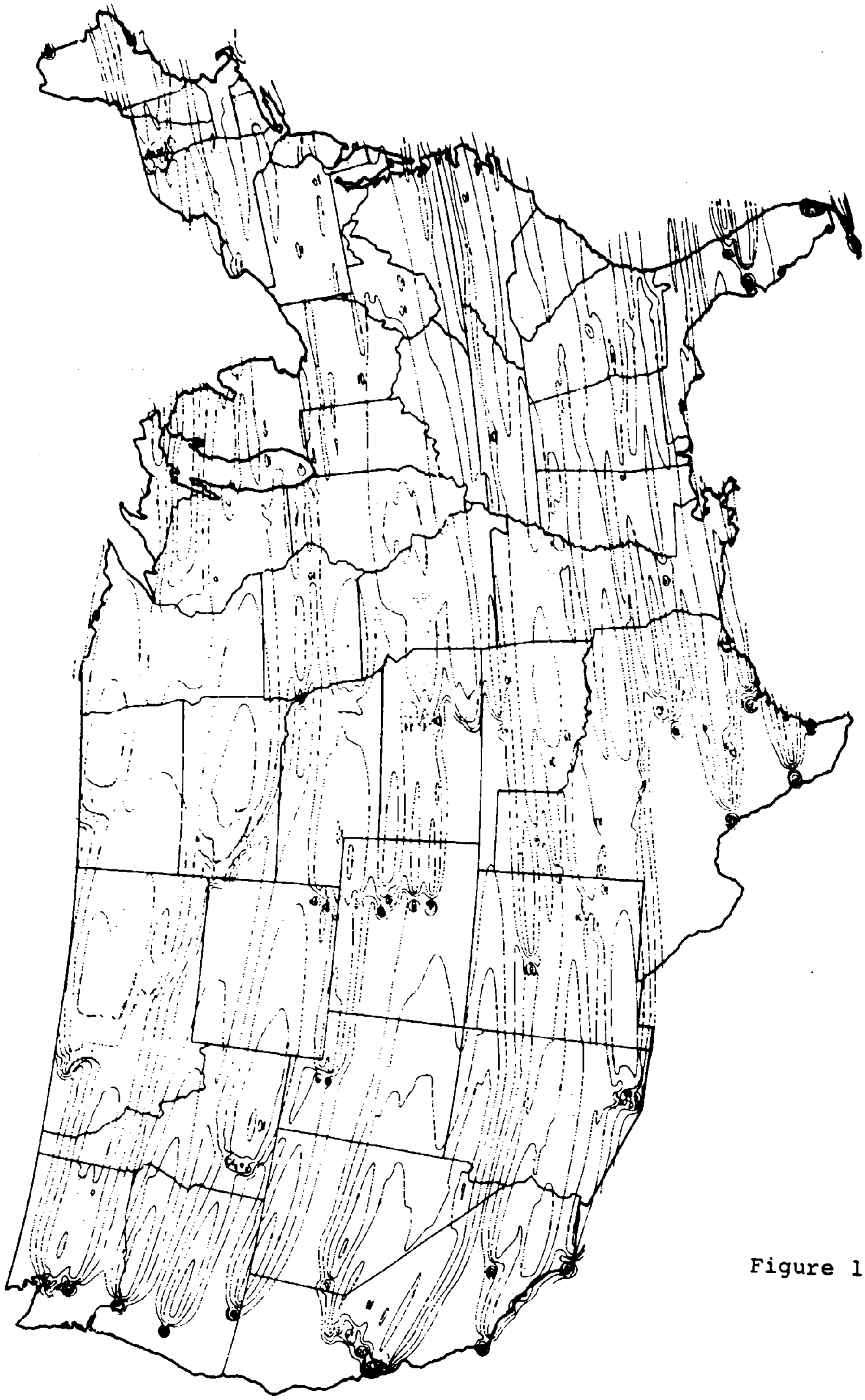

Figure 13.

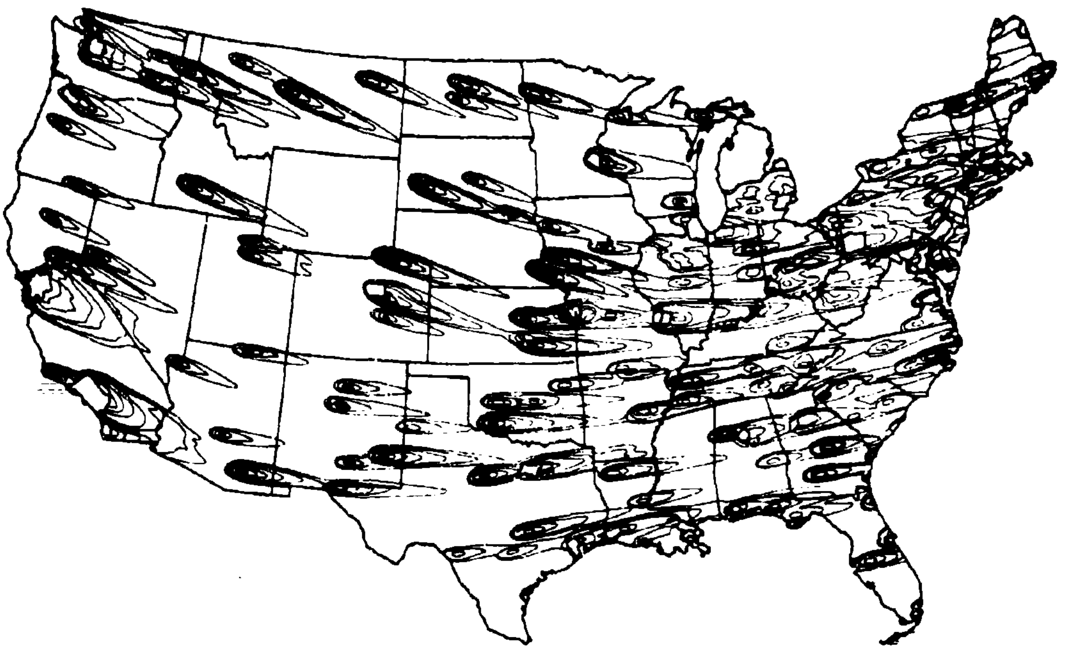

Fig. 14. Attack developed by Callahan, et al., (53). Contour lines represent 2 day cumulative dose in roentgens. The outermost line = 100R with successive values of 300R, 900R, 1500R and 3000R.

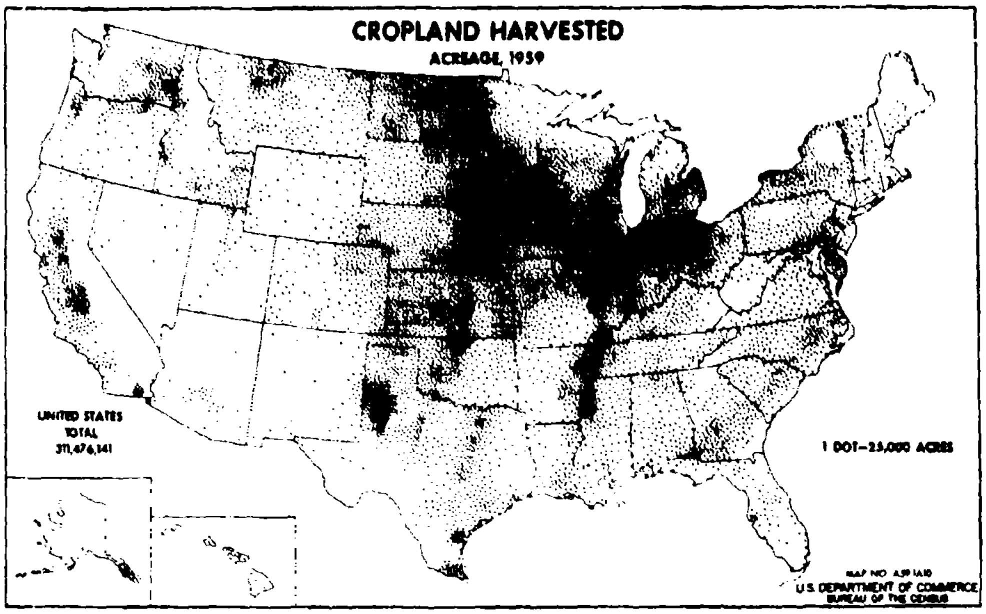

Fig. 15. Distribution of cropland harvested in the United States in 1959.

SELECTED EXAMPLES OF MIGRATION OF PEST SPECIES IN THE U.S.

A. The potato leafhopper, Empoasca fabae (Harris)

Temperature tolerance studies conducted by Decker and Cunningham (43) show that this pest cannot survive the winters in the north central and eastern United States. Winter survival is limited to areas that have about 260 to 270 days of frost-free period and corresponds to latitudes southward from Baton Rouge, Louisiana.

This species is one of the most important pests in the central and north central States. It not only attacks potatoes, alfalfa and a wide number of vegetables but while sucking the plant juice it spreads the yellow virus.

Populations begin increasing in the southern states during March and April and begin their northward movement in May and June. It only requires the migrants about 2 to 3 weeks to reach Minnesota, South Dakota, Wisconsin, Ohio and so forth. The first appearance of the migrant adults in the northern areas seems to occur after the beginning of warm southern winds (Medler, 44).

B. The beet leafhopper, Circulifer tenellus (Baker)

This species is native to the western part of the United States and northern Mexico (Cook, 45 and Dorst and Davis, 46). It feeds and reproduces on a wide variety of rangeland plants. When the rangelands dry the leafhoppers often migrate long distances to find succulent host plants. For example, populations that move into Illinois and Minnesota apparently come from southern New Mexico and western Texas (Douglas, 47).

During its northward migration, sugar beets, tomatoes, beans, spinach and other crops become infested. The beet leafhopper populations rarely reach numbers to cause damage by direct feeding. However, the hoppers carry and transmit a very destructive virus disease known as curly top of sugar beets and western yellow blight of tomatoes. The curly top virus also affects garden beets, swiss chard, spinach, nearly all varieties of beans and various species in the melon family.

California.--Breeding areas in California lie in the San Joaquin Valley, but there are some scattered along the western edge of the Mojave Desert and in southern California (Fig. 16). The leafhoppers remain active during the entire year. The largest winter breeding grounds are in the inner foothills of the coast range and on the west side of the San Joaquin Valley. When the range plants dry, the spring brood leaves the foothills and migrates into the irrigated areas to attack and transmit the virus disease to a variety of cultivated hosts.

Utah, Nevada, and N.W. Arizona.--The leafhoppers overwinter in southern Utah, Nevada and Arizona on filaree and other annual winter host plants. One or more generations are produced on these annuals before they dry up in the spring. With the drying of the vegetation the leafhoppers move northward over the Escalante Desert into northern and central Utah.

Southern Arizona and Western Colorado.--Southern Arizona is the source of most of the leafhoppers infesting the cultivated areas of western Colorado. The first spring brood usually moves northward in late April and feeds on cultivated crops in northern Arizona, southeastern Utah, northwestern New Mexico and northeastern Colorado.

The second brood moves northward in late May. Their numbers may increase enroute by the first spring-brood adults produced in more local breeding grounds. This northward movement is the principal source of leafhopper infestation and curly top disease in western Colorado and eastern Utah.

Southern New Mexico and West Texas.--This is the only breeding area of any size east of the Rio Grande River (Fig. 17). The leafhoppers move northward in late May and in early June. Areas as far north as Pueblo, Colorado, and northeast to Amarillo, Texas, soon become infested by leafhoppers from this breeding area. In the fall, leafhoppers drift southward

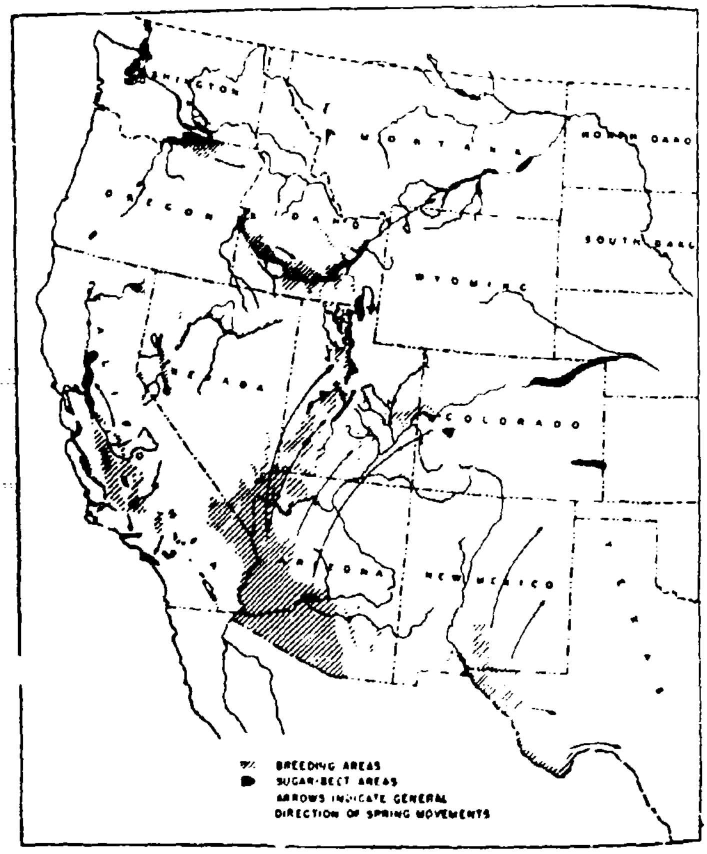

Fig. 16. The major breeding grounds of the beet leafhopper and the sugar beet areas affected by them. Breeding grounds are shown by lined areas, the sugar beet areas by solid black, and the directions of movement by arrows. (After Cook, 45)

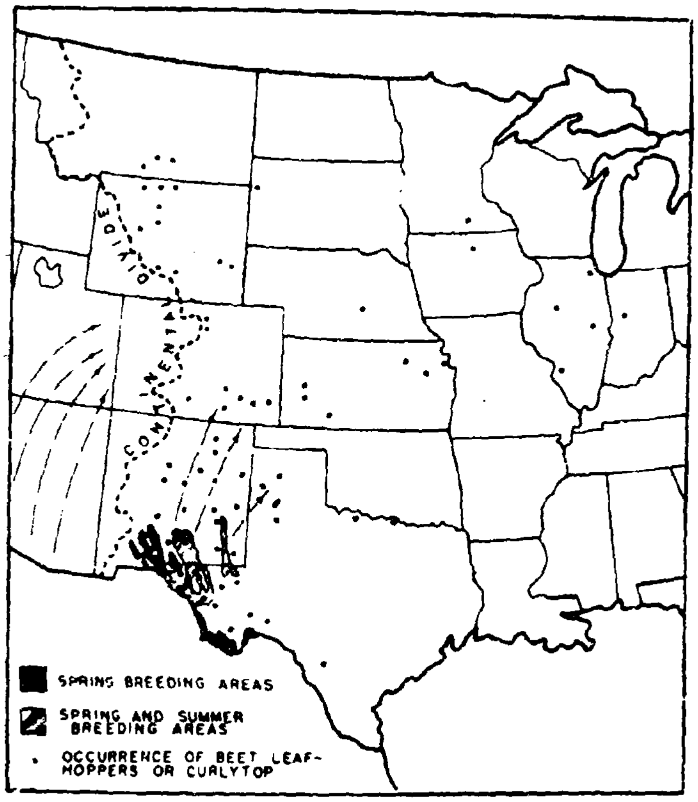

Fig. 17. Breeding areas in New Mexico and western Texas and occurence of beet leafhoppers or curly top east of the Continental Divide. (After Douglas,47)

where they attack the late summer crops.

C. The corn earworm, Heliothis zea (Boddie)

This insect is unable to survive the winter in most of the corn belt, but it migrates into these areas during the summer and causes damage. Occasionally it migrates as far north as Canada (Neiswander, 49).

It is also a serious pest of sweet corn in New York. The greatest injury occurs on Long Island, although other parts of the state are also affected, particularly during the latter part of the growing season (Carruth, 48).

The pest can be found throughout most of the year in southern Florida, and along the Gulf of Mexico, and in southern California. The number of generations per year largely determine the destructiveness of this pest in any given area (Blanchard and Douglas, 50). There may be as many as seven generations in the southern areas. Throughout most of the Corn Belt there are three or four generations annually. In Canada and the most northern parts of the United States there is usually a single generation each year.

In the eastern United States overwintering pupae usually do not survive farther north than a line from central Virginia through St. Louis, Missouri, to Topeka, Kansas. Along the Pacific coast the overwintering pupae may survive in low elevations as far north as southern Washington. During mild, dry winters the pupae may survive in protected areas slightly north of these latitudes.

D. The cotton leafworm, Alabama argillacea (Hubner)

The cotton leafworm is a tropical insect and does not survive the winters in the United States. Annual infestations in cotton begin each spring from moths that fly in from South and Central America. The first moths are generally found in April through early June and usually appear first in southern Texas. When the populations increase the moths fly to other areas. In some years they invade all the cotton states except

California. The larvae feed only on cotton. When abundant they completely defoliate the plant and then feed on the squares and bolls. The adults often reach the northern states and Canada where the moths feed on ripe fruit.

E. The green peach aphid, Myzus persicae (Sulzer)

This aphid is one of the most destructive in the United States because it transmits more than 50 plant viruses (Stefferud, 51). When populations reach high numbers they also cause damage by direct feeding. Each summer this pest becomes extinct in the Imperial Valley, California, but the aphid reappears in October. The reintroduction of the aphid occurs throughout the year, but it can only become established during the cooler seasons. The reinvaders come from the coastal region, a distance of 50 to 75 miles.

F. The spotted alfalfa aphid, Therioaphis trifolii (Monell)

This devastating aphid first appeared in the Imperial Valley, California, in April 1954. By January 1955, it had moved across the Mojave Desert and invaded Kern County about 300 miles to the north. It also spread across the United States from Central New Mexico. It cannot survive the winter in the Great Lakes States but it reinvades this area from warmer regions each summer.

These selected examples are typical of hundreds of species that may be eliminated from an area and rapidly reinvade the region during the favorable season. It adds more weight to the opinion that where insects might be eliminated from radioactive fallout we should expect many of the pest species to rapidly reinvade the disturbed area.

MAJOR FOOD, OIL AND FORAGE CROPS IN THE UNITED STATES AND 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 food crops discussed in the present study are essentially those selected by Billheimer (56) in his study on post attack food availability and accessibility. These crops include cereal grains, wheat, rice, and corn; various vegetable crops, beans, peas, potatoes, tomatoes and cucurbits, i.e. cucumbers, squash, pumpkins and melons; cruciferous crops, cabbage, cauliflower, broccoli, brussel sprouts; vegetable root crops, carrots, table beets, turnips and radishes; oil crops, soybeans; sugar beets and sugar cane; stone fruits, peaches, apricots and cherries; pome fruits, apples and pears, and citrus, oranges and grapefruits.

The major insect and mite pests attacking these crops were obtained from the Agricultural Extension Service Entomologists from all the States except Alaska and Hawaii (Bergman, 57). A literature search of each pest species was made in order to predict a reinvasion potential of the pest after its elimination from an area. Supplementary data to support this prediction was obtained from recorded information and professional 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. The data needed for the formation of such an index for all the 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. Since data is limited this could only be done on selected groups of pests and an example could be the pests attacking alfalfa in California. Such a study may well serve as a model in further studies of potential insect pest problems following a disaster situation.

The references to the reinvasion potential (=R.P.) of the pest species attacking the crops in tables 1-17 in this section 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 density is too great 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.

WHEAT

About 50 million acres of wheat are planted each year. It is our most important cereal crop. Nearly 80 per cent is planted as winter wheat; that is, it is planted in the late fall and harvested early in the following summer. The winter wheat acreage is mostly grown in the mid-central and Great Lakes States and lesser portions in the Pacific northwest and Atlantic region (Fig. 18). The remainder of the crop, i.e. spring wheat, is planted in the early spring and harvested in the late fall of the year it was planted. It is grown mostly in North Dakota and the adjoining states (Fig. 19). The combined wheat acreage appears in Fig. 20.

Insect pests: A variety of insect pests may attack this crop. These include the larval stages of a number of moths and flies, aphids, grasshoppers and beetles.

Reinvasion potential: In the adult stage (Table 1) most insects attacking this crop are good fliers. If eliminated from extensive areas, there appears to be no reason that they would not reinvade the disturbed area after the major effects of radiation had disappeared.

The aphids attacking this crop are not strong fliers but the winged adults can be transported by wind currents for great distances. All the species attacking this crop 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.

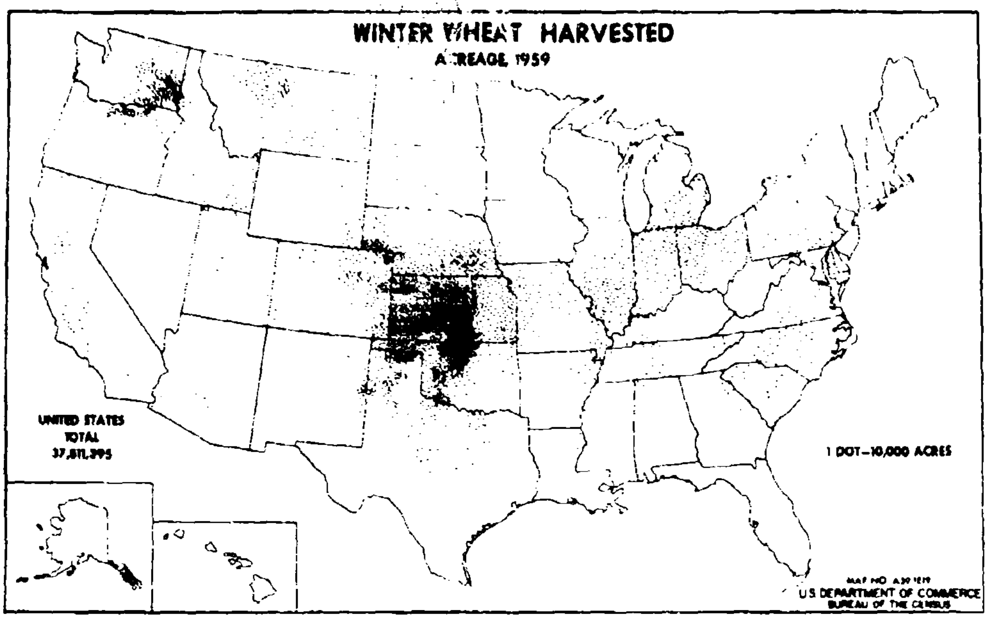

Fig. 18. Distribution of winter wheat in the United States in 1959.

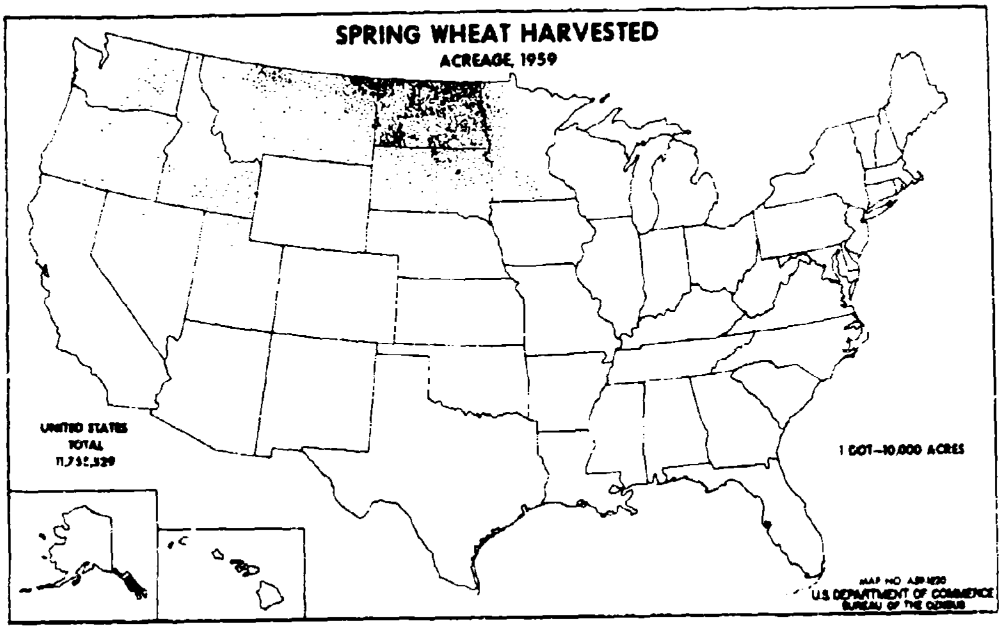

Fig. 19. Distribution of Spring wheat harvested in the United States in 1959.

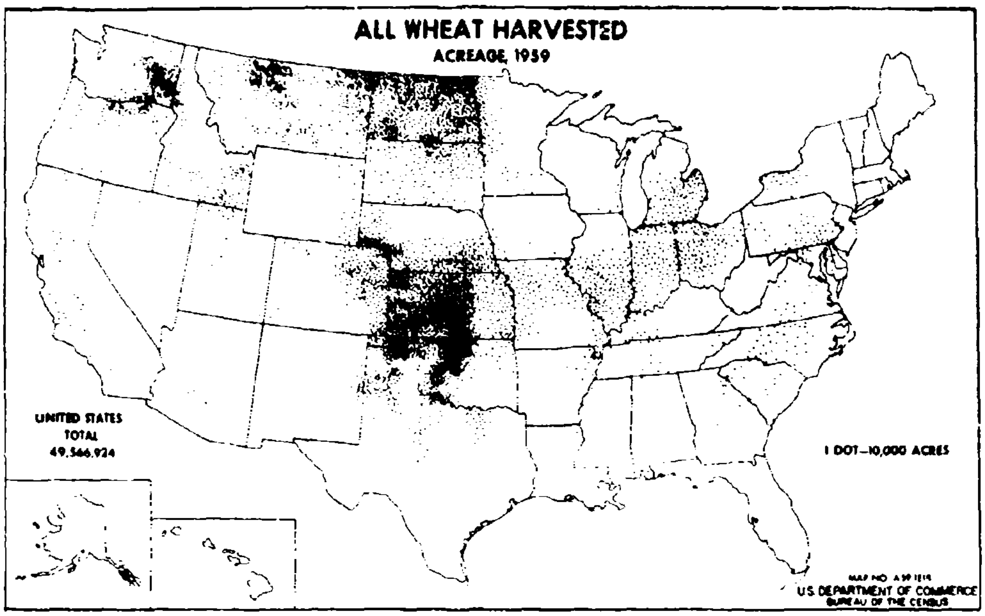

Fig. 20. Distribution of all wheat harvested in the United States in 1959.

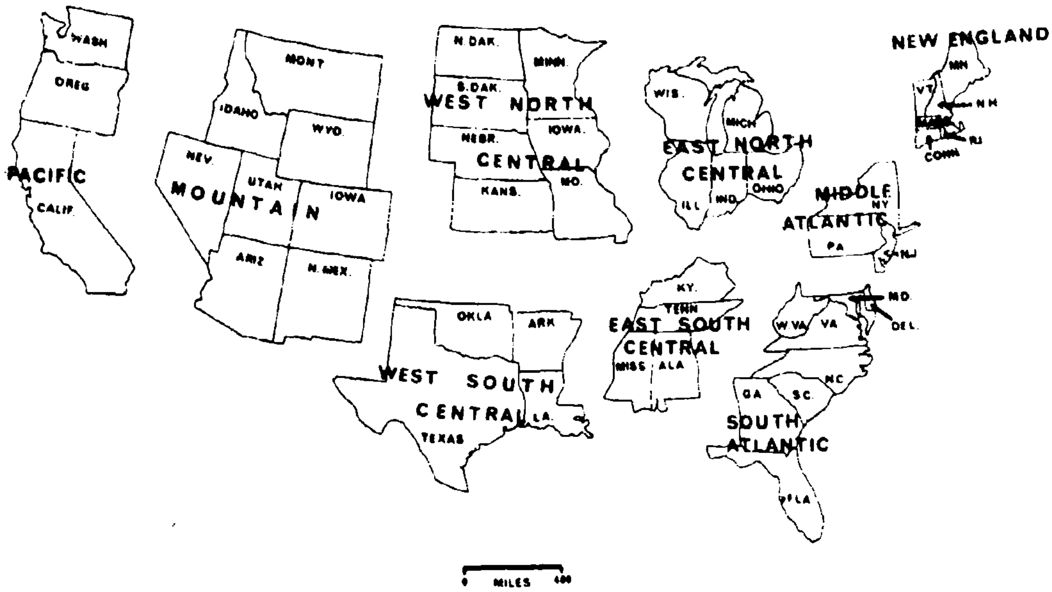

Fig. 21. Regionalization map of the United States used by the Department of Commerce, Bureau of the Census for the 1959 census of agriculture. This map is used herein as a reference to the tables in this section to pin-point the areas where the various spe[illegible] are pests.

Table 1. Major pests of wheat (by Orders); areas of importance and rating of flight habits i.e. reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
<u>Pseudaletia unipuncta</u> armyworm	West South Central West North Central East North Central East South Central Middle Atlantic	4
<u>Agrotis</u> spp., <u>Feltia</u> spp. <u>Euxoa</u> spp. cutworms	West Pacific West South Central	4
<u>Spodoptera frugiperda</u> fall armyworm	South Atlantic West South Central	4
<u>Agrotis orthogonia</u> pale western cutworm	West Mountain	4,5
HOMOPTERA		
<u>Rhopalosiphum fitchii</u> apple grain aphid	West South Central	5
<u>Macrosiphum avenae</u> English grain aphid	West Mountain West North Central West South Central	5
<u>Schizaphis graminum</u> greenbug	West Mountain West North Central East North Central South Atlantic	5
<u>Rhopalosipum</u> spp. aphids	West Mountain West Pacific	5
ORTHOPTERA		
<u>Melanoplus</u> spp. grasshoppers	West Pacific West Mountain West North Central West South Central East North Central	4
COLEOPTERA		
<u>Oulema melanopus</u> cereal leaf beetle	East North Central	4

Table 1. cont'd.

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
COLEOPTERA cont'd.		
Epitrix spp. Phyllotreta spp. flea beetles	West South Central	2,5
Agriotes mancus Limonius spp. Ctenicera spp. wireworms	East North Central West South Central West North Central Middle Atlantic West Pacific	3
DIPTERA		
Mayetiola destructor Hessian fly	East North Central West Mountain West North Central Middle Atlantic	2,5
HYMENOPTERA		
Cephus cinctus Wheat stem sawfly	West Mountain	4

RICE

Rice is produced in northern California, Arkansas, Louisiana and Texas. Studies of nuclear attack situations suggest that the production area in northern California will escape fallout radiation but this is not the case in the other areas (Figs. 13 and 14).

Insect pests: Insects from 4 Orders attack this crop, mainly through boring or puncturing action. A crustacean representative (tadpole shrimp) is a serious pest, especially in northern California. In most years the crop is treated with insecticides 1 to 2 times per year to prevent serious damage. In favorable years in northern California the rice leaf miner can be so serious that without insecticide treatments it will essentially destroy the crop.

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

The tadpole shrimp, being an obligatory aquatic organism, is indicated as being a very slowly dispersing arthropod as an adult or larva. However, eggs of this organism are usually desiccated during dry periods of the year and are readily dispersed by wind and other animals (i.e., birds) (Table 2.).

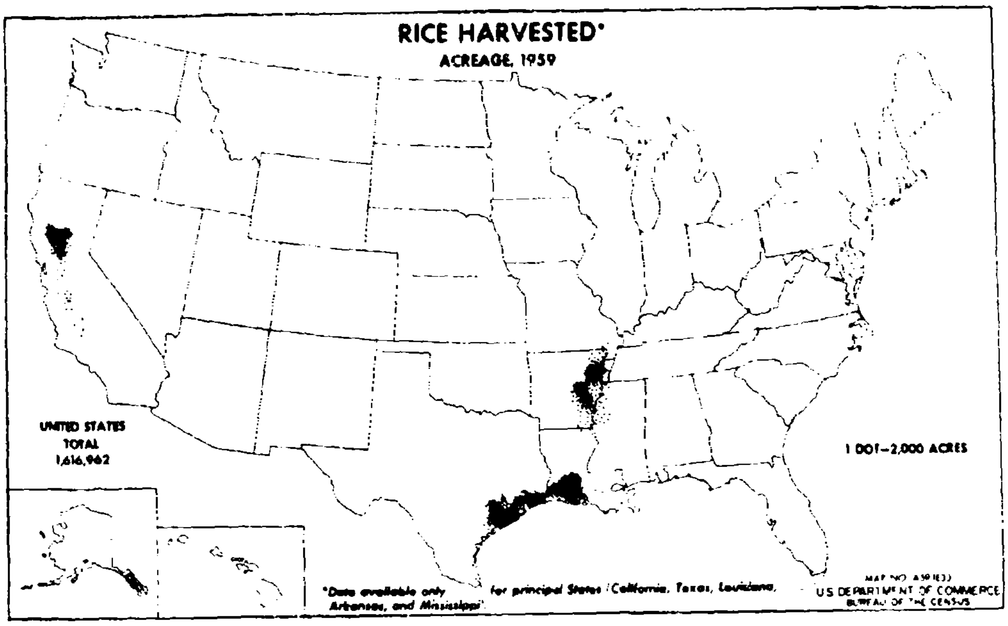

Fig. 22. Distribution of rice harvested in the United States in 1959.

Table 2. Major pests of rice (by Order); area of importance and rating of flight habits i.e. reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
<u>Chilo plejadellus</u> rice stalk borer	West South Central East South Central	3
HEMIPTERA		
<u>Oebalus pugnax</u> rice stink bug	West South Central East South Central	4
COLEOPTERA		
<u>Lissorhoptrus oryzophilus</u> rice water weevil	West South Central East South Central	2
<u>Sphenophorus</u> spp. billbugs	West South Central	2
DIPTERA		
<u>Hydrellia scapularis</u> rice leaf miner	West Pacific	2
CRUSTACAE		
<u>Triops longicaudatus</u> tadpole shrimp	West Pacific	1

CORN

Corn production is centered in the north central states and extends throughout most of the eastern and southern states, with isolated areas in California and Washington (Figs. 23,24,25).

Insect pests: The majority of pests attacking this crop are beetles and lepidopterous insects, with the seed-corn maggot, grasshoppers, chinch bugs and aphids representing other Orders.

Reinvasion potential: The beetles are moderate to good fliers, while the lepidopterous insects are generally excellent fliers. The seed-corn maggot and grasshoppers also have excellent flight characteristics while the chinch bug is only fair. The corn leaf aphid in conditions of favorable winds, has excellent dispersal characteristics. Most likely the pest species attacking corn would rapidly reinvade an area where they may have been eliminated (Table 3).

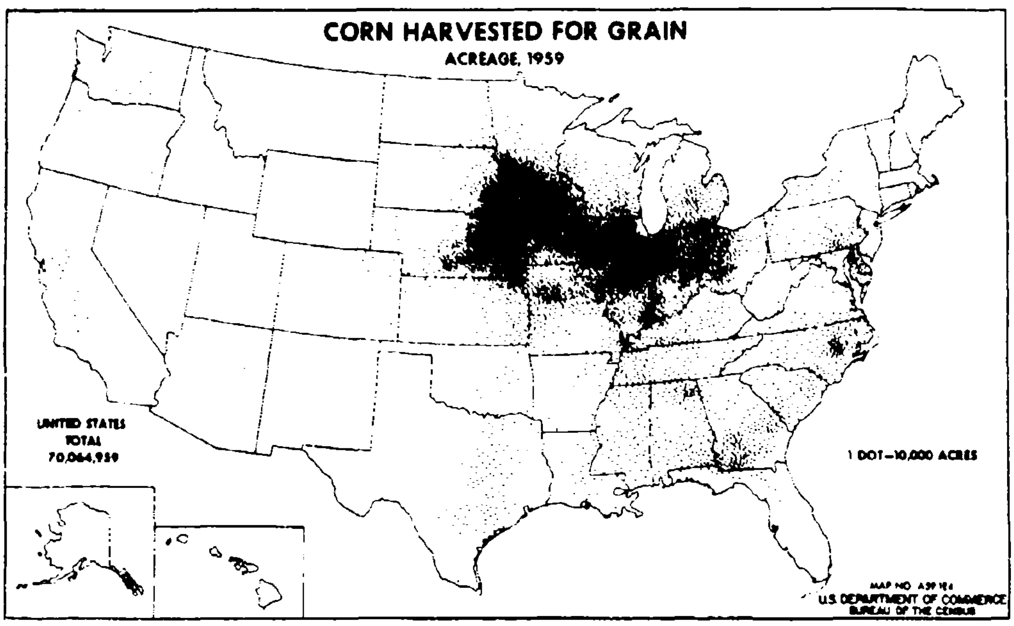

Fig. 23. Distribution of corn harvested for grain in the United States in 1959.

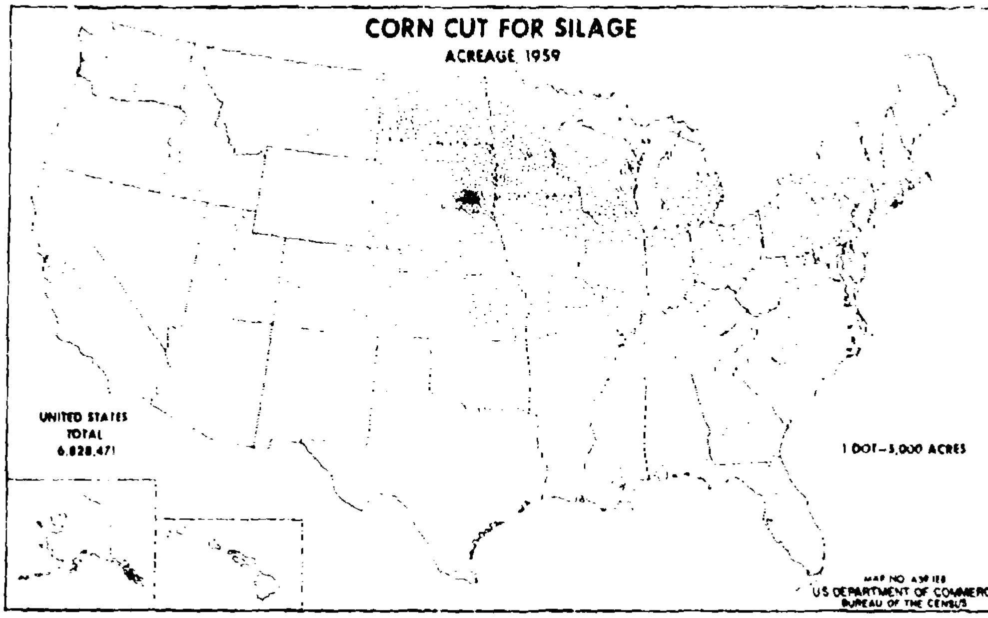

Fig. 24. Distribution of corn cut for silage in the United States in 1959.

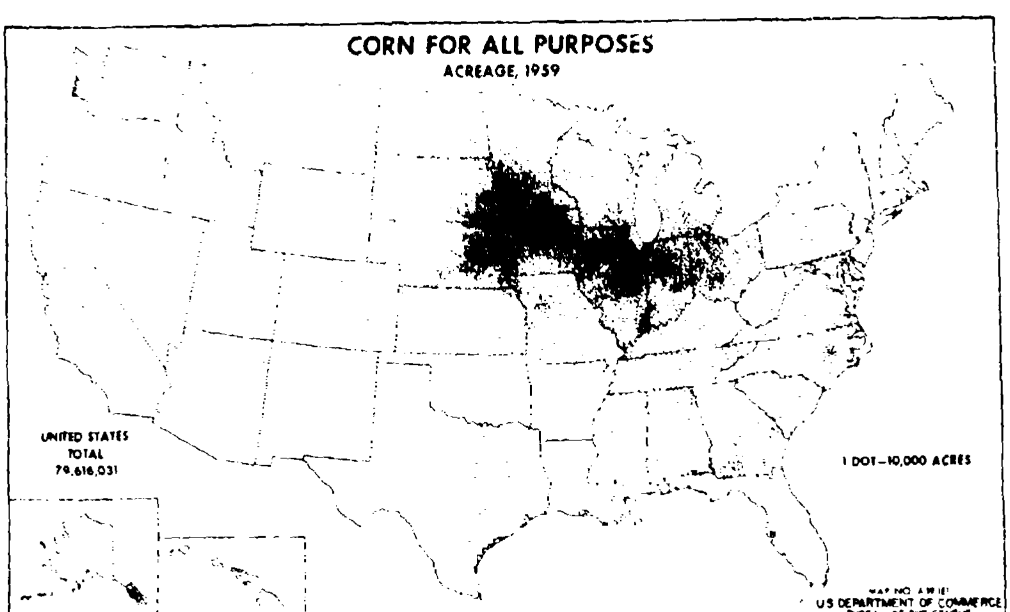

Fig. 25. Distribution of corn for all purposes in the United States in 1959.

Table 3. Major pests of corn (by Order); areas of importance and rating of flight habits i.e. reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Ostrinia nubilalis European corn borer	All areas except West Pacific, and Mountain and New England	2
Heliothis zea corn earworm	All areas	4
Spodoptera f[illegible]a fall army[illegible]	All areas except West Pacific and New England	4
Agrotis spp., Feltia spp. Euxoa spp. cutworms	All areas except New England	4
Pseudaletia unipuncta armyworm	East North Central East South Central	4
Crambus caliginosellus corn root webworm	South Atlantic	2
Elasmopalpus lignosellus lesser cornstalk borer	South Atlantic	2,5
Zeadiatrea grandiosella southwestern corn borer	West South Central East South Central South Atlantic	4
COLEOPTERA		
Chaetocnema pulicaria corn flea beetle	East North Central East South Central South Atlantic	2,5
Diabrotica longicornis northern corn rootworm	East North Central West North Central Middle Atlantic	4
D. undecimpuntata howardii southern corn rootworm spotted cucumber beetle	West South Central East South Central East North Central	4

Table 3. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
COLEOPTERA cont'd.		
D. virgifera western corn rootworm	West Mountain West North Central	4
Limonius spp. Ctenicera spp. wireworms	All Areas	3
Phyllophaga spp. white grubs	West North Central East North Central	2
HEMIPTERA		
Blissus leucopterus chinch bug	West North Central West South Central	2
HOMOPTERA		
Rhopalosiphum maidis corn leaf aphid	West North Central East North Central West South Central South Atlantic	5
ORTHOPTERA		
Melanoplus spp. grasshoppers	West Mountain West North Central East North Central	4
DIPTERA		
Hylemya platura seed-corn maggot	West North Central East North Central Middle Atlantic	4

POTATOES

Potatoes are produced in nearly all states but the main centers of production are in the Pacific northwest and California; Colorado and along the Red River in North Dakota and Minnesota, and in the north central and New England states, particularly Maine and New York (Fig. 26).

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

Reinvasion potential: With the exception of the flea beetles, flight characteristics of potato pests are mostly excellent. With favorable winds aphids and other small insects can disperse rapidly. It can be expected that nearly all pests of potatoes would soon reinvade a disturbed area where they may have been eliminated by fallout (Table 4).

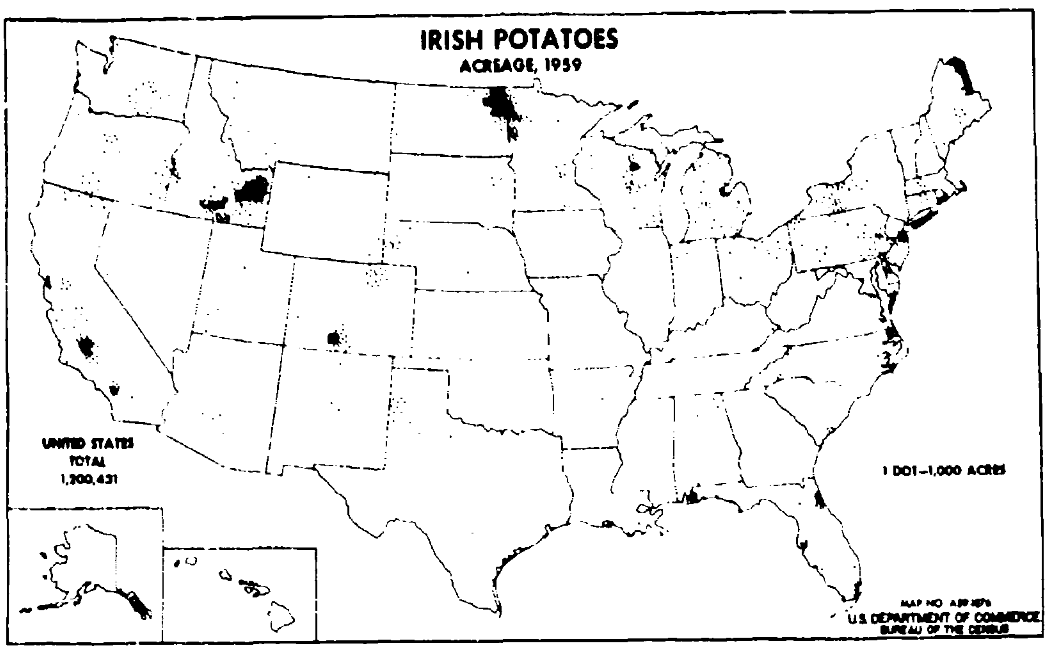

Fig. 26. Distribution of Irish potatoes in the United States in 1959.

Table 4. Major pests of potatoes (by Orders): areas of importance and rating of flight habits i.e. reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Phthorimaea operculella potato tuberworm	South Atlantic West Pacific	3
Agrotis spp., _Feltia_ spp. _Euxoa_ spp. cutworms	West Pacific West North Central East South Central	4
Pseudaletia spp. armyworms	South Atlantic	4
HOMOPTERA		
Empoasca fabae potato leafhopper	West North Central South Atlantic East North Central West Mountain New England	5
Myzus persicae green peach aphid	Middle Atlantic New England West Pacific	5
Macrosiphum euphorbiae potato aphid	West Pacific	5
Aphis spp. other aphids	All Areas	5
Paratrioza cockerelli potato psyllid tomato psyllid	West Mountain West North Central West South Central	5
COLEOPTERA		
Leptinotarsa decemlineata Colorado potato beetle	All Areas except California in West Pacific	3,5
Diabrotica u. undecimpunctata western spotted cucumber beetle	West Pacific	4

Table 4. con't

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
COLEOPTERA cont'd.		
Diabrotica balteata banded cucumber beetle	South Atlantic	4
Epitrix cucumeris potato flea beetle	All Areas except West South Central	2
Agriotes mancus *Limonius* spp. *Ctenicera* spp. wireworms	All Areas	3

VEGETABLES

These include carrots, table beets, turnips, radishes, cucumbers, squash, pumpkins, melons, cabbage, cauliflower, broccoli, brussel sprouts and tomatoes. Various numbers of these crops are produced in all areas except parts of the Mountain and West North Central areas of the United States (Fig. 27).

Insect pests: The major pests of vegetable crops are lepidopterous larvae, aphids, leafhoppers, true bugs, beetles and flies. Some of these pests feed on the foliage, others on the roots. The aphids and leafhoppers can be very destructive when they transmit plant virus diseases.

Reinvasion potential: Nearly all the lepidopterous species represented are excellent fliers as are many of the beetles. When wind and weather conditions are favorable, 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 (Tables 5,6,7 and 8).

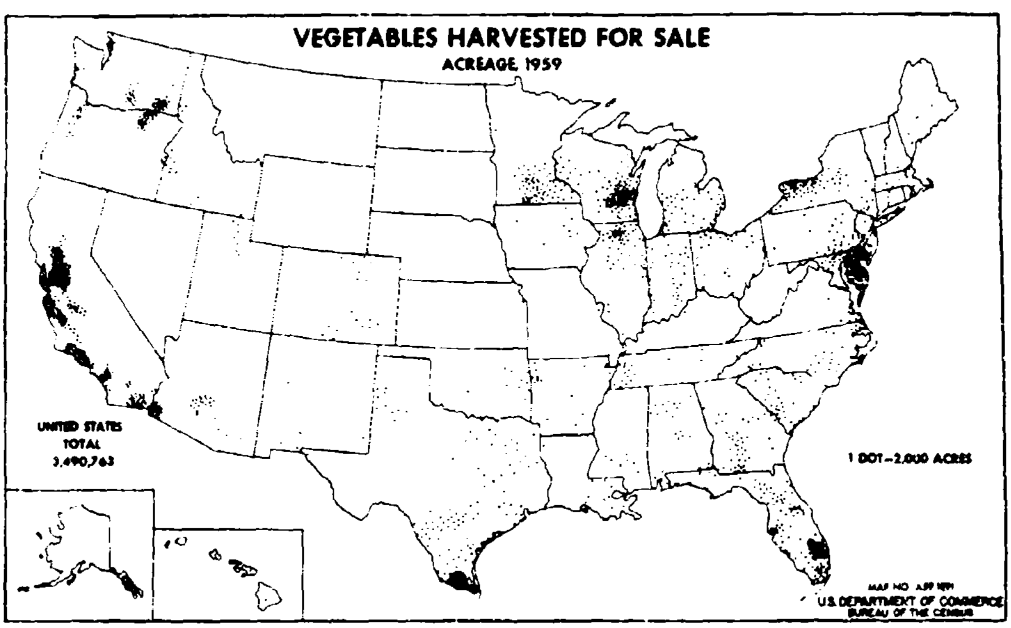

Fig. 27. Distribution of vegetables harvested for sale in the United States in 1959.

Table 5. Major pests of root crops i.e. carrots, beets, turnips, radishes (by Orders); areas of importance and rating of flight habits i.e. reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Agrotis ipsilon black cutworm	West Pacfic	4
Spodoptera frugiperda fall armyworm	South Atlantic	4
Peridroma saucia variegated cutworm	West Pacific	4
Autographa californica alfalfa looper	West Pacific	4
Loxostege sticticalis beet webworm	West South Central	4
DIPTERA		
Psila rosae carrot rust fly	West Pacific Middle Atlantic	4
Hylemya antiqua onion maggot	All Areas	4
COLEOPTERA		
Listronotus oregonensis carrot weevil	Middle Atlantic	2
Phyllotreta spp. flea beetles	All Areas	
Agriotes mancus Limonius spp. Ctenicera spp. wireworms	West Pacific West South Central South Atlantic	3
HOMOPTERA		
Myzus persicae green peach aphid	West Pacific East North Central Middle Atlantic South Atlantic	5

Table 5. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
HOMOPTERA cont'd.		
Circulifer tenellus beet leafhopper	All Areas	5
Macrosteles fascifrons six-spotted leafhopper	East North Central Middle Atlantic	5
THYSANOPTERA		
Thrips tabaci onion thrips	West Pacific East North Central Middle Atlantic	5

Table 6. Major pests of cucurbits i.e., cucumbers, squash, pumpkins, melons (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Trichoplusia ni cabbage looper	West Pacific South Atlantic	4
Agrotis sp., *Feltia* spp., *Euxoa* spp. cutworms	West South Central East South Central East North Central South Atlantic	4
Diaphania hyalinata melonworm	South Atlantic	3
D. nitidalis pickleworm	East South Central East North Central South Atlantic	4
Melittia cucurbitae squash vine borer	East North Central East South Central	4
HOMOPTERA		
Myzus persicae green peach aphid	West Pacific West South Central East North Central Middle Atlantic	5
Empoasca spp. leafhoppers	East North Central Middle Atlantic	5
HEMIPTERA		
Anasa tristis squash bug	West North Central West South Central East North Central East South Central	4
COLEOPTERA		
Acalymma vittatum striped cucumber beetle	West North Central West South Central East North Central East South Central Middle Atlantic South Atlantic	4

Table 6. Cont'd.

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
COLEOPTERA cont'd. *Diabrotica undecimpunctata howardi* southern corn rootworm	West North Central East North Central East South Central South Atlantic	4
Agriotis mancus, *Limonius* spp., *Ctenicera* spp. wireworms	West North Central	3
Phyllophaga spp. white grubs	West North Central	2
DIPTERA *Hylemya platura* seed-corn maggot	East North Central	4

Table 7. Major pests of cruciferous crops i.e., cabbage, cauliflower, broccoli, brussel sprouts (by Order); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVATION POTENTIAL
LEPIDOPTERA		
Trichoplusia ni cabbage looper	West Pacific West South Central East North Central Middle Atlantic South Atlantic	4
Autographa spp. loopers	West Pacific West South Central East North Central Middle Atlantic South Atlantic	4
Agrotis sp., *Feltia* spp., *Euxoa* spp. cutworms	East South Central South Atlantic	4
Pieris rapae imported cabbageworm	West Pacific East North Central Middle Atlantic	4
caterpillars	East North Central East South Central South Atlantic	3,4
Hellula rogatalis cabbage webworm	West North Central	3
Plutella maculipennis diamondback moth	West Pacific West North Central West South Central	4
HOMOPTERA		
Brevicoryne brassicae cabbage aphid	West Pacific Middle Atlantic	5
Myzus persicae green peach aphid	West Pacific West South Central Middle Atlantic	5

Table 7. cont'd.

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
HOMOPTERA cont'd.		
<u>Hyadaphis</u> <u>pseudobrassicae</u> turnip aphid	West South Central East South Central West Pacific	5
<u>Aphis</u> spp. aphids	All Areas	5
<u>Macrosteles</u> <u>fascifrons</u> six-spotted leafhopper	East North Central	5
HEMIPTERA		
<u>Murgantia</u> <u>histrionica</u> harlequin bug	West South Central East South Central	2,5
<u>Lygus</u> <u>lineolaris</u> tarnished plant bug	East North Central	4
DIPTERA		
<u>Hylemya</u> <u>brassicae</u> cabbage maggot	All Areas	4
COLEOPTERA		
<u>Phyllotreta</u> spp. flea beetles	All Areas	2,5
<u>Listroderes</u> <u>costirostris</u> <u>obliquus</u> vegetable weevil	East South Central	2
<u>Agriotes</u> <u>mancus</u>, <u>Limonius</u> spp., <u>Ctenicera</u> spp. wireworms	All Areas	3

Table 8. Major pests of tomato (by Order); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Manduca sexta tobacco hornworm	All Areas	4
M. quinquemaculata tomato hornworm	All Areas	4
Heliothis virescens tobacco budworm	West South Central East South Central South Atlantic	4
H. zea corn earworm	All Areas	4
Keiferia lycopersicella tomato pinworm	West Pacific East South Central South Atlantic	4,5
HOMOPTERA		
Myzus persicae green peach aphid	All Areas	5
Macrosiphum euphorbiae potato aphid	All Areas	5
Empoasca fabae potato leafhopper	All Areas Except West Pacific	5
Paratrioza cockerelli potato psyllid tomato psyllid	West Mountain	5
ACARINA		
Vasates lycopersici tomato russet mite	East South Central South Atlantic	5

BEANS AND PEAS

The major centers of bean production are in eastern Michigan, western New York and various western states (Fig. 28).

Insect pests: A number of lepidopterous larvae, aphids, leafhoppers, beetles and flies are pests of beans.

Reinvasion potential: The lepidopterous insects are excellent fliers and with proper wind conditions the aphids and leafhoppers are capable of far-reaching dispersal. Flight characteristics of the beetle pests range from very poor (cowpea curculio) to excellent (bean leaf beetle and Mexican bean beetle). The true bugs and the seed-corn maggot are excellent fliers. It can be assumed that most of these pests would reinvade a devastated area after the dissipation of the radiaiton disappearance (Table 9).

Pea production is essentially limited to the Pacific northwest (Fig. 29).

Insect pests: Pests of this crop are lepidopterous larvae, aphids and psyllids, beetles and true bugs.

Reinvasion potential: With the exception of the lesser cornstalk borer, the cowpea curculio, aphids and psyllids, many of the insect pests of peas are excellent fliers. During periods of favorable wind and climate, the pea aphid and pear psylla are capable of widespread dispersal. Under favorable conditions, most of these pests would rapidly reinvade a disturbed area (Table 10).

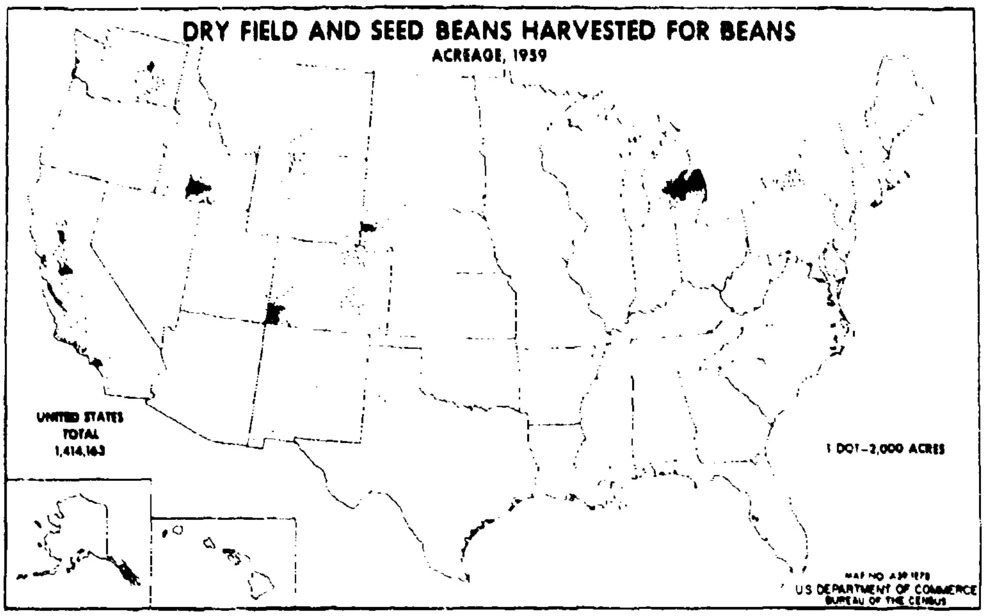

Fig. 28. Distribution of dry field and seed beans harvested for beans in the United States in 1959.

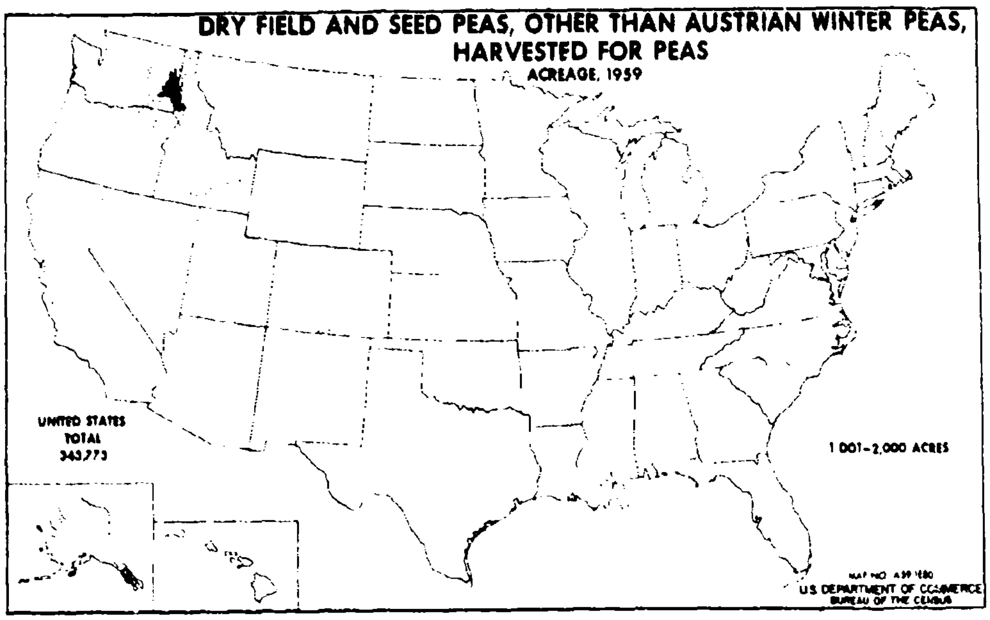

Fig. 29. Distribution of dry field and seed peas, other than Austrian winter peas, harvested for peas in the United States in 1959.

Table 9. Major pests of beans (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea corn earworm	West Pacific West South Central East North Central South Atlantic Middle Atlantic	4
Agrotis sp., *Feltia* spp., *Euxoa* spp. cutworms	West Mountain South Atlantic	4
Plathypena scabra green cloverworm	East North Central	2,5
Pseudaletia unipuncta armyworms	South Atlantic	4
Trichoplusia ni cabbage looper	West South Central West Pacific	4
Elasmopalpus lignosellus lesser cornstalk borer	East South Central South Atlantic	2,5
Etiella zinckenella lima-bean pod borer	West Pacific	2
HOMOPTERA		
Aphis Fabae bean aphid	West Pacific	5
Acyrthosiphon sp., *Nearctaphis* sp. various aphid species	All Areas	5
Circulifer tenellus beet leafhopper	West Mountain	5
Empoasca fabae potato leafhopper	West North Central East North Central Middle Atlantic West Scuth Central South Atlantic	5

Table 9. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
COLEOPTERA		
Cerotoma trifurcata bean leaf beetle	West North Central East North Central East South Central South Atlantic Middle Atlantic	4
Diabrotica u. undecimpunctata western spotted cucumber beetle	West Pacific West South Central South Atlantic	4
Epitrix spp., *Phyllotreta* spp. flea beetles	West South Central	2
Epilachna varivestis Mexican bean beetle	West South Central West Mountain East North Central Middle Atlantic South Atlantic	2,5
Chalcodermus aeneus cowpea curculio	West South Central South Atlantic	2
Agriotes mancus, *Limonius* spp., *Ctenicera* spp. wireworms	West Mountain West North Central	3
HEMIPTERA		
Thyanta custator, *Acrosternum hilare*, *Euschistus impictiventris*, *Nezara viridula*, stinkbugs	East South Central South Atlantic	4
Lygus lineolaris tarnished plant bug	West Pacific Middle Atlantic	4
DIPTERA		
Hylemya platura seed-corn maggot	est Mountain West North Central East North Central	4

Table 10. Major pests of peas (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea corn earworm	West South Central	4
Autographa californica alfalfa looper	West Pacific	4
Elasmopalpus lignosellus lesser cornstalk borer	South Atlantic	2,5
HOMOPTERA		
Acyrthosiphon pisum pea aphid	West Pacific West North Central East North Central	5
Psylla pyricola pear psylla	Middle Atlantic	5
COLEOPTERA		
Epilachna varivestis Mexican bean beetle	East South Central	2,5
Chalcodermus aeneus cowpea curculio	West South Central East South Central South Atlantic	2
Bruchus pisorum pea weevil	West Pacific	4
HEMIPTERA		
Lygus lineolaris tarnished plant bug	Middle Atlantic	4

SUGAR BEETS AND SUGAR CANE

Sugar beets are primarily grown in the north central and western United States (Fig. 30).

Insect pests: These include beetles, aphids, leafhoppers, lepidopterous and fly larvae.

Reinvasion potential: Given adequate wind conditions, the aphids and leafhoppers can disperse long distances. The flight characteristics of the remaining pests range from fair to excellent. It can be expected that most of these pests would soon reinvade a devastated area (Table 11).

Sugar cane is produced in Louisiana and southern Florida (Fig. 31).

Insect pests: These include three beetles, one lepidopterous larva and a mealybug.

Reinvasion potential: Some of these pests are moderate to excellent fliers and could be expected to reinvade areas from which they might be eliminated (Table 12).

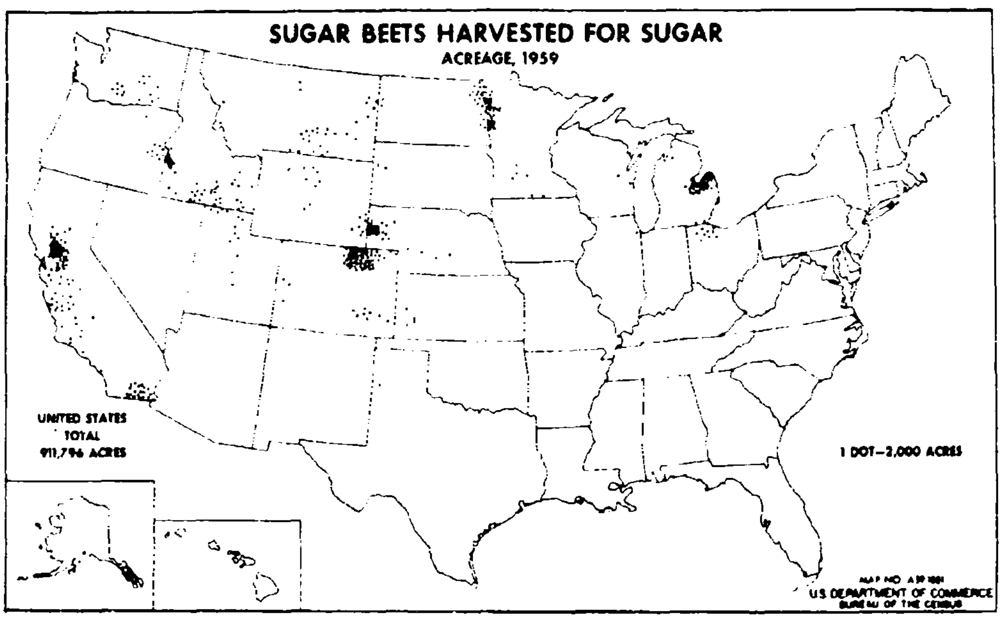

Fig. 30. Distribution of sugar beets harvested for sugar in the United States in 1959.

Table 11. Major pests of sugar beets (by Order); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Loxostege sticticalis beet webworm	West Mountain West Pacific West North Central	4
Agrotis sp., *Feltia* spp., *Euxoa* spp. cutworms	East North Central West Pacific Middle Atlantic	4
HOMOPTERA		
Myzus persicae green peach aphid	West Pacific	5
Pemphigus populivenae sugar-beet root aphid	East North Central	5
Circulifer tenellus beet leafhopper	West Pacific West Mountain	5
Empoasca fabae potato leafhopper	West North Central East North Central Middle Atlantic	5
E. solana southern garden leafhopper	West Pacific	5
COLEOPTERA		
Epitrix spp., *Phyllotreta* spp. flea beetles	West Mountain West North Central East North Central	2,5
Agriotes mancus, *Limonius* spp., *Ctenicera* spp. wireworms	West Pacific West Mountain	3
Epicauta spp. blister beetles	East North Central	3

Table 11. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
HEMIPTERA		
Nysius ericae false chinch bug	West Mountain	4,5
Lygus lineolaris tarnished plant bug	East North Central Middle Atlantic	4
DIPTERA		
Tetanops myopaeformis sugar-beet root maggot	West Mountain West North Central	3

Table 12. Major pests of sugar cane (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Diatraea saccharalis sugarcane borer	All Important Areas in East South Central	3
COLEOPTERA		
Euetheola rugiceps sugarcane beetle	All Important Areas in East South Central	4
Anacentrinus subnudus sugarcane weevil	All Important Areas in East South Central	2
Sphenophorus spp. billbugs	All Important Areas in East South Central	2
HOMOPTERA		
Dysmicoccus boninsus gray sugarcane mealybug	All Important Areas in East South Central	4

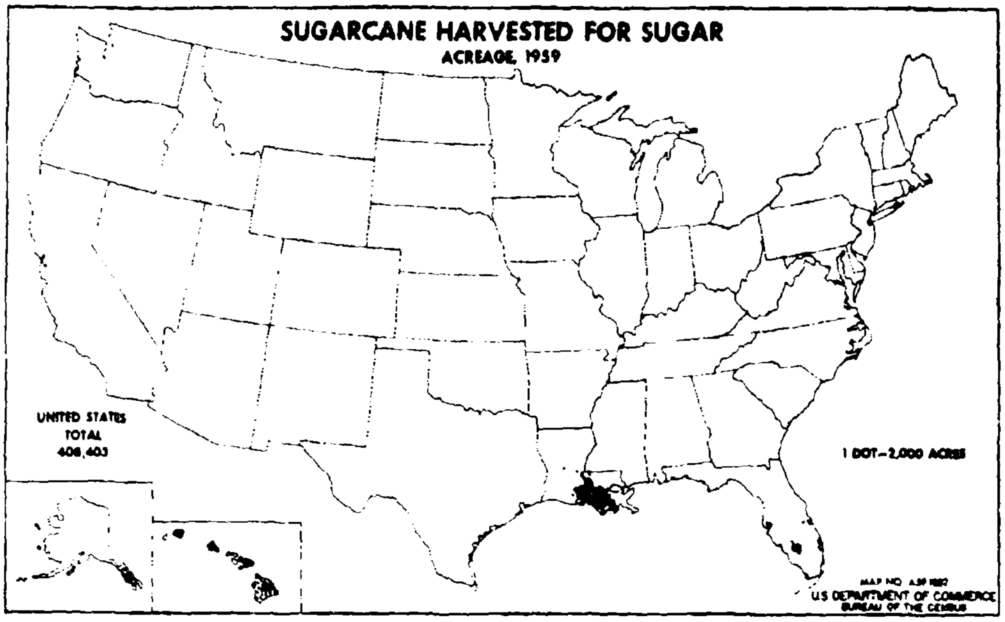

Fig. 31. Distribution of sugarcane harvested for sugar in the United States in 1959.

SOYBEANS

Soybeans are grown throughout the central, southern and mid-Atlantic states (Figs. 32 and 33).

Insect pests: Several lepidopterous insects, grasshoppers, the Mexican bean beetle and stink bugs are pests of this crop.

Reinvasion potential: All pests of soybeans are excellent fliers, and all would undoubtedly be represented among the insects reinvading an area after possible elimination (Table 13).

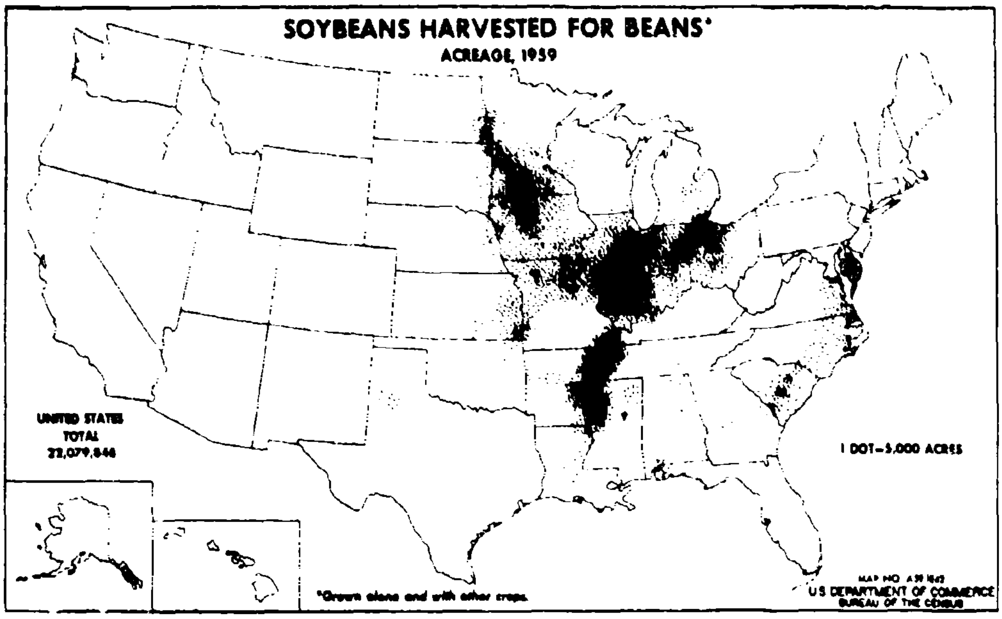

Fig. 32. Distribution of soybeans harvested for beans in the United States in 1959.

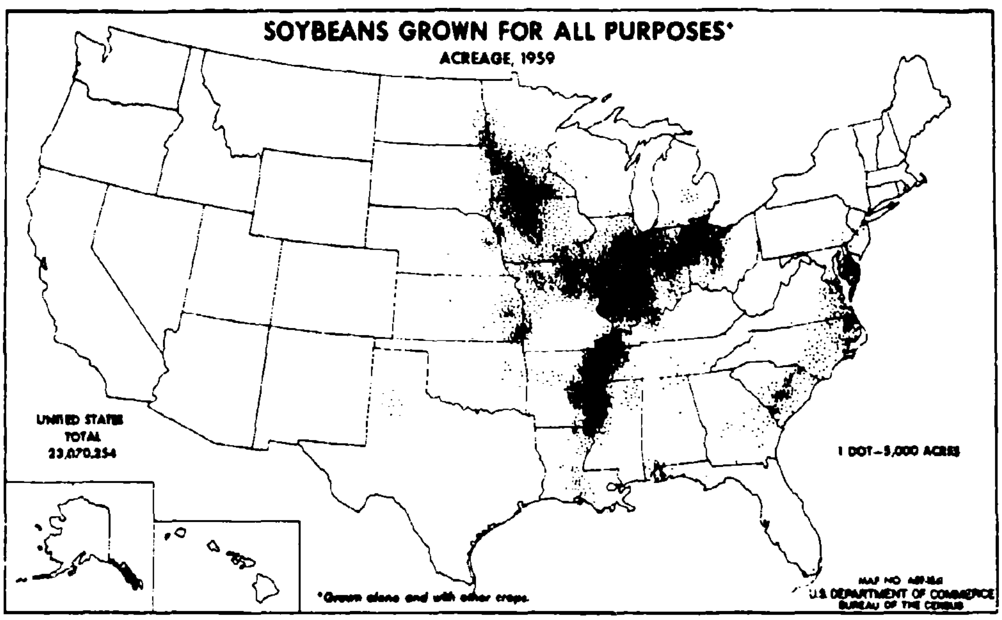

Fig. 33. Distribution of soybeans grown for all purposes in the United States in 1959.

Table 13. Major pests of soybeans (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Heliothis zea corn earworm	West South Central West North Central East South Central South Atlantic	4
Pseudaletia unipuncta armyworm	West North Central East South Central	4
Spodoptera frugiperda fall armyworm	West North Central South Atlantic	4
Plathypena scabra green cloverworm	West North Central	2,5
Autographa spp., Trichoplusia sp. loopers	South Atlantic	4
Loxagrotis albicosta western bean cutworm	West North Central	4
COLEOPTERA		
Epilachna varivestis Mexican bean beetle	East South Central South Atlantic	2,5
HEMIPTERA		
Thyanta custator, Acrosternum hilare, Euschistus impictiventris, Nezara viridula stink bugs	West South Central East South Central South Atlantic	4
ORTHOPTERA		
Melanoplus spp. grasshoppers	West North Central East North Central	4

ALFALFA

Alfalfa is grown in all but the southeastern states, Maine and New Hampshire (Fig. 34). However, when clover, grain and grasses are considered, forage is produced in every state (Fig. 35).

Insect pests: Alfalfa is attacked by a wide variety of lepidopterous larvae as well as aphids, leafhoppers, spittle bugs, beetles, grasshoppers and the imported fire ant. Often the entire crop may be defoliated when insecticides are not used to eliminate the destructive pests.

Reinvasion potential: With one exception, the lepidopterous insects are all excellent fliers. Grasshoppers are fair fliers, and aphids, leafhoppers and similar types of insects are fair fliers, but are capable of wind-borne dispersal. The alfalfa weevil is a poor flier. Most likely the lepidopterous insects and, with favorable wind conditions, the homopterous species would rapidly reinvade disturbed areas (Table 14).

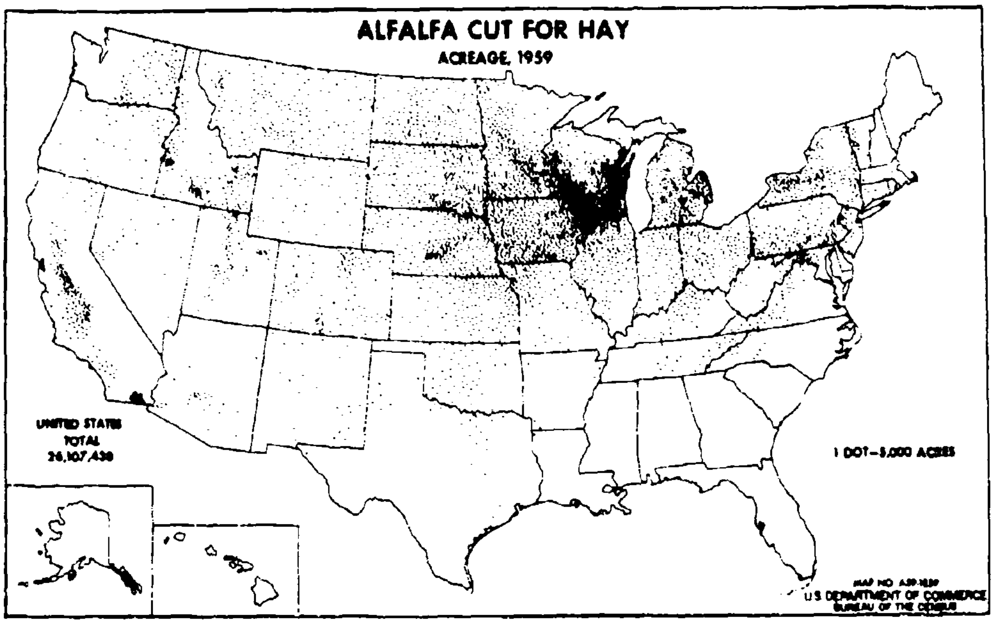

Fig. 34. Distribution of alfalfa cut for hay in the United States in 1959.

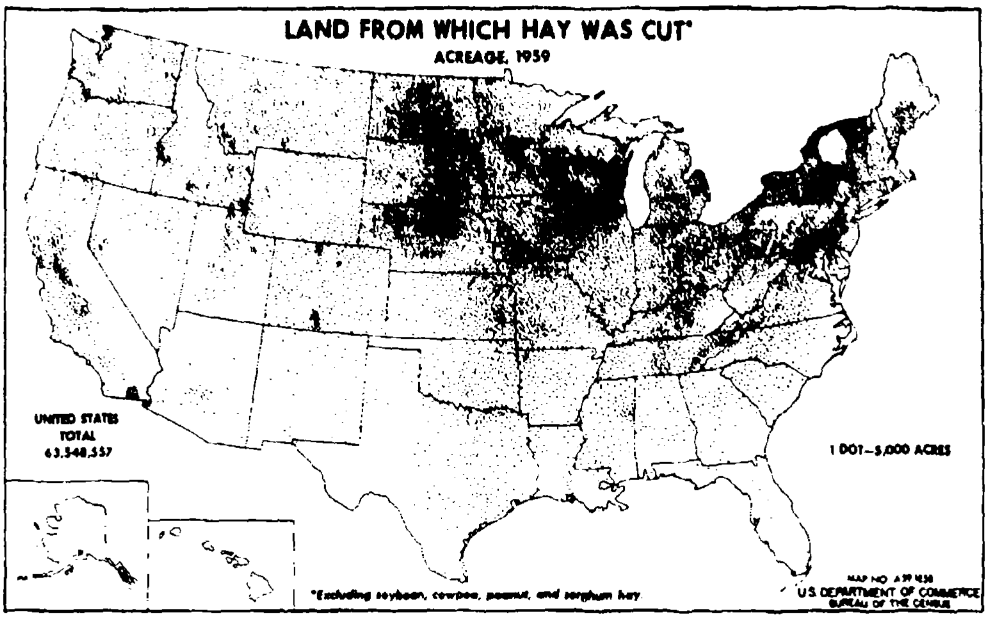

Fig. 35 Distribution of land from which hay was cut in the United States in 1959 (excluding soybean, cowpea, peanut and sorghum hay).

Table 14. Major alfalfa pests (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Loxostege spp. webworms	West South Central West Mountain West North Central	2,5
Colias eurytheme alfalfa caterpillar	West Pacific West Mountain	4
Spodoptera exigua beet armyworm	West Pacific	4
Prodenia ornithogalli yellow-striped armyworm	West Pacific	4
Anticarsia gemmatalis velvetbean caterpillar	West Mountain	4
Peridroma saucia variegated cutworm	West Pacific West South Central West North Central	4
Agrotis ipsilon black cutworm	Middle Atlantic	4
Amanthes c-nigrum spotted cutworm	Middle Atlantic	4
Pseudaletia sp.	West South Central East South Central West North Central East North Central Middle Atlantic West Mountain	4
HOMOPTERA		
Spissistilus festinus three-cornered alfalfa hopper	West South Central East South Central	2
Neophilaenus lineatus lined spittlebug	East North Central Middle Atlantic	2,5

Table 14. Cont'd.

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
HOMOPTERA cont'd. Philaenus spumarius meadow spittlebug	Middle Atlantic	2,5
Empoasca fabae potato leafhopper	East North Central Middle Atlantic	5
Empoasca sp. leafhoppers	West North Central East North Central	5
Therioaphis trifolii spotted alfalfa aphid	West South Central	5
Acyrthosiphon pisum pea aphid	All Areas Except New England and South Atlantic	5
alfalfa aphids	East South Central	5
ORTHOPTERA Gryllus sp. crickets	West North Central West Mountain West North Central	2
HYMENOPTERA Solenopsis saevissima richteri imported fire ant	East South Central	2,5
COLEOPTERA Epicauta spp. blister beetles	East South Central	3
Phyllophaga spp. white grubs	East South Central	2
Hypera postica alfalfa weevil	All Areas Except New England and West South Central	2

FRUITS

Pome Fruits; apples and pears.

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

The major centers of fruit production are in California, Florida, the Pacific Northwest and various sections of the south, central and eastern United States (Fig. 36).

Insect pests: The major pests of these crops include mites, lepidopterous larvae, aphids, leafhoppers, flies and a number of beetles. Most fruit crops require a number of insecticide treatments each year to prevent crop damage.

Reinvasion potential: With few exceptions, nearly all of these fruit pests are capable of rapid dispersal. The aphids and mites require favorable winds for rapid dispersal. It is highly probable that reinvasion into areas where the pests had been eliminated would occur soon after radiation had disappeared (Tables 15 and 16).

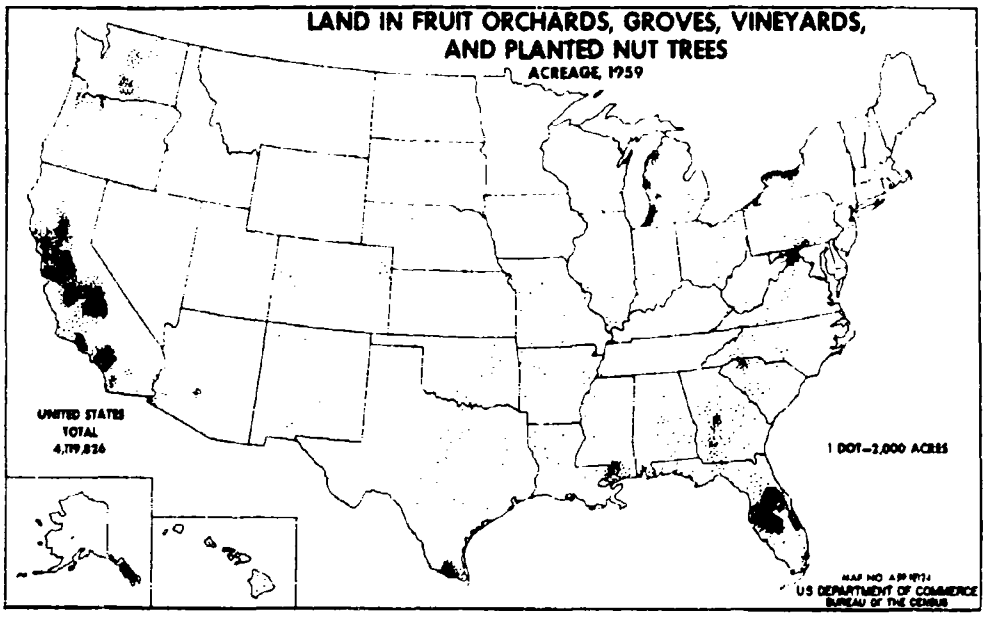

Fig. 36. Distribution of land in fruit orchards, groves, vineyards, and planted nut trees in the United States in 1959.

Table 15. Major pests of pome fruits i.e. apples, pears, (by Orders); areas of importance and rating of flight habits i.e. reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Carpocapsa pomonella codling moth	All Areas	3
Archips argyrospilus fruit-tree leaf roller	All Areas in northern half of U.S.	2,5
Argyrotaenia velutinana red-banded leaf roller	East North Central Middle Atlantic New England	2,5
Spilonota ocellana eye-spotted bud moth	West Pacific East North Central Middle Atlantic New England	3
HOMOPTERA		
Aphis pomi apple aphid	All apple growing areas	5
Dysaphis plantaginea rosy apple aphid	" " " "	5
Rhopalosiphum fitchii apple grain aphid	" " " "	5
Eriosoma lanigerum woolly apple aphid	" " " "	5
DIPTERA		
Rhagoletis pomonella apple maggot	East North Central Middle Atlantic New England	3
Contarinia pyrivora pear midge	East North Central Middle Atlantic New England	2,5

Table 15. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
COLEOPTERA		
Tachypterellus quadrigibbus apple curculio	All areas east of Mississippi River	2
Conotrachelus nenuphar plum curculio	All areas east of Rocky Mountains	2,5
HOMOPTERA		
Typhlocyba pomaria white apple leafhopper	All areas east of Rocky Mountains	5
Edwardsiana rosae rose leafhopper	West Pacific West Mountain	5
Empoasca fabae potato leafhopper	All areas east of Rocky Mountain	5
THYSANOPTERA		
Taeniothrips inconsequens pear thrips	West Pacific East North Central Middle Atlantic New England	5
ACARINA		
Panonychus ulmi European red mite	All areas north of 34° Lat. (Gulf States excluded)	5
Bryobia praetiosa clover mite	All Areas	5
B. arborea brown mite	All Areas	1
Tetranychus pacificus Pacific spider mite	West Pacific West Mountain	5

Table 15. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
ACARINA cont'd		
Tetranychus schoenei Schoene spider mite	East South Central South Atlantic	5
T. atlanticus strawberry spider mite	All Areas	5
Eriophyes pyri pear leaf blister mite	All Areas	5

Table 16. Major pests of stone fruits i.e., peach, plum, apricot, cherry and nectarine (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
LEPIDOPTERA		
Grapholitha molesta Oriental Fruit moth	All Areas	3
Anarsia lineatella peach twig borer	West Pacific	4
Sanninoidea exitiosa peach tree borer	All Areas	3
S. exitiosa graefi Western peach tree borer	West Pacific	3
Argyrotaenia velutinana red-banded leaf roller	East North Central Middle Atlantic New England	2,5
COLEOPTERA		
Phloeotribus liminaris peach bark beetle	East North Central Middle Atlantic New England	4

Table 16. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
HEMIPTERA		
Lygus lineolaris tarnished plant bug	All Areas East of Rocky Mountains	4
L. hesperus lygus bug	All Areas West of Rocky Mountains	4
DIPTERA		
Rhagoletis cingulata cherry fruit fly	West Pacific East North Central Middle Atlantic	3
R. fausta black cherry fruit fly	West Pacific East North Central Middle Atlantic	3
THYSANOPTERA		
Taeniothrips inconsequens pear thrips	West Pacific West Mountain	3
ACARINA		
Panonychus ulmi European red mite	All Areas North of 34°Lat.	5
Bryobia praetiosa clover mite	All Areas	5
B. arborea brown mite	All Areas	1
Tetranychus pacificus Pacific spider mite	West Pacific West Mountain	5
T. schoenei Schoene spider mite	East South Central South Atlantic	5

CITRUS

Citrus is produced in central and southern California, southern Arizona, Florida and the southern tip of Texas (Figs. 37 and 38).

Insect pests: The major pests of citrus include mites, aphids, scales, mealybugs and white flies.

Reinvasion potential: The mite pests, being wingless, require wind for effective dispersal. The homopteran insects, although usually winged at some stage in their life cycles, are moderately strong fliers at best. With appropriate winds they are capable of passive dispersal over long distances. Given suitable meteorological conditions, many of these species would reinvade a devastated area after the effects of radiation had disappeared (Table 17).

Table 17. Major pests of citrus (by Orders); areas of importance and rating of flight habits i.e., reinvasion potential.

PEST SPECIES	AREA OF IMPORTANCE (Fig. 21)	REINVASION POTENTIAL
ACARINA		
Panonychus citri citrus red mite	South Atlantic West Pacific	2,5
Phyllocoptruta oleivora citrus rust mite	South Atlantic West South Central	5
Eutetranychus banksi Texas citrus mite	South Atlantic West South Central	5
Aceria sheldoni citrus bud mite	West Pacific	5
Brevipalpus lewisi citrus flat mite	West Pacific	5
Eotetranychus yumensis Yuma spider mite	West Pacific	5

Table 17. cont'd

PEST SPECIES	AREA OF IMPORTANCE	REINVASION POTENTIAL
HOMOPTERA		
Aphis spiraecola spirea aphid	West Pacific South Atlantic	3,5
A. gossypii melon aphid		5
Myzus persicae green peach aphid		5
Pseudococcus fragilis citrophilus mealybug	West Pacific South Atlantic	2
Lepidosaphes beckii purple scale	West Pacific	5
Aonidiella citrina yellow scale		5
Chrysomphalus aonidum Florida red scale		5
Aonidiella aurantii California red scale	West Pacific West South Central South Atlantic	5
Saissetia oleae black scale	West Pacific South Atlantic	5
Coccus hesperidum brown soft scale	West South Atlantic West Pacific	5
Icerya purchasi cottony-cushion scale	West Pacific	5
Lepidosaphes gloverii Glover scale	South Atlantic	5
Dialeurodes spp., *Aleurothrixus* sp., Aleurocanthus sp. whiteflies	South Atlantic	3

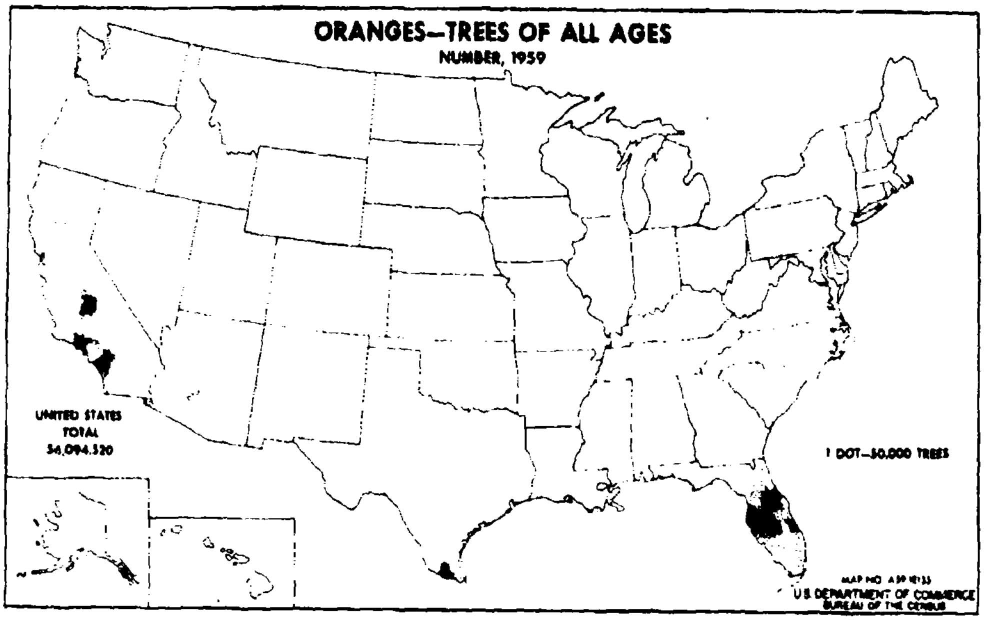

Fig. 37. Distribution and number of orange trees of all ages in the United States in 1959.

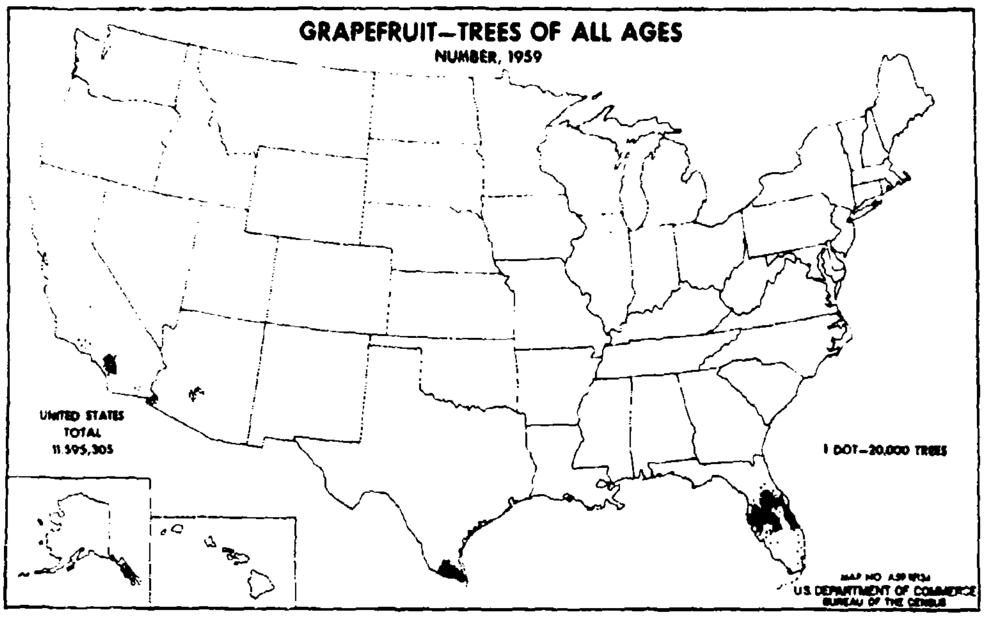

Fig. 38. Distribution and number of grapefruit trees of all ages in the United States in 1959.

Table 18. THE REINVASION POTENTIAL OF THE MAJOR ARTHROPOD PESTS ATTACKING THE CROPS LISTED IN TABLES 1 TO 17 AND LITERATURE REFERENCES ON WHICH THE REINVASION POTENTIAL INDICES WERE BASED.

PEST	CROPS ATTACKED	R.P.	REFERENCE
General			58,59 14,15 16,17 18,19 20,21 22,23 24,25 26,60 27,28 29,30 31,32 33,34 35,36 37,38 39
ACARINA- mites and ticks			
General			61,62 63,64 65
Eriophyidae- eriophyid mites			
<u>Aceria sheldoni</u> citrus bud mite	citrus	5	
<u>Eriophyes pyri</u> pear leaf blister mite	pome fruits	5	
<u>Phyllocoptruta oleivora</u> citrus rust mite	citrus	5	
<u>Vasates lycopersici</u> tomato russet mite	tomatoes	5	66
Tarsonemidae- tarsonemid mites			
<u>Brevipalpus lewisi</u> citrus flat mite	citrus	5	
Tetranychidae- spider mites			

PEST	CROPS ATTACKED	R.P.	REFERENCE
Bryobia arborea brown mite	stone fruits	1	67
B. praetiosa clover mite	stone fruits pome fruits	5	
Eutetranychus banksi Texas citrus mite	citrus	5	
E. yumensis Yuma spider mite	citrus	5	
Panonychus citri citrus red mite	citrus	2,5	68
P. ulmi European red mite	stone fruits pome fruits	5	
Tetranychus atlanticus strawberry spider mite	pome fruits	69	
T. pacificus Pacific spider mite	stone fruits pome fruits	5	69
T. schoenei Schoene spider mite	stone fruits pome fruits	5	69
ORTHOPTERA- grasshopper & allies			
General			
Acrididae- grasshoppers			
Melanoplus spp.	wheat corn soybeans	4	71 p.595-604 59 p.129-34 72
Gryllidae- crickets			
Gryllus spp. crickets	alfalfa	2	
THYSANOPTERA- thrips			
General			73 62 74
Thripidae			
Taeniothrips inconsequens pear thrips	stone fruits pome fruits	5	75
Thrips tabaci onion thrips	root crops	5	75 76

PEST	CROPS ATTACKED	R.P.	REFERENCE
HEMIPTERA- true bugs			
General			
Coreidae- coreid bugs			
Anasa tristis squash bug	cucurbits	4	77
Lygaeidae- lygaeid bugs			
Blissus leucopterus chinch bug	corn	2	79 p.185
Nysius ericae false chinch bug	sugar beets	4&5	62
Miridae- plant bugs General			80
Lygus hesperus lygus bugs	stone fruits	4	
L. lineolaris	crucifers beans peas sugar beets stone fruits	4	
Pentatomidae- stink bugs General			81 80
Acrosternum hilare green stink bug	beans soybeans	4	77
Euschistus impictiventris western brown stink bug	beans soybeans	4	77
Murgantia histrionica harlequin bug	crucifers	2&5	75
Nezara viridula southern green stink bug	beans soybeans	4	77
Oebalus pugnax rice stink bug	rice	4	77
Thyanta custat[illegible] red-shouldered plant bug	beans soybeans	4	77
HOMOPTERA- aphids, leafhoppers, scales, and allies. planthoppers General			62

PEST	CROPS ATTACKED	R.P.	REFERENCE
Aleyrodidae- whiteflies			
Aleurocanthus spp.	citrus	3	
Aleurothrixus spp.	citrus	3	
Dialeurodes spp.	citrus	3	82
Aphididae- aphids General			83,84 85,86 87,75 73,88 89,90 91,92 93,34.
Acyrthosiphon spp. aphids	beans	5	
A. pisum	peas	5	94,95 96.
Aphis spp. aphids	potatoes crucifers	5	97
A. fabae bean aphid	beans	5	90,98 99.
A. gossypii cotton aphid (Melon aphid)	citrus	5	62
A. pomi apple aphid	pome fruits	5	
A. spiraecola spirea aphid	citrus	3&5	100
Brevicoryne brassicae cabbage aphid	crucifers	5	73
Dysaphis plantaginea rosy apple aphid	pome fruits	5	101
Eriosoma lanigerum woolly apple aphid	pome fruits	5	102, 103.
Hyadaphis pseudobrassicae turnip aphid	crucifers	5	
Macrosiphum avenae English grain aphid	wheat	5	

PEST	CROPS ATTACKED	R.P.	REFERENCE
M. euphorbiae potato aphid	potatoes tomatoes	5	104 105
Myzus persicae	potatoes root crops cucurbits crucifers sugar beets citrus tomatoes	5	71 p.523-4 106 107.
Nearctaphis spp. aphids	beans	5	
Pemphigus populivenae sugar-beet root aphid	sugar beets	5	62
Rhopalosiphum spp. aphids	wheat	5	108
R. fitchii apple grain aphid	wheat pome fruits	5	108
R. maidis corn leaf aphid	corn	5	
Schizaphis graminum greenbug	wheat	5	109 110
Therioaphis trifolii spotted alfalfa aphid	alfalfa	5	111 112 113
Cicadellidae-leafhoppers General			114
Circulifer tenellus beet leafhopper	root crops sugar beets	5	115 145 46,47 116
Edwardsiana rosae rose leafhopper	pome fruits	5	
Empoasca spp. leafhoppers	cucurbits alfalfa	5	
E. fabae	potatoes beans sugar beets alfalfa tomatoes pome fruits	5	59 p.292-4 44,117 114

PEST	CROPS ATTACKED	R.P.	REFERENCE
E. solana southern garden leafhopper	sugar beets	5	97
Macrosteles fascifrons six-spotted leafhopper	root crops crucifers		
Typhlocyba pomaria McAtee white apple leafhopper	pome fruits	5	
Membracidae-treehoppers			
Spissistilus festinus three-cornered alfalfa hopper	alfalfa	2	
Cercopidae- spittlebugs			
Neophilaenus lineatus lined spittlebug	alfalfa	2&5	
Philaenus spumarius	alfalfa	2&5	59 p.239-42 102 118 119 120 34
Coccidae- soft scales			
Coccus hesperidum brown soft scale	citrus	5	
Saissetia oleae black scale	citrus	5	120 121
Diaspididae- armored scales			
Aonidiella aurantii California red scale	citrus	5	120 121
A. citrinia yellow scale	citrus	5	
Chrysomphalus aonidum Florida red scale	citrus	5	122
Lepidosaphes beckii purple scale	citrus	5	
L. gloverii Glover scale	citrus	5	123

PEST	CROPS ATTACKED	R.P.	REFERENCE
Margarodidae- margarodid scales			
Icerya purchasi cottony-cushion scale	citrus	5	124 121 125
Pseudococcidae- mealybugs General			126
Dysmicoccus boninsus gray sugarcane mealybug	sugar cane	4	
Pseudococcus fragilis citrophilus mealybug	citrus	2	127
Psyllidae- jumping plantlice General			73 128
Paratrioza cockerelli potato psyllid (tomato psyllid)	potatoes tomatoes	5	71 p517
Psylla pyricola pear psylla	pome fruits peas	5	129
LEPIDOPTERA- moths, butterflies			
General			130 131 132 133 134 135 136 137,62.
Caterpillars	crucifers	5	71 p.23 138
Aegeriidae- clearwing moths			
Melittia cucurbitae squash vine borer	cucurbits	4	77
Sanninoidae exitiosa peach tree borer	stone fruits	3	77
S. exitiosa graefi western peach tree borer	stone fruits	3	77
Crambidae- grass moths			

PEST	CROPS ATTACKED	R.P.	REFERENCE
Chilo plejadellus rice stalk borer	rice	3	77
Crambus caliginosellus corn root webworm	corn	2	77
Diatraea saccharalis sugarcane borer	sugar cane	3	77
Zeadiatrea grandiosella southwestern corn borer	corn	4	77
Gelechiidae- gelechiid moths			
Keiferia lycopersicella tomato pinworm	tomatoes	4&5	97
Anarsia lineatella	stone fruits	4	139 140
Phthorimaea operculella potato tuberworm	potatoes	3	77
Noctuidae			
Agrotis spp. cutworms	wheat corn potatoes cucurbits crucifers beans sugar beets	4	141-2 134 143
A. ipsilon	root crops alfalfa	4	144 145
A. orthogonia pale western cutworm	wheat	4&5	137 75
Amathes c-nigram spotted cutworm	alfalfa	4	137
Anticarsia gemmatilis velvetbean caterpillar	alfalfa	4	59 p222
Autographa spp. loopers	crucifers soybeans	4	146-9
A. californica alfalfa looper	root crops peas	4	77

PEST	CROPS ATTACKED	R.P.	REFERENCE
Euxoa spp.	wheat corn potatoes cucurbits beans sugar beets	4	150-4
Feltia spp. cutworms	wheat corn potatoes cucurbits crucifers beans sugar beets	4	77
Heliothis virescens tobacco budworm	tomatoes	4	155
H. zea	corn tomatoes beans peas soybeans	4	59 p158-61
Loxagrotis albicosta western bean cutworm	soybeans	4	77
Peridroma saucia variegated cutworm	root crops alfalfa	4	137
Plathypena scabra green cloverworm	beans soybeans	2&5	62
Prodenia ornithogalli yellow-striped armyworm	alfalfa	4	77
Pseudaltia spp. armyworm	potatoes alfalfa	4	77
P. unipuncta armyworm	wheat corn beans soybeans	4	156
Spodoptera exiqua beet armyworm	root crops alfalfa	4	157
S. frugiperda fall armyworm	wheat corn root crops soybeans	4	59 p148-50
Trichoplusia spp. loopers	crucifers soybeans	4	77

PEST	CROPS ATTACKED	R.P.	REFERENCE
T. ni cabbage loopers	cucurbits crucifers beans	4	77
Olethreutidae- olethreutid moths			
Carpocapsa pomonella codling moth	pome fruits	3	158-9 137 160
Grapholitha molesta Oriental fruit moth		3	161-3 129
Spilonota ocellana eye-spotted bud moth	pome fruits	3	77
Phycitidae			
Elasmopalpus lignosellus lesser cornstalk borer	corn peas beans	2&5	62
Etiella zinckenella lima-bean pod borer	beans	2	77
Pieridae- whites & sulfur butterflies.			
Colias eurytheme alfalfa caterpillar	alfalfa	4	145 137
Pieris rapae imported cabbageworm	crucifers	4	144-5 151
Pyraustidae- pyraustid moths			
Diaphania hyalinata melonworm	cucurbits	3	77
D. nitidalis pickleworm	cucurbits	4	164
Hellula rogatalis cabbage webworm	crucifers	3	77
Loxostege spp. webworms	alfalfa	2&5	62
L. sticticalis beet webworm	root crops	4	165-7
Ostrinia nubilalis European corn borer	corn	2	168-9

PEST	CROPS ATTACKED	R.P.	REFERENCE
Sphingidae- sphinx moths			
Manduca quinquemaculata tomato hornworm	tomatoes	4	59 p.284-6
M. sexta tobacco hornworm	tomatoes	4	59 p.284-6 155
Tortricidae- leaf roller moths			
Arachips argyrospilus fruit-tree leaf roller	pome fruits	2&5	77
Argyrotaenia velutinana red-banded leaf roller	pome fruits stone fruits	2&5	77
Yponomeutidae- ermine moths			
Plutella maculipennis diamondback moth	crucifers	4	137
COLEOPTERA- beetles, weevils			
General			73,62
Bruchidae- seed beetles			
Bruchus pisorum pea weevil	peas	4	170-171
Chrysomelidae- leaf beetles			
Acalymma vittatum striped cucumber beetle	cucurbits	4	
Cerotoma trifurcata bean leaf beetle	beans	4	62
Chaetocnema pulicaria corn flea beetle	corn	2&5	62
Diabrotica balteata banded cucumber beetle	potatoes	4	
D. longicornis northern corn rootworm	corn	2&5	
D. undecimpunctata howardi southern corn rootworm (spotted cucumber beetle)	corn potatoes cucurbits beans	4	172-3

PEST	CROPS ATTACKED	R.P.	REFERENCE
Diabrotica virgifera western corn rootworm	corn	4	59 p186
Epitrix spp. flea beetles	wheat beans sugar beets	2&5	174 97
E. cucumeris potato flea beetle	potatoes	2	175
Leptinotarsa decimlineata Colorado potato beetle	potatoes	3&5	75 176 14 p57-60
Oulema melanopus cereal leaf beetle	wheat	4	177
Phyllotreta spp. flea beetles	root crops crucifers beans sugar beets	2&5	62
Coccinellidae- lady beetles			
Epilachna varivestis Mexican bean beetle	beans peas soybeans	2&5	71,75
Curculionidae- snout beetles, weevils			
Anacentrinus subnudus sugarcane weevil	sugar cane	2	
Chalcodermus aeneus cowpea curculio	beans peas	2	59 p251-2
Conotrachelus nenuphar plum curculio	pome fruits	2&5	178
Hypera postica alfalfa weevil	alfalfa	2	179
Lissorhoptrus oryzophilus rice water weevil	rice	2	
Listronotus oregonensis carrot weevil	root crops	2	59 p368-9
Listroderes costrostris obliquus vegetable weevil	crucifers	2	

PEST	CROPS ATTACKED	R.P.	REFERENCE
Sphenophorus spp. billbugs	rice sugar cane	2	180
Tachypterellus quadrigibbus apple curculio	pome fruits	2	
Elateridae- wireworms, click beetles			
Agriotes mancus wheat wireworm	wheat potatoes root crops cucurbits crucifers beans sugar beets	3	181
Ctenicera spp. wireworms	wheat corn potatoes root crops cucurbits beans crucifers sugar beets	3	181
Limonius spp. wireworms	wheat corn potatoes root crops cucurbits crucifers beans sugar beets	3	181
Meloidae- blister beetles			
Epicauta spp. blister beetles	sugar beets alfalfa	3	77
Scarabaeidae- scarabs			
Euetheola rugiceps sugarcane beetle	sugar cane	4	
Phyllophaga spp. white grubs	wheat corn cucurbits alfalfa	2	77
Scolytidae- bark beetles			

PEST	CROPS ATTACKED	R.P.	REFERENCE
Phloeotribus liminaris peach bark beetle	stone fruits	4	
HYMENOPTERA- ants, bees wasps and allies			
Cephidae- stem sawflies			
Cephus cinctus wheat stem fly	wheat	4	182
Formicidae- ants			
Solenopsis saevissima richteri imported fire ant	alfalfa	2&5	75 183
DIPTERA- flies			
Anthomyiidae- anthomyiid flies			
Hylemya antiqua onion maggot	root crops	4	184
H. brassicae cabbage maggot	crucifers	4	184
H. platura seed-corn maggot	corn cucurbits beans	4	184
Cecidomyiidae- gall midges			
Contarinia pyrivora pear midge	pome fruits	2&5	77 184
Mayetiola destructor Hessian fly	wheat	2&5	185-7
Ephydridae- shore flies			
Hydrellia scapularis rice leaf miner	rice	2	77 184
Otitidae- otitid flies			
Tetanops myopaeformis sugar-beet root maggot	sugar beets	3	77 184
Psilidae			

PEST	CROPS ATTACKED	R.P.	REFERENCE
Psila rosae carrot rust fly	root crops	4	77 184
Tephritidae- fruit flies			
Rhagoletis cingulata cherry fruit fly (Cherry maggot)	stone fruits	3	188
R. fausta black cherry fruit fly	stone fruits	3	188
R. pomonella apple maggot	pome fruits	3	189
CRUSTACEA- shrimp, crabs, lobsters, pill bugs, copepods, etc.			
Branchiopoda-			
Triops longicaudatus tadpole shrimp	rice		

COMPARATIVE BIOLOGICAL EFFECTS OF RADIATION ON FOOD AND FORAGE CROPS AND THEIR REPRESENTATIVE INSECT PESTS

This section is a condensation and integration of the extensive literature on radiation effects of plants and insects. Only the important food and forage plants and their insect pests discussed in Tables 1-17 were selected for comparative biological effects of radiation. A number of difficulties were encountered. First, radiological effects on only a few of the major commercial plant species and their insect pests have been studied. In special cases some inferences might have been made from radiation studies on phylogenetic plant or insect species; or, perhaps more reliably, from radiation studies on interphase chromosome volume research. For a number of reasons, particularly funds and time, this was not possible within the scope of the present project.

Secondly, a certain number of reports were published by foreign investigators. The present authors have little or no knowledge of the quality of the research and under what conditions and in which institutions this work was conducted. This raised some question concerning the universal acceptance of the published data, particularly in regard to dose monitoring techniques and the reported biological response. Nevertheless the data seem to suggest that commercial plant species might be more radiosensitive than the pest species attacking or feeding on these crops (Table 19).

WHEAT

Radiation studies on wheat show that 2.5 Kr X radiation of seeds produces cytogenetic disturbances (Ehrenberg, et al., 190). Since reproductive systems are usually quite radiosensitive this dose may approximate the minimum responsive dose. Twenty Kr X radiation of seeds proved to be lethal in the seedling stage. (Scossiroli and Pellegrini-Scossiroli, 191). Under these conditions, there may be an X-ray radiosensitivity range in wheat seeds from approximately 2.5-20 Kr. It was also shown that an X-ray dose of 3 Kr applied to adult plants completely stopped growth (Vasiliev, et al., 192). Wheat seeds treated with 5-10 Kr gamma rays showed a slight increase in seedling growth, while doses of 5-30 Kr produced a decrease in seedling survival with increased deleterious effects in the maturing plants. Evidently, the lower gamma-doses which produce increased growth are accompanied by decreased survival. Gamma exposures of 20-30 Kr in delayed seedling emergence (Mohamed, et al., 193). Furthermore, Strazhevskaya (194) has shown that gamma radiation of seedlings at the 10 Kr level results in a 23.7% depression of growth.

The cereal leaf beetle, Oulema melanopus, is a serious pest of wheat, particularly in the East North Central agricultural region of the United States. The only radiation data available on this species indicates that adults receiving 500 r X-rays suffer reduced fecundity, while at a 5 Kr dose there is a complete loss of egg viability (Hoppingarner, et al., 195).

In the adult stage this pest would seem to suffer deleterious effects from radiation long before any serious disturbances are seen in wheat due to seed radiation. Serious population damage (i.e., loss of egg vitality), however, does not occur until well after doses are achieved which may impair the host population.

CORN

Experiments show that seeds receiving 0.5 Kr X-rays suffer no modification in germination. However, a 1 Kr X-ray dose inhibits growth and 22 Kr X-rays cause a reduction of green mass yield and number of ears by 50-70% (Sydorenko, 196). Gamma rays at 0.1 Kr produce a decrease in germination rate with increased dose, and 1-20 Kr exposures gives a decrease in root growth proportional to dose (Erdelesky, 197). Sydorenko (196) modified the range for gamma-ray effect upon germination when he reported that 1 Kr doses have no effect on germination. The dose range within which gamma-rays decrease germination rate is probably from greater than 1 Kr to 20 Kr. Growth inhibition is attained at gamma-exposures of 2 Kr, while 22 Kr reduce the green mass yield and number of ears by 50-70%.

The European corn borer, Ostrinia nubilalis, is a serious pest of corn in the major corn belt. Walker (198, 199) has shown that X-ray treatments of male and female pupae at the 5 Kr level result in only a 15.8% egg hatch in the F_1 generation. An exposure of young male pupae to a 7 Kr dose reduced the viability of eggs by 50% in the next generation. Radiation of both sexes during the pupal stage results in a fecundity 3 times lower than when only male pupae are radiated. When young adult males were subjected to 32 Kr X-rays and mated with normal females there was fecundity of about 99%.

POTATO

Tubers of the potato have been shown to be quite susceptable to radiation damage as compared to other plants. Sparrow and Christensen (200) have demonstrated that X radiation doses of 0.75-2.4 Kr produced no noticeable mutations in the succeeding generation, and that no modification of yield occurred at exposures of 18.75-300 r (Sparrow and Christensen,201). Avakyan, et al., (202), later reported that non-sprouted tubers receiving as little as 100 r suffer a yield decrease of 23.9% with a range extending to a 56.2% decrease at 2 Kr. Tubers that have sprouted indicate that yield is increased by 13% at X-ray exposures of 100-500 r. At 2 Kr, however, sprouted tubers give a decreased yield. The data of Sparrow and Christensen (201) indicate that 4.8 Kr X-rays represented the lethal limit of exposure and decreased yield to 4% of normal. Heiken (203) showed that gamma ray exposure of 250 r to 8 Kr gave a decrease in vitality. Kuzin, et al. (204) reported that 10 Kr gamma rays gave increased growth and 50 Kr decreased growth, but Burton and De Jong (205) stated that 10 Krad gamma rays were sufficient to prevent sprouting of tubers.

The potato tuber worm, Phthorimaea operculella, is a major pest of potatoes in the South Atlantic and West Pacific agricultural regions. Elbadry (206) reported that a gamma ray exposure to mature pupae of 500 r was sufficient to prevent emergence of the adults. An exposure of 900 r on three day old eggs produce larvae that were smaller, lighter and contained less stored fat than normal. Elbadry (207) later reported that mature larvae receiving 6 Krad gamma rays produced malformed adults and 24-96 Krads prevented pupation. Adult females radiated at the 24 Krad level produced non-viable eggs.

The potato tuberworm seems to have a high radiosensitivity threshold in comparison to other insects. It may not be a representative insect pest of potatoes, but is the only one studied in the literature. In order for radiation to adversely affect this pest requires radiation levels which would produce at least moderately deleterious effects on the crop.

LEGUMES

Beans and peas appear to have a relatively high radioresistance. Breslavets, et al. (208), showed that 500 r X or gamma rays increased the yield of peas when the seeds were radiated. Mamedov and Khalisi (209) reported that initial suppression of growth occurred at 1.1 Kr gamma exposure when 5 day old seedlings were radiated, and at 2.05 Kr on 10 day old seedlings. Gottschalk (210) showed that seeds receiving 7-15 Kr X-rays produced mutants and most were lethal, sterile, or only weakly fertile.

Avramenko, et al. (211) reported that there was about 14% bean seeds radiated at a level of 9 Kr gamma rays. He also stated that seeds of the Russian black bean receiving this dosage suffered 21% male sterility. Mamedov and Khalisi (209) reported that the gamma dose required for initial suppression of growth in the Russian black bean was 860 r and 1.47 Kr for 5 day and 10 day old seedlings respectively. When the bean, Phaseolus vulgaris received 12 Kr gamma dose on the seeds there was 50% mortality and, a mutation in the surviving plants which eliminated flower production (Moh and Alan, 212). The broad bean, Vicia faba, suffers decreased root growth after radiation with 60-150 r gamma rays on the seeds. At 270 r, root growth is inhibited (Mamedov, 213). Spalding, et al. (214) reported that a 400 r gamma dose on the roots of this species produced 50% mortality. In the horse bean, V. faba equina, decreased accessory root growth was observed at X-ray exposures on the adult plant within the range of 200-400 r. Above 400 r, root growth was completely inhibited (Lozeron, et al., 215).

Radiation effects on two major pests of beans and peas appear in the literature and these are the bean pea weevil, Bruchus quadrimaculata, and the Mexican bean beetle, Epilachna varivestis. Huque (216) reported that 25 Kr gamma radiation of the eggs of the former species can prevent hatching. Henneberry, et al. (217), found the following sterilization doses of gamma rays for the Mexican bean beetle: 8 Kr for adult males;

16 Kr for adult females; 1-16 Kr for female pupae; and 4-16 Kr for male pupae.

It would appear that at least moderate crop damage would occur before radiation levels were high enough to seriously affect these two pests.

Alfalfa has been shown to suffer 50% mortality at X-ray doses of 90 Kr (Brock and Andrew, 218). This minimal evidence may indicate a very high radioresistance in this crop.

The alfalfa weevil, Hypera postica is a major pest of alfalfa. Studies of Burgess and Bennett (220) on adult male alfalfa weevils showed that a range of 2-10 Kr X-rays produced nonviable eggs in the F_1 generation. When males were treated with 4 Kr X-rays and mated with non-radiated females, less than 1% of the eggs hatched.

In the case of alfalfa the alfalfa weevil may be effected at a dose below that harmful to the crop.

VEGETABLES

Of all the vegetable crops grown in the United States, studies have only been conducted on certain root crops. Seeds of the radish were subjected to 1 Kr X and gamma rays by Breslavets, et al. (208). Apparently, this increased yield by 11-33%. Vlasyuk (221) later reported that 2 Kr also increased growth, but in other tests 1-10 Kr gamma exposure on the seeds seriously effected the meristematic tissue.

Breslavets, et al. (222), and Vlasyuk (221) reported there was increased growth when carrot seeds were radiated with 2-4 Kr X-rays and 0.1-3 Kr. gamma rays respectively.

Two insect pests of some root crops are the beet armyworm, Spodoptera exigua, and the carrot rust fly, Psila rosae. Rasulov (223) radiated female beet armyworm pupae with X-rays and found that 5 Kr caused 100% sterilization. A 10-11 Kr dose on male pupae produced sterilized adults and decreased their longevity. McClanahan (224) reported that a 1.4 Ka gamma dose to 15 day old female pupae of the carrot rust fly eliminated oviposition in the adult. Male and female pupae subjected to a 3 Kr dose caused a 93% reduction of larvae in the succeeding generation and males subjected to a 4.3 Kr dose produce sterile sperm.

These data suggest that the pest populations mentioned might be affected at a dose below that required to produce injury to radishes and carrots.

FRUIT TREES

Lapins (225) conducted studies on apples and reported that a gamma exposure on the exposed buds at 3.35-6.1 Krad caused 50% mortality.

Studies by Proverbs and Newton (226) on the codling moth, Carpocapsa pomonella show that female pupae receiving 25 Krad gamma ray dose suffer 99% egg sterility in the F_1 generation. When 40 Krads were applied to 1 day pre-emergence male pupae only 2% of the eggs hatched when the males were mated with normal females. Proverbs (227) slater reported that this low egg viability was due to the induction of 99% dominant lethals in the sperm. Twelve to 24 hour old adult males exposed to 40 Krads we e essentially sterilized.

Due to the limited d on radiation effects to apple trees and their pests interpretations are difficult. However, if apple buds can be compared to pupae it might appear that this pest is more radioresistant than the buds.

In a number of instances, radiation damage would occur to the crop (wheat, corn, potato, pea, bean, apple) before radiation exposures reached a level sufficiently high to seriously effect the pests mentioned. The exceptions appear to be alfalfa and the root crops. In these cases the pests would seem to suffer harmful radiation effects at levels below those necessary to induce damage to the host crop.

Table 19. COMPARATIVE BIOLOGICAL EFFECTS OF RADIATION ON FOOD AND FORAGE CROPS AND THEIR REPRESENTATIVE INSECT PESTS.

CROP & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS	PEST & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS
Triticum sp. wheat Ehrenberg et al., 190	2.5 Kr X	Seed	Cytogenetic disturbance	*Oulema melanopus* cereal leaf beetle			
Mohamed, et al., 193	20-30 Kr γ	Seed	Delayed seedling emergence	Hoopingarner, et al., 195	500r X	Adult m, f*/	Reduced fecundity
	5-10 Kr γ	Seed	Slight increase in seedling growth		5 Kr X	Adult m, f*/	Complete loss of egg viability
	5-30 Kr γ	Seed	Decreased seedling survival; increased deleterious effects in mature plants				
Scossiroli & Pellegrini Scossiroli, 19[illegible]	20 Kr X	Seed	Lethal as seedlings				
Strazhevskaya, 194	10 Kr γ 3 Kr X	Seedlings	24% depression of growth				
Vasilev, et al., 192		Growing plant	Completely arrested growth				
Zea mays corn				*Ostrinia nubilalis* European corn borer			
Erdelsky, 197	0.5-20 Kr γ 0.5 Kr γ	Seed Seed	Decreased germination Slight increase in root growth	Walker, 198	32 Kr X	Young Adult m	1% egg hatch in F^1

*/ m=male; f= female

Table 19. (con't)

CROP & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS	PEST & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS
Burton & DeJong, 205	10 Krad γ	Tuber	Prevents sprouting				
Kuzin, 204	10 Kr γ 50 Kr γ	Tuber Tuber	Increased growth Decreased growth				
Sparrow & Christensen, 200	0.75-2.4 Kr X	Tuber	No noticeable mutations in F^1				
Sparrow & Christensen, 201	18.75-300 Kr X (4.8 Kr/Hr)	Tuber	No effect on yield; 300r produced increased germination over lower dose				
	1.2 Kr X (4.8 Kr/Hr)	Tuber	Decreased yield to 75%				
	4.8 Kr X (4.8 Kr/Hr)	Tuber	Decreased yield to 4%; lethal limit				
<u>Pisum</u> sp pea Breslavets, 208	0.5 Kr X	Seed	Increased yield	<u>Bruchus quadrumaculata</u> bean, pea weevil Huque, 216	25 Kr γ	Eggs	Prevents hatching
Gottschalk, 210	7-15 Kr X (100 r/min)	Seed	Produces mutants of which: 27% were lethal, 24% sterile, 21% weakly fertile	<u>Epilachna varivestis</u> Mexican bean beetle Henneberry, et al., 217	8 Kr γ 16 Kr γ 1-16 Kr γ 4-16 Kr γ	Adult m Adult f Pupa f Pupa m	Sterilization " "

Table 19. (con't)

CROP & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS	PEST & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS
	1-20 Kr γ	Seed	Decrease in root growth	Walker, 199	5 Kr X	Pupa, m f	16% egg hatch in F^1
Sydorenko, 196	0.5 Kr X	Seed	No effect on germination		7 Kr X	2-3 day old pupa m.	50% egg hatch in F^1
	1 Kr γ	Seed	" " " "				
	1 Kr X	Seed	Inhibits growth		30 Kr X	Adult m	0.1% egg hatch in F^1
	2 Kr γ	Seed	" "				
	22 Kr X	Seed	Reduction in plant yield and ears by 50-70%		32 Kr X	Young adult m	0.4% egg viability
	33 Kr γ	Seed	" " " " "				
Solanum sp. potato Avakyan, 202	0.1-2 Kr X	non-sprouted tubers	Decreased yield by 24-56%	*Phthorimaea operculella* potato tuberworm	0.5 Kr γ	Mature pupe	Prevents adult emergence.
	0.1-0.5 Kr X	sprouted tubers	Increased yield by 12-14%	Elbadry, 206	0.9 Kr γ	3 day old egg	Smaller, lighter larvae with less stored fat.
	2 Kr X	sprouted tubers	Decreased yield				
Heiken, 203	0.25-8 Kr	tuber	Suppression of vitality	Elbadry, 207	6 Krad γ	Mature larva	Adult malformation
					24 Krad γ	Adult f	Non-viable eggs
					24-96 Krad γ	Mature larva	Prevents pupation
					96 Krad γ	All	body movements sluggish

Table 19. (con't)

CROP & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS	PEST & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS
Spalding, et al, 214	401.4 $\pm$ 21.2 r γ	Root	LD_{50}				
V. faba equina horse bean Lozeron, et al, 215	200-400 r X	Adult	Decreased growth of accessory roots with dose				
	400 r X	Adult	Completely inhibits growth of roots				
Medicago polymorpha alfalfa Brock & Andrew, 218	90 Kr X	Adult	LD_{50}	Gryllus domestica cricket Sumarukov, 219	4.2 Kr γ	Adult	LD_{50}
				Hypera postica alfalfa weevil Burgess & Bennett, 220	2-10 Kr X	Adult m	Non-viable eggs in F^1
					4 Kr X	Adult m	0.8% egg hatch
					8, 10 Kr X	Adult m	Sterility
Raphanus sp. radish Breslavets, 208	1 Kr X γ	Seed	Increased yield by 11-33%	Spodoptera exiqua beet army worm Rasulov, 223	5 Kr X	Pupa f	100%
					10-11 Kr X	Pupa f,m	sterility

Table 19. (con't)

CROP & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS	PEST & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS
Vlasyuk, 221	0.1-3 Kr 1-10 Kr	Seed Seed	Increased growth Damaged metabolism, degeneration of meristematic tissues				Decreased male longevity
Daucus sp. carrot Breslavets, 222	2-4 Kr X	Seed	Increased growth	*Psila rosae* carrot rust fly McClanahan, 224	1.4 Kr	15 day old pupa f	No egg laying as adult
					3 Kr	15 day old pupa f,m	93% reduction of F^1 larvae
Vlasyuk, 221	0.1-3 Kr	Seed	Increased growth		4.3 Kr	15 day old pupa m	Sterile sperm
Pyrus sp. apple Lapins, 225	3.35-6.1 Krad γ	Exposed buds	LD_{50} of buds	*Carpocapsa pomonella* codling moth	25 Krad γ	Pupa f	99% sterility of F^1 eggs
				Proverbs & Newton, 226	40 Krad γ	Pupa m 1 day pre-emergence	High sterility 2% egg hatch in F^1
				Proverbs, 227	40 Krad γ	"	99% induction of dominant lethals in sperm
						12-24 hr old adult m	99% induction of dominant lethals in sperm

Table 19. (con't)

CROP & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS	PEST & REFERENCE	EXPOSURE	LIFE STAGE	RESULTS
Mamedov & Khalisi, 209	1.1 Kr γ	5 day old seedlings	Initial suppression of growth				
	2.05 Kr γ	10 day old seedlings	Initial suppression of growth				
Phaseolus white bean Avramenko, 211	9 Kr γ	Seed	Male sterility of 14%				
Russian black bean Avramenko, 211	9 Kr γ	Seed	Male Sterility of 21%				
Mamedov & Khalisi, 209	0.86 Kr γ	5 day old seedlings	Initial suppression of growth				
	1.47 Kr γ	10 day old seedlings	Initial suppression of growth				
Phaseolus vulgaris bean Moh & Alan, 212	12 Kr γ (1.5 Kr/min)	Seed	LD_{50} with mutation of survivors; no flowers				
Vicia faba broad bean Mamedov, 213	60-150 r γ	Seed	Decreased root growth 5-7 days post radiation				
	270 r γ	Seed	Root growth inhibited				

EFFECTS OF BETA RADIATION ON VARIOUS INSECTS

Very little work has been done on the effects of beta radiation on insects. The recorded information is conspicuous in its omission of exposure values. A few general trends from the effects of beta radiation may be noted from the few species studied.

Treatments of 3.5-9.9 uc/g. of food fed to the boll-weevil, Anthonomus grandis resulted in reduced fecundity and increased larval mortality when treatment was applied during the larval stage. In general, treatment of the larvae produces a greater effect than does treatment of adults.

General effects on Diptera (Chironomus tentans and Drosophila melanogaster) included chromosomal aberrations in the pupae and increased sex-linked recessive lethals in the adults.

In the Braconidae (Hymenoptera), treatment of adult females of Habrobracon spp. resulted in morphological abnormalities and decreased fecundity and longevity.

Doses of 0-5 uc/g. food fed to Ephestia kuhniella (Lepidoptera: Phycitidae) decreased the progeny and delayed development.

When adults of the American cockroach, Periplaneta americana were treated with 10,000 roentgen doses, the effect was a decrease in body weight and blood volume and increased mortality.

Treatments of 1-5 uc/g. of food fed during the terminal nymphal instar of the North American field cricket Gryllus assimilis resulted in zero fecundity due to sterility in adult males. Five uc/g. food doses produced 100% mortality within 24 hours.

Studies on eggs of the German cockroach, Blatella germanica, show that, although 1 Kr Eq. beta exposure has no effect on egg hatch, 2 Kr Eq. reduces egg hatch to 66% and doses of 5-70 Kr Eq. result in 0% egg hatch.

Table 20. EFFECTS OF BETA RADIATION

Organism & reference	Beta Exposure or amt. rad. in diet	Life Stage	Results
COLEOPTERA: CURCULIONIDAE			
Anthonomus grandis boll weevil Mitlin, et al., 228	3.5 uc/g food	larva: m,f	Inhibition of development to adult stage.
		adult: m,f	Small decrease in fecundity; sterility when both sexes irradiated.
Mayer & Brazzel 229	4.9 uc/g food	larva: m,f	No egg laying as adults, males fertile
	9.9 uc/g food	larva: m,f	Larval mortality increased, no egg laying as adults, males fertile.
	4.9 uc/g food	adult: m,f	Females fertile, 90% egg hatch
	9.9 uc/g food	adult: m,f	Longevity of both sexes decreased, but not as much as when larvae are irradiated.
DIPTERA: CHIRONOMIDAE			
Chironomus tentans biting midge Nelson, et al. 230		larva: m,f	Increased chromosomal aberration
		pupa: m,f	" " "
		adult: m,f	" " "
DIPTERA: DROSOPHILIDAE			
Drosophila melanogaster fruit fly Stroemnaes, 231	10.4 specific activity.	larva: m	Dominant lethals present, but seemed not to be radiation induced.
		adult: m 6-24 hr old.	Significant increase with frequency of sex-linked recessive lethals.

(con't) Table 20. EFFECTS OF BETA RADIATION

Organism & reference	Beta Exposure or amt. rad. in diet	Life Stage	Results
HYMENOPTERA: BRACONIDAE			
Habrobracon sp. wasp Grosch, 232		adult: f	Damage to gonads, decreased egg hatch, decreased longevity, temporary and permanent infecundity and sterility.
H. juglandis wasp Martin, 233		adult: f	28% morphological abnormalities in progeny
LEPIDOPTERA: NOCTUIDAE			
noctuid moths Smith & Kimeldorf 234	1 mr at 20 mr/sec.	adult: m,f	Electroretinogram response
LEPIDOPTERA: PHYCITIDAE			
Ephestia kuhniella Mediterranean meal moth Erdman, 235	0-5 uc/g food	adult throughout life cycle	Progressive decrease in progeny; life span not influenced; development delayed.
ORTHOPTERA: BLATTIDAE			
Periplaneta americana American cockroach Wharton, et al., 236	10 Kr	Adult: m,f	Early & continuous loss of body wt. from third day after irradiation; increasing mortality; blood vol. percent greatly reduced

(con't) Table 20. EFFECTS OF BETA RADIATION

Organism & reference	Beta exposure or amt. rad. in diet	Life Stage	Results
ORTHOPTERA: GRYLLIDAE			
Gryllus assimilis North American field cricket Adbel-Malek&McKevan 237	1-5 uc	nymph: m,f last instar	No egg laying as adults; males sterile
	1-5 uc	nymph: m last instar	No egg laying when mated untreated female
	5 uc	nymph: last instar	100% mortality within 24 hours.
Blatella germanica German cockroach Anderson & Cromroy, 238	1 Kr Eq.		100% capsule hatch
	2 Kr Eq.		66% " "
	5-70 Kr Eq.		0% " "

EFFECTS OF GAMMA AND X-RADIATION ON
ARTHROPODS (Table 21).

The published data on gamma and x radiation effects on arthropods is more extensive than that for beta radiation effects.

The effects of radiation on species from four familes of Acarina were found in the literature. For the tick, Hyalomna asiaticum, gamma doses of 800 roentgens applied to the larvae resulted in reduced development while 1500 roentgen doses destroyed the ovary function in adult females. X-rays of 1000-12,000 KR/MIN produced no noticeable change in adults of either sex. Experiments on male and female adults of the flour mite, Tyroglyphus farinae show that, gamma-doses of 5000 and 10,000 rads increased fecundity and exposures of 20,000 rads resulted in decreased fecundity. Forty thousand rads produced sterilization of the population. When quiescent female deutonymphs of the carmine spider mite, Tetranychus telarius were treated with 32,000 roentgen X-rays, no viable eggs were produced. Treatment of adult males with 2000 and 4000 roentgen gamma-rays resulted in decreased production of viable eggs by the F_1 generation females. Above 8000 roentgens, the surviving F_1 females were incapable of reproduction. Adult males treated with gamma doses above 96,000 roentgens suffered sperm inactivation or death. Treatment of adult males and females of tyroglyphid mite, Tyrophagus dimidiatus, with 25,000-50,000 rad X-rays prevented reproduction.

General studies on beetles show that survival of X-radiated adults (7000 roentgens at 50 and 500 roentgens per minute) is inversely dependent on oxygen concentration. Exposures of 8000 roentgens at the same rate left no survivors after 50 days. Further studies on adult males show a reduced egg hatch in the F_1 generation as the gamma-doses of 5000,7000 and 10,000 roentgens.

Gamma radiation of the larvae of the lesser grain beetle, Rhizopertha dominica showed 12,000 roentgens to be the effective minimum dose capable of arresting larval development or reproduction. Adults subjected to doses of 20,000 roentgens suffered 100% mortality.

Within the Family Bruchidae, gamma doses of 25,000 roentgens applied to eggs of the weevil, Bruchus quadrumaculatus prevented hatching. Gamma exposures of 20,000 rads applied to larvae of Acanthoscelides obsoletus proved to be the minimum dose capable of arresting larval development or reproduction. Treatment of cowpea weevil, Callosobruchus maculatus eggs with 1000 and 3000 rad gamma-rays produced 50% and 100% mortality respectively. Treatment of adults with 10,000 rad doses resulted in complete sterilization. There was 100% mortality in the eggs, larvae and pupae of Callosobruchus chinesis through application of 15,000, 20,000 and 47,000 rad gamma-rays respectively. Doses of 42,000 and 67,000 rads applied to adults resulted in sterilization.

X-irradiation of adults of the cereal leaf beetle, Oulema melanopus produced reduction in egg viability and in the numbers of eggs produced at exposures of 500 roentgens, and complete loss of egg viability at 5000 roentgens.

When eggs of the lady beetle, Epilachna philippinensis were treated with gamma-rays of 1000 and 20,000 roentgens, mortalities of 10 and 90% were recorded respectively. Inhibition of larval development occurred at exposures of 1000 roentgens. Pupae treated with 5000 and 10,0000 roentgen doses developed into adults with abnormal wings and legs, and adults exposed to 10,000 and 20,000 roentgens suffered 75 and 99.9% mortality respectively. Sterilization in the Mexican bean beetle, Epilachna varivestis occurred at exposures of 1000-16,000 roentgens for female pupae, 400-16,000 roentgens for male pupae, 800 roentgens for adult males and 16,000 roentgens for adult females.

A number of studies have been conducted on species in the Family Curculionidae. Gamma radiation of the adult boll weevil, Anthonomus grandis produced a marked decrease in longevity and egg production at a dose of 5000 roentgens. Data indicate that adult exposures to 2000 roentgens results in reduced egg fertility. Exposure to 4000 roentgens produced almost complete sterility. The threshold of sensitivity appears to be 5000 roentgens for adult males and 6000-8000 roentgens for adult females. Adult males subjected to 10,000 and 15,000 roentgen exhibit transient and permanent sterility respectively, and in both cases, increased mortality. Although doses of 6000 roentgens applied to eggs results in no adverse effects, 2500 roentgen exposure reduces hatching. At 700 roentgens per minute for a total of 7200 results in decreased adult longevity. Ten thousand roentgen exposure of prepupal and young pupal stages result in irradiation and reduction of adult emergence respectively. A similar treatment of older pupae has no effect upon the emergence of adults.

Studies on the grainary weevil, Sitophilus granaria indicate that 5000 roentgen gamma-rays are sufficient to produce extermination when applied to any life cycle stage. Earlier work, however, indicates that doses of 500-1000 roentgens applied to adults produce partial lethal and sterilizing effects and complete sterilization occurs at 8000 roentgens. Ten thousand roentgens applied to the larvae seems to be the minimum dose capable of arresting larval development or reproduction in the adult stage. X-irradiation of adults produced 100% mortality at 8000 roentgens.

Studies on the granary weevil also show that 20% and 100% mortalities are achieved with the X-irradiation of adults at 3330 and 6700 roentgens respectively. When treated with 10,000 roentgen gamma-rays in the adult stage there was 100% mortality and 250,000 roentgen exposure produced instant death. Treatment of the rice weevil, S. oryzae with X-rays at 5000 roentgens during the egg stage and 7500 roentgens during the first instar larval stage resulted in failure of adult emergence. Seven day old adults subjected to 7500-10,000 roentgens caused 50% mortality and complete sterilization of the survivors. Adult rice weevils treated with gamma-rays suffered 40% mortality one week after radiation at 60,000 roentgens, 75% mortality in 2 weeks after treatment with 80,000 roentgens and 100% mortality 1 month after treatment with 100,000 roentgens. For the weevil, S. sasakii, the gamma-ray threshold of sensitivity levels was determined as being 5000 roentgens for adult males and 6000-8000 roentgens for adult females. There was a significant reduction in longevity at 5000 and 7000 roentgens for adult males and females respectively. Two thousand roentgens seem sufficient to reduce fertility by one half, while decreasing the weight and rate of development of the progeny. Four thousand roentgen exposure produced near complete sterilization after 2 months, while a 5000-6000 roentgen exposure produced temporary sterility, and complete sterility at 15,000 roentgens. Death occurs within 12 days after an 80,000 roentgen dose and within 4 days after 100,000 roentgen dose.

At 2000-10,000 roentgens X-radiation on the adult male alfalfa weevil, Hypera postica apparently causes sterility and the eggs fail to hatch when females are mated to exposed males.

Gamma exposures of 30,000-60,000 rads at any stage of the life cycle constitute the effective killing dose for the mango seed weevil, Sternochefus mangiferae. Lethal sterilization occurs when adults are directly exposed to 25,000 rad and at 100,000 rads when the weevils are in the fruit.

In gamma-irradiation of the sweet potato weevil, Cylas formicarius, 20,000 roentgens produce sterilization of the male adult.

Studies on the dermestid, Trogoderma glabrum, show that a gamma-ray dose of 25,000 rads produced- complete sterilization in the adult male, but has no effect on longevity. Similar doses applied to the larvae of T. granarium gave 100% mortality in 26 days. A 6000 rad exposure of male pupae produced a reduction in reproductive capacity, but a 7500 rad dose to female pupae showed no effect on reproduction. A 10,000 rad exposure of the pupae of either sex results in emergence of some adults with malformed elytra and 15,000 rad exposure is sufficient to produce complete sterilization in the male. Five to six thousand rads on female adults caused sterilization and sterilization is complete when male adults are exposed to 16,000 rads, but incomplete at 15,000 rads.

Adult males of the scarab, Melolontha vulgaris, can be sterilized with 3000 roentgen X-rays.

The California five-spined ips, Ips confusus, suffers reduced longevity when adults are exposed to 5000 roentgen gamma-rays and 7500 roentgens are sufficient to produce sterilization and mortality of 50% of an exposed adult males. Sterilization occurs among females at 10,000 roentgens.

Within the Family Tenebrionidae, considerable data has been recorded for the stored products pests, Tribolium confusum and T. castaneum. X-radiation of adult males of T. confusum results in a decrease in fertility at 1450-2900 roentgen doses. Although X-ray doses of 2000 and 4000 roentgens are reported to have no effect on mortality. A 3000 roentgen exposure of 3 day old male adults caused a decrease in the number of their progeny. Four thousand produce 90% sterility in the adults of both sexes and 6000 roentgens caused 100% mortality. Doses of 3000-6000 rads applied to eggs and adults produced sterility, while doses ranging from 6000 to 12,000 rads caused large increases in mortality but doses in excess of 12,000 rads showed only slight mortality increases. Gamma radiation of T. confusum produced sterility in adults at the 10,000 rad level. Exposures of 100,800 roentgens caused 100% mortality in 2 months in larvae and adults, and doses of 151,200 roentgens produced similar results within 6 days. X-ray studies on T. castaneum resulted in 90% sterility in adults at 4000 roentgens, while 6000 roentgens produced decreased fertility. Gamma-ray studies on adults of this species indicate 4000-6000 roentgens as the threshold dosage, with 100% mortality occurring within 11 days after exposure to 20,000 roentgens.

Some excellent studies have been conducted on members of the Diptera, (flies and mosquitos) because of the economic importance of this order. Reports on the screw worm, Cochliomyia hominivorax indicate 100% mortality in larvae when treated with 1593 roentgens of gamma rays. Male pupae are sterilized by 2500 roentgens, and females by 4500 roentgens. Adults from female pupae subjected to 5000 roentgens fail to oviposit and 86% of the adults from male pupae receiving 8000 roentgens survive only one week.

Gamma effects on pupae of the eye gnat, Hippilates pusio, include inhibition of growth at 500 roentgens, chromosome aberrations in the testes of males at 2500 roentgens, sterility at 3750 roentgens and in females at 4500 roentgens. At 4500 roentgens, males have a decreased growth rate, and the same is noted in females at 4700 roentgens. At 5000 roentgens males and females exhibit a decrease in fertility to 1% of normal. Although doses of 5000 roentgens showed no effect on the life span over a 7 week test period, 12,000 roentgens resulted in a 50% mortality in the test population and 135,000 roentgens produced total mortality within 4 days.

There was 50% mortality in eggs of the yellow-fever mosquito when they were exposed to gamma radiation of 800-7500 roentgens during the prehatching period. When 3 hour old pupae were treated with 8000-12000 roentgens there was decreased emergence and egg viability. The same treatment to pupae 11 hours old showed a marked reduction in egg viability. Similar treatment to pupae 22 and 45 hours old produced no noticeable effect. Adult females receiving 2500 roentgens suffered reduced egg production. There was no oviposition when females were exposed to 10,000 roentgens 4 hours after feeding. Dosages of 30,000 roentgens on males gave a reduction in oviposition after they mated with unexposed females. The malarial mosquito Anopheles quadrimaculatus was sterilized when 0-24 hour old pupae were exposed to a gamma dose of 12,000 roentgens. When male pupae of the mosquito, Culex fatigans were irradiated with 7700 roentgen gamma-rays, the adults were sterile.

Experiments on Drosophila melanogaster show that dominant lethal factors were induced in eggs receiving 1000 roentgen gamma-rays. Adults radiated at 60,000 roentgens suffer 50% mortality within 30 days.

X-ray exposure of 2000 roentgens on Musca domestica pupae 2 to 3 days prior to emergence produced complete sterilization of males. A 10,000 rad exposure on pupae that were 36 and 48 hours old produced 90% successful emergence with no adverse effects. When 30,000 rads were applied to such pupae there was only 19% emergence. There was 50% normal fertility when adults were treated with 2000 roentgen gamma dose. At 4000 roentgens, fertility was reduced to 4% normal for 27 days, and after 2 months sterility was nearly complete. When adults received 5000 roentgens there was a transient sterility occurring from the seventh to the twelfth day. Five thousand roentgens is considered the threshold of sensitivity for male adults and 6000-8000 roentgens for female adults.

Treatment of the horn fly, Haematobia irritans pupae with 5000 roentgen gamma rays produced sterilized adults, but emergence, vitality and longevity were normal. A dose of 25,000 roentgens produced 100% mortality within 24 hours.

When male and female Hypoderma lineatum pupae were gamma radiated at 2500 roentgens the females were sterilized, but there was incomplete sterilization of the males. Male pupae treated at 5000 roentgens gave complete sterilization.

When 15 day old female pupae of the carrot rust fly, Psila rosae were radiated with 1400 roentgen gamma rays, no oviposition occurred in the adult females. Sterility occurred when 15 day old male pupae were exposed to 4300 roentgens.

X-rays at 960 roentgens applied to early pupae of Sarcophaga peregrina resulted in high mortality at the beginning of adult life, while twice the dosage applied to older pupae produced 100% mortality by the seventh week.

The Mexican fruit fly, Anastrepha ludens can be sterilized by gamma radiation of eggs and larvae at a 1000 roentgen dose. There is a 50% mortality within 3 weeks after males and females were exposed to 50,000 roentgens. It was also found that there was no emergence when pupae received a 5000 rad dose. Experiments on the eggs of the Mediterranean fruit fly, Ceratitis capitata show 95% mortality on exposure of newly laid eggs to 300-2000 roentgens, and the same mortality requires in nearly mature eggs 86000-125000 roentgens. Only 5% of the larvae reached the pupal stage when 1 day old larvae received 30,000 roentgens, and no pupation when mature larvae were exposed to 160,000 roentgens. Application of 8400-10,000 roentgens to mature pupae produced sterilization and there was no oviposition when a 7500 roentgen dose was applied to 7,8 and 9 day old female pupae. A dose of 10,000-13,000 roentgens showed no change in longevity and mating activity, but dominant lethal factors were produced in the sperm of 100% of the resultant adults.

Studies on the melon fly, Dacus cucurbitae show that exposure of newly laid eggs to 1300 roentgens of gamma rays is sufficient to produce 95% mortality but it requires 86,000-125,000 roentgens to give equivalent results in nearly mature eggs. Exposure of eggs to 13,000 roentgens and 1 day old larvae to 30,000 roentgens reduced pupation 95%. Mature larvae requires 160,000 roentgens to give 100% reduction in pupation.

The effects of radiation on the oriental fruit fly, D. dorsalis are similar to those on the melon fly mentioned above.

Sterilization of the olive fruit fly, D. oleae occurs at gamma doses of 2000±300 rads, when applied to the fourth instar larvae, but 6000 rads and 15,000-18,000 rads are necessary to produce this result when applied to pupae and adults respectively. Four day old pupae exposed to 2000 roentgens show arrested development, and a 5000 roentgen exposure of 12 day old pupae produced sterility, but no effect on longevity or adult mating behavior.. Adult females receiving 2000-30,000 roentgens show an inhibition of ovariole development.

Whole body gamma radiation of the honey bee at the 200,000 roentgen level resulted in immediate death of workers. Queen honey bees receiving 10,000 roentgen X-rays suffered 100% mortality within 3 weeks, but when the III, IV and V abdominal segments were shielded, normal numbers of eggs were laid, but all fertilized eggs contained dominant lethal factors.

When female larvae of the braconid, Habrobracon sp; were exposed to 5000 roentgen X-rays, there was a reduction in the life span but a similar result required 200,000 roentgens when the adult females were exposed.

Exposures of the eulophid, Aphytis lingnanensis, to X-ray doses of 250-4000 roentgens showed no effect on longevity, but resulted in a pronounced decrease in fecundity with fewer females in the progeny. The data also indicate that there was less effect on mature eggs than on younger ones.

An exposure of 5-2000 roentgen gamma rays to 3 day old host eggs of the parasite, Copidosoma koehleri, produced pathologic mutations in the polyderm stage. Radiation of the trichogrammid, Trichogramma semifumatum, in the egg stage, showed that this organism was not materially affected by doses sufficiently high to cause host mortality.

Essentially 100% of all lepidopterous species feed on plants.

Eggs of the silk worm, Bombyx mori exposed to 2000 roentgen X radiation suffered increased mortality, while a 500,000 roentgen doses produced genetic distortion in the larvae.

Inhibition of development and sterilization occur when immature stages of Argyroploce leucothreta, are exposed to gamma rays at 10,000-120,000 and 5000-70,000 roentgens respectively.

When 3 day old eggs of the potato tuberworm, Phthorimaea operculella are exposed to 900 roentgen gamma dose the larvae were smaller, lighter in weight and have less stored fat. There was no adult emergence when 500 roentgens were applied to mature pupae. A 6000 rad gamma exposure on the mature larvae produce adult malformation, while 24,000-96,000 rads prevent pupation. When adult females receive 24,000 rads, no larvae hatch from eggs laid.

Females mated with pink bollworm, Pectinophora gossypiella, males that had received a 30,000-60,000 roentgen gamma dose when the pupae were 7 days old produced 3% viable eggs in the F_1 generation. Complete sterility and decreased longevity occur when 7 day old male pupae receive 55,000 roentgens. The larvae of the mallow moth, P. malevella, receiving 5000 roentgen X-rays died. Five hundred roentgens is a lethal dose to emerging adults when the pupa is radiated, and 10,000 roentgens is a lethal dose for the pupa itself.

When both sexes of larvae and pupae of the Angoumois grain moth, Sitotroga cerealella receive a 20,000 roentgen gamma dose complete sterilization.

A 20,000 roentgen gamma exposure of the fourth instar larval of the gypsy moth, Porthetria dispar causes mortality in 7-10 days. This dose applied to 9 day old male pupae produces a decrease in egg viability to less than 1% after mating with non-radiated females.

The threshold of sensitivity for adults of the Mediterranean flour moth, Ephestia kuhniella occurs in the female at a 6000-8000 roentgen gamma dose and for males at 5000 roentgens. Transient sterility occurs in 7 to 12 days. A 4000 roentgen dose produced a decrease in fertility 4% normal with nearly complete sterility after 2 months. Larvae receiving a 15,000 roentgen X-ray dose suffered arrested development. A dose of 50,000 roentgens on larvae within 3 to 5 days of pupation caused instant death.

A 30,000 roentgen X-irradiation of 1 day old adult European corn borer, Ostrinia nubilalis, males reduced egg hatch by 99%. Pupae of both sexes receiving 5000 roentgens, produced 84% viable eggs, but when the male pupae receive 7000 roentgens, the egg hatch was only 50%.

A 4000-32,000 roentgen gamma dose applied to adults of the leaf roller, Platynota stultana, nearly eliminated egg hatch in the F_1 generation, but there was no effect on the number of eggs laid.

Exposure of the adult locust, Locusta migratoria, to 4700 roentgen X-rays produced 50% mortality. Radiation at 700 roentgens was lethal for eggs and adults of the cockroach, Blaberus craniifer. There was 50% mortality when adults of the cricket, Gryllus domesticus, were exposed to a 4200 roentgen gamma dose in air and 6750 roentgens were required for the same effect when cysteine was used as a protective agent. Similar results were obtained with radiation in a nitrogen atmosphere, at a dose of 9900 and 11,900 roentgens without and with cysteine, respectively.

Studies on the citrus mealybug, Planococcus citri show retarded development and high mortality in the F_1 progeny when adult males were exposed to a 15,000 rep. gamma dose.

It should be noted that there is a certain amount of conflicting data in the published literature on the effects of radiation on arthropods, as noted in the above discussion and in Table

21. One reason for conflict probably lies in the inaccurate dosimetry of some investigators. Thus, in a preliminary attempt to unscramble radiation effects, the author does not necessarily agree or disagree with the present analysis.

Table 21. EFFECTS OF GAMMA RADIATION ON ACARINA

Organism & Reference	Gamma exp. excpt. where x-rays ind.	Life stage radiation applied [1]	Radiation effects
ACARINA: mites & ticks	800r	Larval: m,f	Inhibition of development.
Hyalomna asiaticum tick	1-12 X-ray Kr/min	Adult: m,f	No external differences, dose not lethal.
Sidorov & Grokhouskaya 239	1.5 Kr	Adult: f	Complete destruction of ovary function.
	3 Kr	Adult: f	No egg laying
Tyroglyphus farinae flour mite Melville, 240	5,10 Krad	Adult: m,f	Increase in number of eggs laid and hatched.
	20 Krad	Adult: m,f	Reduction of number of eggs laid and hatched.
	40 Krad	Adult: m,f	Sterilization of pop.
TETRANYCHIDAE Tetranychus telarius carmine spider mite Henneberry, 241	32 Kr	Adult: m,f	m(i)+f(u) male progeny no female progeny. non-viable eggs produced.
	1-24 Kr	Quiescent f deutonymph	m(u)+f(i) fewer male, female progeny.
	32 Kr	Quiescent f deutonymph	Non viable eggs produced
	greater than 8 Kr	Adult: m	Surviving female progeny incapable of reproduction.
	2; 4 Kr	Adult: m	Female progeny produced fewer m,f and more non-viable eggs than female progeny of untreated parents.
	greater than 96 Kr	Adult: m	Sperm inactivation or death.

1. m=male, f=female

(con't) Table 21. EFFECTS OF GAMMA RADIATION ON ACARINA

Organism & Reference	Gamma exp. excpt. where x-rays ind.	Life stage radiation applied	Radiation effects
Tyrophagus dimidiatus			
mite Farkas, 242	25-50 Krad X-ray	Adult: m,f	Reproduction prevented

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. excpt. where x-rays ind.	Life stage radiation applied	Radiation effects
COLEOPTERA: beetles	8 Kr at 500 & 50 r/min. xray	Adult: m,f	No survival after 50 days
Bychkovskaya & Ochinskaya, 243	7 Kr at 500 r/min.	Adult: m,f	Survival rate dependent on oxygen concentration. 100% at 2.2% $[O_2]$ 0% at 8% $[O_2]$
	7 Kr at 50 r/min.	Adult: m,f	0% at 6.6% $[O_2]$
Abdul-Matin, et al., 244.	10 Kr	Adult: m	Average egg hatch 1.4%
	7 Kr	Adult: m	9.3%
	5 Kr	Adult: m	14.5%
Bostrichidae			
Rhyzopertha dominica lesser grain borer Huque, 216	20 Kr	Adult: m,f	100% mortality
R. dominica Pesson, 245	12 Kr	Larval: m,f	Effective minimum dose capable of arresting larval development or reproduction.
Bruchidae			
Bruchus quadrumaculatus weevil Huque 216	25 Kr	Eggs	Prevented hatching

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x-rays ind.	Life stage radiation applied	Radiation effects
Callosobruchus chinesis			
Quraishi & Metin, 246	15 Krad	Egg	100% mortality
	20 Krad	Larval	100% mortality
	47 Krad	Pupal	100% mortality
	42 Krad	Adult: m.f	Sterilization, eggs did not hatch
	67 Krad	Adult: m, f	Production of sterile eggs
C. maculatus cowpea weevil Neharin, et al., 247	1 Krad	Eggs	50% mortality
	3 Krad	Eggs	100% mortality
	10 Krad	Adult: m, f	Complete sterilization, eggs not viable
Acanthoscelides obsoletus Pesson, 245	20 Krad	Larval: m, f	Effective minimum dose capable of arresting larval development or reproduction
Chrysomelidae Oulema melanopus cereal leaf beetle	500 r	Adult: m, f	Reduction of egg produced & egg viability
Hoopingarner, et al., 195	5 Kr x-ray	Adult: m, f	Complete loss of egg viability

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x-rays ind.	Life stage radiation applied	Radiation effects
Coccinellidae *Epilachna philippinensis* lady beetle Viado & Manoto, 248	1 Kr	Egg	Percentage of unhatched eggs= 10% mortality
	20 Kr	Egg	Percentage of unhatched eggs= 90% mortality. Embryos of eggs which failed to hatch [illegible] not develop
	1 Kr	Larval	Inhibition of devel. to pupal stage
	5,10 Kr	Pupal m,f	Abnormally developed wings, legs as adults
	10-20 Kr	Adult m,f	75% mortality, 9919% mortality respectively.
E. varivestis Mexican bean beetle Henneberry, et al., 217	8 Kr	Adult m	Sterilization
	16 Kr	Adult f	Sterilization
	4-16 Kr	Pupae m	Sterilization
	1-16 Kr	Pupae f	Sterilization
Curculionidae *Anthonomus grandis* boll weevil Davich & Lindquist, 249	5,000 r	Adult m,f	Longevity and egg laying capacity drastically reduced
	2,500 r	Egg	Hatching greatly reduced
	600 r	"	No effect on hatching or subsequent development
	10 Kr	Adult m	Transient sterility, rapid mortality of both sexes
	15 Kr	Adult m	Permanent sterility, rapid mortality of both sexes
	10 Kr	Prepupal	Emergence of adults eliminated

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x-ray ind.	Life stage radiation applied	Radiation effects
Anthonomus grandis (con't)	10 Kr	Young pupal	Emergence of adults greatly reduced
	10 Kr	Old pupal	Emergence of adults unaffected
Mayer, 250	8 Kr	Adult m 12,36 Hr. old	Sterilization, testes decreased in size, resembled a sac-like mass of sperm
	8 Kr	Adult f	No eggs laid, death sooner than controls
	8 Kr	Adult m,f	Inhibition of mitosis within regenerative nidi in midget cells
Mayer & Brazzel, 251	7.2 Kr 700/min.	Eggs 12-36 hr. old	Longevity of ensuing adults decreased
	8 Kr	Adult m 12-36 hr. old	Reduction of sperm fertility to 18%
Nardon, 252	5 Kr	Adult m	Threshold of sensitivity
	6-8 Kr	Adult f	Threshold of sensitivity
	2 Kr	Adult	Fertility halved
	5 Kr	Adult	Transient sterility from 7th-12th day
	4 Kr	Adult	Fertility reduced 1/25 of normal for 27 days, almost complete sterility after 2 months
Sitophilus granarius granary weevil	0.5-1 Kr	Adult m,f	Partial lethal & sterilizing action
Andreer, et al., 253	8 Kr	Adult m,f	Complete sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x-ray ind.	Life stage radiation applied	Radiation effects
Bychkouskaya & Ochinskaya, 254	8 Kr x-ray 13 Kr	Adult m,f Adult m,f	100% lethality under ordinary oxygen conditions 100% lethality under hypoxia conditions
Blazek, et al., 255	5 Kr	Adult m,f Eggs Larval	Extermination
S. granarius granary weevil Huque, 216	10 Kr 250 Kr	Adult Adult	100% mortality Instant kill
Sitophilus sp. Pesson, 245	10 Kr	Larval	Effective minimum dose capable of arresting development or reproduction
Zakladnoi, 256	50 Kr	Adult m,f	99% mortality
Bychkovskaya & Ochinskaya, 257	3.35 c 6.7 c x-ray	Adult m,f Adult m,f	20% mortality 100% mortality
S. oryzae rice weevil Hoover, et al., 258	5 Kr 7.5 Kr x-ray	Eggs First instar Larvae	No adults emerged Failure to develop into adults
	2.5 Kr	First instar	Develop. to pupal and adult stages, no emergence
	7.5-10 Kr	Adult 7 day old	LD 50, complete sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x-ray ind.	Life stage radiation applied	Radiation effects
S. oryzae Abdul-Matin, 259	5-100 Kr	Adult	100% mortality within one month except 5 Kr
S. oryzae Viado & Manoto, 248	60,80 Kr	Adult	40% mortality one week after irradiation 75% mortality two weeks after irradiation
S. sasakii Laviolette & Nardon, 260	5 Kr	Adult m	Significant reduction in life expectancy
	7 Kr	Adult f	Significant reduction in life expectancy
	80 Kr	Adult m,f	Death within 12 days after irradiation
	100 Kr	Adult m,f	Death within 4 days after irradiation
	2 Kr	Adult m,f	Fertility reduced by half decrease in offspring wt. decrease in rate of devel.
	5-6 Kr	Adult m,f	Temporary sterility
	15 Kr	Adult m,f	Complete sterility
	16 Kr	Adult f	Eggs laid
S. sasakii Nardon, 252	5 Kr	Adult m	Threshold of sensitivity
	6-8 Kr	Adult f	Threshold of sensitivity
	4 Kr	Adult m,f	Fertility reduced 1/25 of normal for 27 days Sterility almost complete after 2 months

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x-rays ind.	Life stage radiation applied	Radiation effects
Sternochetus mangiferae febricus mango weevil Upadhya, et al., 261	30-60 Krad	Adult Larval Pupal	Effective killing dose
Ross, 262	25 Krad	Adult, direct exposure	Sterilization, lethal
	100 Krad	Adult inside fruit	Sterilization, lethal
H. postica alfalfa weevil Burgess & Bennett, 220	2-10 Kr x-ray	Adult m	m(i)+f(u) eggs failed to hatch
	4 Kr	Adult m	m(i)+f(u) eggs 0.8% hatched
	8-10 Kr	Adult m	Sterility induced

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp excpt. where x rays ind.	Life stage radiation applied	Radiation effects
Cylas formicarius sweet potato weevil Walker, 263	20 Kr	Adult m	Sterilization without adverse affects on competative ability of males with untreated males for females
Dermestidae *Trogoderma glabrum* Tilton et al., 264	25 Kr	Adult m	Complete sterilization, longevity not significantly shortened.
Trogoderma granarium khapra beetle Huque, 216	25 Kr	Larval	100% mortality in 26 days
T. granarium Carney, 265	5 Krad 15 Krad	Adult f Adult m	Sterilization Sterilization not complete
T. granarium Nair & Rahalkar, 266	6 Krad 16 Krad	Adult f Adult m	Sterilization Sterilization complete
T. granarium Kansu, 267	6 Kr 15 Kr 7.5 Kr 10 Kr	Pupal m Pupal m Pupal f Pupal m,f	Reduction of repro. capacity Sterilization complete No effect on repro. capacity Emergence of some adults with malformed elytra.

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
Scarabaeidae *Melolontha vulgaris* white grub Horber, 268	3 Kr x ray	Adult m	Sterilization
Scolytidae *Ips confusus* California five-spined ips Wood & Stark, 269	7.5 Kr	Adult m	Sterilization
	10 Kr	Adult f	Sterilization
	5 Kr	Adults	Longevity reduced
	7.5 Kr	Adult m	LD50 at 11.5 days (29 days in control)
Tenebrionidae *Tribolium confusum* confused flour beetle Farkas, 270	6-12 Krad x ray	Adult	Lethal effect increased abruptly
	12 Krad	Adult	Mortality raised small degree
	3-6 Krad	Adult	Sterilization
	3-6 Krad	Eggs	Sterilization
T. confusum Harvey, 271	10 Krad	Adults	Sterilization
T. confusum McDonald, 272	1.45-2.9 Kr x ray	Adult m	Depression of fertility

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
T. castaneum Huque, 216	20 Kr	Adult	100% mortality in 11 days
T. castaneum Erdman, 277	250 KV x ray	Adults	50% dominant lethals induced
T. castaneum Bartlett, et al., 278	5 Kr x ray	Adults	Drop in fertility 66.9% for irradiated foundation adults, 58.8% for irradiated selected adults.
T. castaneum Erdman, 279	6 Kr	Adult f	Eggs laid by some, none viable
	4 Kr x ray	Adult	90% sterilization
T. castaneum Erdman, 274	6 Kr	Adults	100% sterilization
	4 Kr x ray	Adults	90% sterilization
T. confusum Niavssat, et al., 273	20 Kr	Adult	LD 50/30
T. confusum Erdman, 274	2.4 Kr	Adult	Mortality not affected, 94-100% alive at 10 weeks
	4 Kr	Adult	90% sterilization
	6 Kr	Adult	100% sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON COLEOPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
T. confusum (con't)	6 Kr x ray	Adults	Mortality affected, 75 and 85% alive in single and mixed population (*T. confusum* + *T. castaneum*)
T. confusum Dennis, 275	100.8 Kr 100.8 Kr 151.2 Kr 151.2 Kr	Adult Larval Adult Larval	96% mortality within 2 months 100% mortality within 2 months 100% mortality within 6 days 100% mortality within 6 days
T. confusum Sokoloff, 276	3 Kr x ray 1.5-3 x ray	Adult m 3 day old Adult f	Males susceptible, offspring number decreased Primary effect on the egg, any eggs that did hatch into larvae, nearly all larvae reached adult stage
T. castaneum red flour beetle Viado & Manoto, 248	40-60 Kr	Adult	Threshold dose

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. excpt. where x rays ind.	Life stage radiation applied	Radiation effects
DIPTERA:Calliphoridae			
Cochliomyia hominivorax screw-worm	5-10 Kr	Pupal	Each nucleus contains at least one dominant lethal mutation
Bushland, 280	5-10 Kr	Adult	Each nucleus contains at least one dominant lethal mutation
	2.5 Kr	Pupal m	Sterilization
	5 Kr	Pupal f	Sterilization, no oviposition
	7.5 Kr	Pupal f	Egg production prevented
C. hominivorax Dixon, 281	1.593 Kr	Larval	100% mortality shortly after hatching.
C. hominivorax Baumhover, 282	11.1 Kr	Pupal f	Sterilization in carbon dioxide atmosphere.
	5.5-6.2 Kr	Pupal f	Sterilization in oxygen and air atmosphere.
C. hominivorax Gibbons et al, 283	.8 Kr	Pupal	Sexual sterilization 5½ days after entering pupal stage.
C. hominivorax La Chance, 284	4.5 Kr	Adult f	Complete sterilization in CO_2+ air
	5.5-6.2 Kr	Adult f	Complete sterilization in air.
C. hominivorax Crystal, 285	8 Kr	Pupal m	Survival at 1 wk. 85% of survival of control flies.

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
Chlobopidae *Hippelates pusio* eye gnat Flint, 287	5 Kr	Adult m,f	Fertility less than 1%, 1/3 reduction in egg laying
	4.5 Kr	Pupal	Fertility less than 1%, almost no egg laying
	2.5, 3 Kr	Adult m	Significant recovery of fertility
	12 Kr	Adult	LD 50
H. pusio Flint, 286	4.55 Kr	Adult m	Sterilization
	3.75 Kr	Pupal m	Sterilization
	4.9 Kr	Adult f	Sterilization was 2/3 of the egg production
	4.7 Kr	Pupal f	Sterilization, no egg laying as adults
	135 Kr	Adults	Mortality within 4 days
	5 Kr	Adults	No effect on life span during 7 week test period
	12 Kr	Pupal	50% decrease in emergence
	500 r	Pupal	Inhibition of growth
	4.5 Kr	Adult f	Inhibition of growth & development of ovaries
	4.5 Kr	Pupal m	Retarded growth and sperm mobility
	2.5 Kr	Adult m Pupal m	Visible chromosomal abnormalities in treated testes
H. pusio Flint, 288	4.5 Kr	Pupal m,f	Sterilization, significant reduction in testes size
	5 Kr	Adult	Sterilization, (reduction of eggs laid)

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
Culicidae			
Aedes aegypti yellow-fever mosquito	30 Kr	Adult m	Reduction in egg production m(i) + f(u)
	2.5 Kr	Adult f	Reduction in egg production m(u) + f(i)
	10 Kr	Adult f	No oviposition in females exposed 4 hrs. after blood meal
	100 Kr	Adult f	No oviposition in females exposed 42 hrs. after blood meal
	.8-7.5 Kr	Egg	LD50 during pre-hatching period
	30-75 Kr	Egg	LD50 when 3 to 5 days old
A. aegypti Dame & Schmidt, 290	8,12 Kr	Pupal 3 hr. old	Reduction of emergence and viability
	8,12 Kr	Pupal 11 hr. old	Little reduction of emergence, but serious reduction of viability at 12 Kr and slightly lower at 8 Kr
	8,12 Kr	Pupal (22 or 45 hrs. old)	No demonstrable effect
Anopheles quadrimaculatus common malaria mosquito Dame, et al., 291	12 Kr	Pupal 0-24 hr. old	Sterilization
Culex fatigans common house mosquito Krishnamurthy, et al., 292	7.7 Kr	Pupal m	Adults sterile upon emergence

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
Drosophilidae *Drosophila melanogaster* fruit fly Nickel, 293	1 Kr	Egg	Dominant lethal factors induced
D. melanogaster Niavssat, et al., 273	60 Kr	Adult	LD 50/30, 50% mortality in 30 days
Muscidae *Musca domestica* house fly Nardon, 25.	5 Kr	Adult m	Threshold of sensitivity
	6-8 Kr	Adult f	" " "
	2 Kr	Adult	Fertility 1/2 normal
	4 Kr	Adult	Fertility reduced to 1/25 normal for 27 days and after 2 months sterility almost complete
	5 Kr	Adult	Transient sterility from 7 to 12 days
M. domestica Sacca, 294	3 Kr	Pupal 3 hrs. before emergence	Complete sterilization of emerged adults, no difference in viability, longevity, and sexual activity
M. domestica Sacca, 295	2 Kr x ray	Pupal m 2-3 days before emergence	Complete male sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x-rays ind.	Life stage radiation applied	Radiation effects
M. domestica Nair, 296	2 Kr	Pupal 5 hrs.	No emergence to adults, but devel. complete
		Pupal 30-80 hrs.	No appreciable effect of mechanism of emergence
M. domestica Dauer, et al., 297	10 Krad x ray	Pupal m	Increased mean survival over normal males by 2.8 days
	20 Krad	Pupal m	No signigicant difference in aver. survival time until after 15th day when treated pupal mortality much higher than untreated ones.
	30 Krad	Pupal m	50% died within 10 days. 100% mortality by 19th day mean life span 10 days as compared to 13.2 of normal
	10 Krad	Pupal m 36,48 hrs.	90.1% successful emergence, no external detectable effects (96.3% control)
	30 Krad	Pupal m 36,48 hrs.	19.5% successful emergence
M. domestica Schmidt, 298	2.85 Kr	Pupal, 31,54 hrs. prior to moulting	Sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
Haematobia irritans horn fly Lewis & Eddy, 299	5 Kr	Pupal m,f	Sterilization, excellent emergence, vitality normal, longevity not materially affected
	25 Kr	Pupal m,f	Great reduction in vitality, 100% mortality in 24 hrs.
Oestridae Hypoderma lineatum common cattle grub Drummond, 300	5 Kr	Pupal m,f	Complete sterilization
	7.5 Kr	Pupal m,f	" "
	2.5 Kr	Pupal f	" "
	2.5 Kr	Pupal m	Reduced fertility; sterilization imcomplete
Psilidae Psila rosae carrot rust fly McClanahan, 224	4.3 Kr	Pupal m, 15 days old	0% hatch m(i)+f(u) sterile sperm
	1.4 Kr	Pupal f, " "	No egg laying as adults
	3.0 Kr	Pupal m,f " "	93% reduction of larvae m(i)+ f(i)
Sarcophagidae Sarcophaga peregrina Sakka, 301	1.86 Kr	Pupal, early	100% mortality at 7th week
	x ray 960 r	Pupal	High mortality observed at beginning of adult life
Tephritidae Anastrepha ludens Mexican fruit fly Benschoter & Telich, 302	50 Kr	Adult m,f 1 day old	Mortality 50% over a 3 wk. period
	1 Kr	Egg, larva	Sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
A. ludens Brownell & Yudelovitch, 303	5 Krad	Pupal	No adult flies emerged
Ceratitis capitata Mediterranean fruit fly Katiyar & Ferrer, 304	10 Kr	Pupal m	Sterilization
C. capitata Little, 305	10 Kr 10 rad x ray	Adult	Normal appearance of midgut epithelia
C. capitata Bushland, 280	8.4-10 Kr	Pupal m,f	Complete sterilization, no egg laying
C. capitata Katiyar, 306	10-13 Kr	Pupal	Sterilization, no deleterious side effects on longevity & mating
C. capitata Katiyar & Valerio, 307	10-12 Kr	Pupal m 7,8,9 days old	100% dominant lethal factors in sperm
	7.5 Kr	Pupal f 7,8,9 days old	No egg laying
C. capitata Balock, et al.,308	1.3 Kr	Egg newly laid	LD95
	86-125 Kr	Egg	LD95
	13 Kr	Nearly mature eggs	95% reduction in pupae

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x rays ind.	Life stage radiation applied	Radiation effects
C. capitata (con't)	30 Kr	Larval 1 day old	95% reduction in pupae
	160 Kr	Larval mature	Prevention of pupation
	6.5 Kr or less	Young eggs, larvae, pupae	95% prevention of emergence of adults
	100 Kr	Older pupae	Prevention of emergence of adults
	10 Kr	Mature pupae	Sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x-ray ind.	Life stage radiation applied	Radiation effects
Dacus cucurbitae melon fly Huque & Hafiz, 309	7-9 Kr	Adult m	Sterilization, no viable eggs
D. cucurbitae Balock, et al., 308	1.3 Kr	Eggs newly laid	LD95
	86-125 Kr	Eggs nearly mature	LD95
	13 Kr	Eggs	95% reduction in pupae
	30 Kr	Larval 1 day old	95% reduction in pupae
	160 Kr	Larval mature	Prevention of pupation
	6.5 Kr or less	Eggs, larval	95% prevention of emergence of adults
	100 Kr	Older pupal	Prevention of emergence of adults
	10 Kr	Mature pupal	Sterilization
D. cucurbitae Bushland, 280	8.4-10 Kr	Pupal m,f	Sterilization, no egg laying
D. cucurbitae Balock, 310	160 Kr	Larval mature	Prevention of pupation
	6.5 Kr or less	Egg, larval, pupal young	95% prevention of emergence as adults
	100 Kr	Egg, larval	Prevention of emergence as adults
	10 Kr	Mature pupal	Sterilization

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON DIPTERA

Organism & reference	Gamma exp. except where x-ray ind.	Life stage radiation applied	Radiation effects
D. dorsalis oriental fruit fly Balock, et al., 310	1.3 Kr	Eggs newly laid	LD95
	86-125 Kr	Egg nearly mature	LD95
	13 Kr	Eggs	95% reduction in pupae
	30 Kr	Larval 1 day old	95% reduction in pupae
D. dorsalis Bushland, 280	8.4-10 Kr	Pupal m,f	Sterilization, no egg laying
D. oleae olive fruit fly Rhode, et al., 311	2 Kr	Pupal 4 day old	Arrested development
	5 Kr	Pupal m,f 12 day old	Sterility, no egg development no effect on longevity, mating behavior
D. oleae Thomou, 312	2-3 Krad	Larval 4th instar	Sterilization
	11-15 Krad	Pupal	"
	15-18 Krad	Adults	"
	3-15 Krad	Pupal 8 day old	Maximum emergence
D. oleae Baccetti & Dominicis, 313	2-30 Kr	Adult	Inhibition of normal development of ovary; very little nurse cells and egg cells, scarce in number, abnormal structure and ultrastructure.
D. oleae Tzanakakis, et al., 314	6 Krad	Pupal m	Sterilization, no effect on time or percent of adult emerg.
	6,8,12 Krad	Pupal f	No mature eggs in ovaries

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON HEMIPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
HEMIPTERA: Reduviidae			
Rhodnius prolixus assasin bug Shaver, 315	x ray 4 Kr	Nymph m	Complete sterilization, egg laying reduced when m(i) + f(u)
	2 Kr	Nymph f	Almost complete inhibition of egg eclosion
	17.5 Kr	Nymph m, 5th instar	0% hatch when m(i) + f(u)
	8 Kr	Nymph f	Complete sterilization
R. prolixus Gomez-Numez, et al., 316	20 Kr	Adult m	Fertility 0.3%
	40 Kr	Adult m	Complete sterilization, males unable to mate; mean longevity reduced from a normal 116 days to 17 days

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON HYMENOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
HYMENOPTERA: Apidae *Apis mellifera* honey bee Courtois & Lecomte, 317	200 Kr	Adult	Immediate death, 100% mortality
Queen honey bee Lee, 318	x ray 10 Kr	Adult, segments III-V	100% mortality within 3 weeks
Queen honey bee Lee, 319	x ray 10 Kr	Adult, shielding segments III-V	Normal number of eggs laid, but all fertilized eggs contained dominant lethals
	5.4 Kr	Adult	Permanent sterility when re-exposed to 5.4 Kr 9 days after first 5.4 Kr dose
Braconidae *Habrobracon* sp. Clark, 320	x ray 5 Kr	Larva f	Reduction in life span
	200 Kr	Adult f	Survival, but with decreased life span

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON HYMENOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
Eulophidae *Aphytis lingnanensis* DeBach & White, 321	x ray 250,500 r 1000,2000 r 4000 r	Adult	No effect on longevity Pronounced reduction of net fecundity Indications that mature eggs were less affected Fewer female progeny
Encyrtidae *Copidosoma koehleri* Elbadry, 206	5-2000 r	Eggs 3 days old	Pathological condition to polyderm stage
Trichogrammidae *Trichogramma semifumatum* Elbadry, 206		Egg	Not materially affected by dosages heavy enough to cause host mortality

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON LEPIDOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
LEPIDOPTERA Bombycidae Bombyx mori silkworm Legay & Teulade, 322	x ray 2 Kr	Egg 5 days after start of incubation	No increase in development, mortality rate significantly higher
Murakami & Kondo, 323	600 rad 14.1 M neutrons	Eggs	LD50
	2 Krad Cs 137	Eggs	LD50
Strunnikov, 324	x ray 500 Kr	Eggs	Ger›tic distortion of caterpillars
Eucosmidae Argyroploce leucothreta Myburgh, 325	10-120 Kr 5-70 Kr	Immature Immature	Inhibition of development Sterilization
Gelechidae Phthorimala operculella potato tuberworm Elbadry, 206	0.5 Kr	Pupa, fully developed	Prevention of adult emergence
	0.9 Kr	Eggs, 3 days old	Resulting larvae were smaller size, lighter weight, stored less fat tissue
Elbadry, 207	24-96 Krad 6 Krad	Larva, mature Larva, mature	Prevention of pupation Adult malformation

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON LEPIDOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
P. operculella (con't)	24 Krad	Adult f	No larvae hatched from eggs laid
	96 Krad	All	Body movements decreased, sluggish
Pectinophora gossypiella pink bollworm Ouye, et al., 326	55 Kr	Pupa, m	Complete sterilization m(i) + f(u), m longevity shortened
	30-60 Kr	Pupa, m 7 days old	No more than 3% of oviposited eggs hatched when m(i)+f(u)
Petinophora malevella mallow moth Vasilyan, 327	x ray		
	500 r	Pupa	Lethal dose to emerging moths
	5 Kr	Larva	Lethal dose
	10 Kr	Pupa	Lethal dose to pupa
Sitotroga cerealella Angoumois grain moth Qureshi, 328	20 Kr	1st, 3rd last instar, prepupal early pupal m,f	Complete sterilization, reduction in body weight of 1st instar, early and late
Lymantriidae Porthetria dispar gypsy moth Rule, et al., 329	20 Kr	Pupa, m 9 days old	Egg viability reduced to less than 1% with min. somatic injury
	20 Kr	Larva, instar IV	Mortality in 7-10 days, degeneration of germinal cysts, shattering of sperm bundles within follicles, plugging of entrance to vas deferens by interstitual and other tissue, thickening of testes walls and septa and of vas deferens, clumping of fat body cells around testes

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON LEPIDOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
Spodoptera exigna beet armyworm Cotton moth Resulov, 223	x ray 10-11 Kr	Pupa m, f	100% sterilization, decrease in m longevity
	5 Kr	Pupa f	100% sterilization
Chloridea obsoleta bollworm Andreer, et al., 330	8 r	Larva m	No effect on life span, fertility
	8-10 Kr	Larva m	Optimum sterilizing dose
	15 Kr	Larva m	Deformed adults, short life
Olethreutidae Carpocapsa pomonella codling moth Proverbs & Newton, 226	40 Krad	Pupa m, 1 day before emergence	High sterilization, 2% egg hatch when m(i) + f(u)
	25 Krad	Pupa f	Greater than 99% sterilization of eggs laid
Proverbs, 227	40 Krad	Pupa m, 1 day before emergence Adult m, 12-24 hr. old	99% induction of dominant lethals in sperm without undesirable side effects
C. pomonella Proverbs & Newton, 331	40 Krad	Pupa, mature Newly emerged adult	Induction of dominant lethals in at least 98% of the sperm without affecting adult emergence, mating behavior, or adult longevity

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON LEPIDOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
Phycitidae Ephestia kühniella Mediterranean flour moth	5 Kr	Adult m	Threshold of sensitivity, transient sterility from 7-12 day
Nardon, 252	6-8 Kr	Adult f	Threshold of sensitivity
	2 Kr	Adult	Fertility halved, no effect on longevity
	4 Kr	Adult	Fertility 1/25 of normal for 27 days, almost complete sterility after 2 months
Whiting, 332	x ray 40-160 Kr	Larva, full grown	Inhibition of pupation
Erdman, 333	20 Kr	Larva	Irreversible developmental arrest, damage to mitotically active imaginal discs and/or to neurosecretory complex
E. kühniella Mueller, et al., 334	x ray 20-1000 r	Pupa	Mutation frequency proportional to $(dose)^2$
Erdman, 335	x ray 50 Kr	Larva, 3-5 days within pupation	Instantaneous lethal dose
	15 Kr	Larva	Arrested development

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON LEPIDOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
Galleriidae Galleria mellonella greater wax moth Kritskii & Chiwei, 336	x ray 2 Kr	Larva	7% decrease in total extinction of acid soluble compounds; ATP content falls 36%
Pyraustidae Ostrinia nubilalis European corn borer Walker, 198	x ray 32 Kr	Adult m, 1 day old	1% egg hatch when m(i) + f(u)
Walker, 199	x ray 30 Kr	Adult m, 0-24 hr. old	Average egg hatch 0.1%, m(i) + f(u)
	32 Kr	Adult m	Egg viability 0.4%, m(i) + f(u)
	7 Kr	Pupa m, 48-73 hr. old	49.9% egg hatch when m(i) + f(u)
	5 Kr	Pupa f,m	15.8% egg hatch when m(i) + f(i)
Sphingidae Celerio cuphorbia Piechowska, 337	2.6 Kr	Young larvae	95% growth and weight increase stopped, death occured between 15-25th day after irradiation
Tortricidae Platynota stultana leaf roller Jacklin, et al., 338	4-32 Kr	Adult	Hatching nearly eliminat , no reduction in number of eg,s laid/female
	16 Kr	Adult f	Over 99% egg mortality
	32 Kr	Adult m	Over 99% egg mortality

(con't) TABLE 21. EFFECTS OF GAMMA RADIATION ON ORTHOPTERA

Organism & reference	Gamma exp. except where x ray ind.	Life stage radiation applied	Radiation effects
Acrididae *Locusta migratoria* Jolly & Biclimann, 339	x ray 4.7 Kr	Adult	LD 50
Blattidae *Blaberus craniifer* Larsen, 340	x ray 0.7 Kr	Embryo, adults	Lethal
Larsen, 341	x ray 2-5 Kr	Embryo	Normal development if irradiation occured before dorsal closure
Blabera fusca Mortreuil-Langlois, 342	x ray 25 Kr	Adult	Radiolesions of mucous membrane of the middle intestine
Gryllidae *Gryllus domesticus* cricket Sumarukov, 343	4.2 Kr	Adult	LD50 in air without use of protective agent
	6.75 Kr	Adult	LD50 with protective agent-cysteine
	9.9 Kr	Adult	LD50 in nitrogen without use of protective agent
	11.9 Kr	Adult	LD50 in nitrogen with protective agent

(con't) TABLE 21. EFFECTS OF RADIATION ON HOMOPTERA

Organism & reference	Gamma exp. except where x-ray ind.	Life stage radiation applied	Radiation effects
HOMOPTERA:			
Pseudococcidae Planococcus citri citrus mealybug Nelson & Rees, 344	15 Krad	Adult m	Retardation of development, pronounced lethality of sons as well as daughters.

RECOMMENDATIONS FOR FUTURE RESEARCH

The present study was principally concerned with the possible threat to food production from arthropods following a nuclear disaster. Although we were primarily concerned with the direct effects of arthropods on agriculture, there are a number of indirect factors that arise from the action of radiation on insect populations which become immediately apparent. These factors largely involve interwoven food chains, and these are often in such a delicate balance that the slightest disruption can cause adverse effects.

Forests not only serve as a prime source of building materials but they also provide food and shelter for many organisms and are important in erosion control. Most tree species support a number of phytophagous arthropods and these pests are usually held in check by a parasite-host and/or predator-prey relationship. Any differential effect of radiation on these ecologically related populations which favored the survival of the pest species could produce catastrophic effects in forest areas.

The vast grasslands also serve as important areas of food and shelter for many small mammal and bird populations as well as those of lower organisms. Again, the natural balance is critical and elimination of key species could cause widespread disturbances.

Another important aspect of fallout radiation is associated with the insect pollination of plants. The supression or elimination of these beneficial insect species could have a serious effect on subsequent plant generations through the curtailment of pollination.

Finally, a disruption of the balance between insect populations could result in a sharp increase in disease vector and nuisance species directly affecting man and domestic animals. This could have additional effects of compounding problems in a post attack situation.

After conducting an extensive literature review a number of facts became apparent:

1. There has been almost no work reported on the effects of beta radiation on arthropods, even though it constitutes a significant part of radioactive fallout (Nishita, et al., 341; Miller, 342, 343; Wong, 344). Calculations of Teresi and Newcombe (345) indicated that the potential plant and animal contact from fallout beta radiation might be much greater than the associated potential gamma dose. The studies of Rhodes, et al., (346) on plant life in the PLOWSHARE PROGRAM substantiate the predictions of Teresi and Newcomb (345).

2. Most of the research on arthropods relates to radiation effects on pest species. Recently, these have been oriented toward male sterilization techniques to control pest species. Practically nothing is known about the effects of radiation on the insect predators and parasites that help to control pest populations. This is a serious void in our present knowledge because about 50% of all insect and mite species are predatore of parasites of other arthropods. For example, the Hemiptera (true bugs) represent a diversified group in which approximately one-half of the estimated 60,000 species are phytophagous, hematophagous, and so forth, while the other half are predaceous on other insects. There is a similar ratio between plant feeders and predators in Coleoptera (beetles) where there are about 250,000 species. Estimates of the number of Hymenoptera (bees, wasps, ants, sawflies, etc.) range from 250,000 to over one-half million species. The vast majority are beneficial and nearly two-thirds are parasites or predators of pest species. They may attack the egg, larval, pupal or adult stages of a wide variety of pests. In the order Diptera (flies, mosquitoes, etc.) there are about 80,000 species. There are about as many parasites and predators in this group as there are pest species. On the other hand, some orders are mainly phytophagous. These include the Lepidoptera (butterflies and moths) and Homoptera (aphids,

scale insects, leafhoppers, mealybugs, etc.). These two orders comprise about 150,000 species. The adult moths and butterflies are mostly nectar feeders and are not directly harmful, but nearly all the larval forms are phytophagous. These species represent some of the worst agricultural pests. However, they are attacked by a wide variety of parasites and predators of other insect orders.

In any study of radiation effects on agricultural ecosystems, the beneficial species must be included since they serve an important role in the supression of pest populations. Any differential effects of radiation between the beneficial and harmful species must be known. During the post-attack recovery phase this could be critical when the probability of weakened human control agencies may be high. This research could be closely allied with that of H. Cromroy, University of Florida, to include additional interphase chromosome volume studies on beneficial species.

3. A large number of radiation studies on arthropods have been conducted on specific life stages. Emphasis on the use of the sterile male technique to control pest populations seems to have emphasized pupal and adult treatments. Fallout radiation could affect any insect life stage depending on the season and locality. To more accurately predict the overall effects of radiation stress on any agro-ecosystem, studies should be conducted on all life stages of pest and beneficial species over a wide range of exposures. This would greatly improve our knowledge of the most susceptible life stage affected. For example, if sterilizing radiation is most effective when reproductive cells are increasing, then radiation stress would differ between species depending on their biology. More basic knowledge must be gained to explain the differences in mortality between species and life stages at similar radiation dosage levels.

4. The data presented in this paper indicate a need to initiate a study at the ecosystem level. The senior investigator is currently seeking an extension of the present study to

examine the effects of radioactive fallout on the agricultural ecosystem in the San Joaquin-Sacramento Valley, California. An analysis of the effects of fallout on food plants and their insect pests could then be reapplied to other agricultural areas. The information obtained could also be used for light as well as heavy MT burst effects. This study would lead to a better understanding of potential physical and biological disruptions in food production following nuclear disaster.

5. An additional study should include laboratory and field investigations on the effects of radiation stress on a group of ecologically related species. The senior author has studied the population dynamics and integrated control of insects affecting alfalfa since 1956. This has led to the accumulation of fundamental ecological data on these insects. This data could be utilized in carrying out the following research program.

On the Riverside Campus, University of California, there are two instruments essential to such a study. Currently available is a Westinghouse X-ray generator of 240Kv constant potential capable of 15 milliamps at this voltage. A typical target distance of 35 cm allows for an exposure of 500 r per minute over a uniform field of 35 cm radius. Also available is a U.S. Nuclear Corp. GR-12 Co^{60} irradiator. The specific activity of this source is currently on the order of 10,500 curies (renewable to 15,000 curies) and it has a geometry capable of exposures between 800 and 1800 r per hour (at 15,000 curies).

Because the pest species and their corresponding insect parasites and predators are already known on alfalfa, this would be an excellent beginning for studies on ecologically related arthropods. The species concerned represent a wide cross section of taxa (Lepidoptera, Homoptera, Hemiptera, Orthoptera, Coleoptera, Hymenoptera, and Diptera) and display a full range of predaceous, parasitic and phytophagous feeding habits.

In one way or another these studies should be encouraged to better understand and predict the potential role of arthropods in a case of nuclear disaster.

REFERENCES CITED

1. Ayers, R. U., 1965. Environmental effects of nuclear weapons. Vol. 1. OCD Task No. 3511A, Hudson Inst., xii + 265 pp.

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

3. Thomas, E. L., Jr. (ed.), 1956. Man's role in changing the face of the earth. Univ. Chicago Press. 1193 pp.

4. Ullyett, G. C., 1951. Insects, man and the environment. J. Econ. Ent., 44(4): 459-464.

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

6. Smith, R. F., 1959. The spread of the spotted alfalfa aphid, Therioaphis maculata (Buckton) in California. Hilgardia, 28(21): 647-691.

7. Doutt, R. L., 1958. Vice, virtue and the vedalia. Bull. Ent. Soc. Amer., 4(4): 119-123.

8. Ewart, W. H. & P. DeBach, 1947. DDT for control of citrus thrips and citricola scale. Calif. Citrog., 32: 242-245.

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

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

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

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

13. Bensen, D. W., R. Kologrinov, J. L. Kulp & K. A. Roach, 1963. Contamination of human food following nuclear attack. Third quarterly report. OCD contract No. OS-62-193, Isotopes, Inc.

14. Elton, C. S., 1960. The ecology of invasions by animals and plants. Methuen, London, 181 pp.

15. Glick, P. A., 1942. Insect population and migration in the air. Aerobiology, Amer. Ass'n. Adv. Sci. Publ. 17, pp. 88-98.

16. Gressitt, S. L., 1960. Air dispersal of insects in the Pacific and Antarctic areas. Proc. 11th Intern. Congr. Ent., Vienna.

17. Hardy, A. C. & P. S. Milne, 1937. Insect drift over the North Sea. Nature (Lond.), 139(3516): 510-511.

18. Hardy, A. C. & P. S. Milne, 1938. Aerial drift of insects. Nature (Lond.), 141: 602-603.

19. Hardy, A. C. & P. S. Milne, 1938. Studies in the distribution of insects by aerial currents. J. Anim. Ecol., 7: 199-229.

20. Hocking, B., 1953. The intrinsic range and speed of insects. Trans. Roy. Ent. Soc. Lond., 104: 223-345.

21. Holzapfel, E. P. & T. C. Harrell, 1968. Transoceanic dispersal studies of insects. Pacific Insects, 10(1): 115-153.

22. Huffaker, C. B., 1958. Experimental studies on predation: dispersion factors and predator-prey oscillations. Hilgardia, 27: 343-383.

23. Hurd, W. E., 1920. Influence of the wind upon the movements of insects. U.S. Mon. Weather Rev., 48: 94-98.

24. Johnson, C. G., 1960. A basis for a general system of insect migration and dispersal by flight. Nature (Lond.), 186: 348-350.

25. Kettle, D. S., 1951. Some factors affecting population density and flight range of insects. Proc. Roy. Ent. Soc. Lond., (A), 26: 59-63.

26. Lutz, F. E., 1927. Wind and direction of insect flight. Amer. Mus. Novit., 291: 1-4.

27. Müller, A. 1871. On the dispersal of non-migratory insects by atmospheric agencies. Trans. Roy. Ent. Soc. Lond., 1871: 175-186.

28. Profft, J., 1939. Ueber Fluggenwohnheiten der Blattläuse in Zusammerhang mit der Verbreitung von Kartoffelvirosen. Arb. Physiol. angew Ent., 6: 119-145.

29. Schneider, F., 1962. Dispersal and migration. Ann. Rev. Ent., 7: 223-242.

30. South, R., 1885. Insect migration. Ent. Mon. Mag., 21: 208-211.

31. Tutt, T. W., 1902. Migration and dispersal of insects. London, 132 pp.

32. Uvarov, B. P., 1931. Insects and climate. Trans. Roy. Ent. Soc. Lond., 79: 1-247.

33. Wellington, W. G., 1945. Conditions governing the distribution of insects in the free atmosphere. Canad. Ent., 77: 21-28.

34. Wester, F. M., 1902. Winds and storms as agents in the diffusion of insects. Amer. Nat., 36(430): 795-801.

35. Williams, C. B., 1924. Notes on insect migration in Egypt and the Near East. Trans. Ent. Soc. Lond., 72(18): 439-456.

36. Williams, C. B., 1930. The migration of butterflies. Oliver & Boyd Publ., London, 473 pp.

37. Williams, C. B., 1957. Insect migration. Ann. Rev. Ent., 2: 163-180.

38. Williams, C. B., 1958. Insect migration. The New Naturalist, Collins, London, 235 pp.

39. Wolfenbarger, D. O., 1946. Dispersal of small organisms: distance dispersion rates of bacteria, spores, seeds, pollen and insects; incidence rates of diseases and injuries. Amer. Midl. Nat., 35(1): 1-152.

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

41. Webb, F. E., J. R. Blais & 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. Ent., 93(5): 360-379.

42. Stern, V. M., R. van den Bosch, T. F. Leigh, O. D. McCutcheon, W. R. Sallee, C. E. Houston & M. J. Garber, 1967. Lygus control by strip cutting alfalfa. Univ. Calif. Agric. Ext. Serv., AXT-241, 13 pp.

43. Decker, G. C. & H. B. Cunningham, 1968. Winter survival and overwintering area of the potato leafhopper. J. Econ. Ent., 61(1): 154-161.

44. Medler, J. T., 1957. Migration of the potato leafhopper--A report on a cooperative study. J. Econ. Ent., 50(4): 493-497.

45. Cook, W. C., 1941. The beet leafhopper. U.S.D.A. Farmer's Bull. No. 1886, 21 pp.

46. Dorst, H. E. & E. W. Davis, 1937. Tracing long-distance movements of beet leafhopper in the desert. J. Econ. Ent., 30(6): 948-954.

47. Douglas, J. R., 1954. Outbreak of beet leafhoppers north and east of the permanent breeding areas. Amer. Soc. Sugar Beet Technologists, 8(1): 185-193.

48. Carruth, L. A., 1940. The corn earworm and its control. N.Y. State Agric. Exp. Sta. Circ. No. 190, 14 pp.

49. Neiswander, C. R., 1931. The source of American corn insects. Ohio Agric. Exp. Sta. Bull. No. 473, 98 pp.

50. Blanchard, R. A. & W. A. Douglas. 1953. The corn earworm as an enemy of field corn in the eastern states. U.S. D. A. Farmer's Bull. No. 1651, 15 pp.

51. Stefferud, A. (ed.), 1953. Plant Diseases: The Yearbook of Agriculture. U.S.D.A., 940 pp.

52. Miller, C. F., 1963. Fallout and radiological countermeasures. Vols. 1 & 2. S.R.I. Project No. IM-4021, Stanford Research Inst., Menlo Park, California.

53. Callahan, E. D., et al., 1960. The probable fallout threat over the continental United States. Technical Operations, Inc., Report No. TO-B60-13.

54. Holifield Committee in conjunction with the U.S. Weather Bureau. Congressional Hearings, 1959.

55. Benson, D.W., J.F. Gamble, R. Kologrinov, J.L. Kulp & K.A. Roach. 1965. Summary report on contamination of human food following nuclear attack. Vol. 1, Food contamination model. OCD Contract No. OS-62-193. Isotopes, Inc., 166 pp.

56. Billheimer, J. 1966. Postattack food availability and accessibility=a case study. OCD Work Unit no. 3423A, Stanford Research Inst. Menlo Park, California.

57. Bergman, P. 1967. Federal extension service and extension entomologists by state. U.S.D.A. Extension Newsletter. Washington, D. C.

58. Cockerell, T.D.A. 1939. The floating population of the air. Science 90(2337): 353-354.

59. Davidson, R.H. & L.M. Peairs. 1966. Insect pests of farm, garden and orchard. John Wiley & Sons, N. Y., 6th Edition, 675 pp.

60. Korting, A. 1931. Beobachtung uber die fritflege und einige getreidethysanopteren. Zeit. angew Ent., 18: 154-160.

61. Banks, N. 1915. The acarina or mites. A review of the group for the use of economic entomologists. U.S.D.A. Report No. 108, 153 pp.

62. Glick, P.A. 1939. The distribution of insects, spiders and mites in the air. U.S.D.A. Tech. Bull. No. 673, 150 pp.

63. Parker, W.B. 1913. The red spider on hops in the Sacra mento Valley of California. U.S.D.A. Bur. Ent. Bull. No. 117, 41 pp.

64. Savory, T. 1964. Arachnida. Academic Press, N.Y. 291 pp.

65. Stab[illegible]r, H.P. 1913. Red spiders spread by the wind. The Mon. Bull. Calif. State Comm. Hort. II, 12:777-780.

66. Anderson, L.D. 1954. The tomato russet mite in the United States. J. Econ. Ent., 47(6): 1001-1005.

67. Anderson, M.H. & C.V.G. Morgan. 1958. Life histories and habits of the clover mite, Bryobia praetiosa Koch, and the brown mite, Bryobia arborea M&A, in British Columbia. Can. Ent., 90(1): 23-42.

68. Fleschner, C.A. 1956. Field approach to population studies of tetranychid mites on citrus and avocado in California. Proc. 10th Int. Congr. Ent., Montreal, 2: 395-615.

69. Ewing, H.E. 1914. The common red spider or spider mite. Oregon Exp. Sta. Bull., 121, 95 pp.

70. Parker, J.R. & R.V. Connin. 1964. Grasshoppers: their habits and damage. Agric. Info. Bull., U.S.D.A., No. 287, 27pp.

71. Stefferud, A. (ed.) 1952. Insects: The yearbook of Agriculture. U.S.D.A., U.S. Gov. Print. Off., Washington, D.C., pp. 595-604.

72. Parker, J.R. 1957. Grasshoppers: A new look at an ancient enemy. U.S.D.A. Farmer's Bull. No. 2064, 40 pp.

73. Freeman, J.A. 1938. Composition of the aerial insect fauna up to 300 feet. Nature, 142 (3586): 153-154.

74. Johnston, H.B. 1925. Heliothrips indicus (Bagnall) injurious to man in the Sudan. Ent. Mon. Mag. 61:132-133.

75. Felt, E.P. 1928. Dispersal of insects by air currents. N.Y. State Mus. Bull., 274: 59-129.

76. Fernald, H.T. 1925. Flights of onion thrips. J. Econ. Ent., 18(4): 638.

77. Anderson, L.D. 1969. Personal communication. Dept. of Entomology, University of California, Riverside, Cal.

78. Borror, D.J. & D.M. DeLong. 1965. An Introduction to the study of insects. Holt, Reinhart & Winston, Pub. N.Y. 819 pp.

79. Packard, C.M., P. Luginbill & C. Benton. 1951. How to fight the chinch bug. U.S.D.A. Farmer's Bull. No. 1780, 21 pp.

80. Southwood, T.R.E. 1960. The flight activity of Heteroptera. Trans. Roy. Ent. Soc. Lond., 112: 173-220.

81. Le Quesne, W.T. 1946. Migration of Hemiptera. Ent. Mon. Mag., 82:42.

82. Targe, A., L. Desportes & R. Joubert. 1954. L'Aleurode et les traitements des agrumes dans les Alpes-Maritimes. Phytoma, 7(59):28-32.

83. Britton, W.E. 1919. Swarms of Aphids. 19th Report State Entomologist, Conn. Agric. Exp. Sta. Bull 218:203.

84. Davidson, J. 1927. The biological and ecological aspect of migration in aphides. Part I. Sci. Progr. 20th Cent., 21:641-658.

85. Davidson, J. 1927. The biological and ecological aspect of migration in aphides, Part II. Sci. Progr. 20th Cent., 22:57-69.

86. Dicker, G.H.L. 1959. A field study of the spread of apterous forms of the strawberry aphid, Pentatrichopus fragaefolii (Cock.). Ann. Rep. East Malling Res. Sta., Kent, A43:105-108.

87. Elton, C.S. 1925. The dispersal of insects to Spitzbergen. Trans. Lond. Ent. Soc., 1925:289-299.

88. Haine, E. 1955. The flight activity of the sycamore aphid, Drepanosiphum platanoides Schr. J. Anim. Ecol., 24(1):388-394.

89. Johnson, C.G. 1953. The role of population level, flight periodicity and climate in the dispersal of aphid . Trans. 9th Int. Congr. Ent., 1952, I:429-431.

90. Johnson, C.G. 1954. Aphid migration in relation to weather. Biol. Revs, Cambridge Phil. Soc., 29(1):87-118.

91. Johnson, C.G. 1956. Changing views on aphid dispersal. NAAS Quart. Rev., 32.

92. Johnson, C.G. & H.L. Penman. 1951. Relationship of aphid density to altitude. Nature (Lond.), 168(4269):337-338.

93. Thomas, I. & E.J. Vevai. 1940. Aphis migration: an analysis of the result of five seasons' trapping in North Wales. Ann. Appl. Biol., 27:393-405.

94. Cook, W.C. & B.A. App. 1956. The pea aphid on alfalfa and pea, and its control. Agric. Chem., 11(8):32-33, 113.

95. Evans, W.G. & G.G. Gyrisco. 1956. Notes on the biology of the pea aphid. J. Econ. Ent. 49(6):878-879.

96. Shands, W.A., G.W. Simpson & J.E. Dudley, Jr. 1956. Low-elevation movement of some species of aphids. J. Econ. Ent., 49(6):771-776.

97. Glick, P.A. 1957. Collecting insects by airplane in southern Texas. U.S.D.A. Tech. Bull. No. 1158, 28 pp.

98. Johnson, C.G. 1951. The study of wind borne insect populations in relation to terrestrial ecology, flight periodicity and estimation of aerial populations. Sci. Prog. 20th Cent., 39:41-62.

99. Johnson, C.G. 1952. The changing numbers of Aphis fabae Scop. flying at crop level in relation to current weather and to the population on the crop. Ann. Appl. Biol, 39:525-547.

100. van Hoof, H.A. 1962. Observations on aphid flights in Surinam, Ent. Exp. Appl., 5(4):239-243.

101. Barnes, M.M. & H.F. Madsen. 1961. Insect and mite pests of apple in California. Calif. Agr., Exp. Sta. Circ. 502, 31 pp.

102. Cooke, M. 1881. A treatise on the insects injurious to fruit and fruit trees of the state of California and remedies recommended for their extermination. Sacramento, California, 72 pp., Cal. Hort. Comm.

103. Hoyt, S.C. & H.F. Madsen, 1960. Dispersal behavior of the first instar nymphs of the wooly apple aphid. Hilgardia, 30:267-299.

104. Daiber, C.C. 1963. Notes on the population dynamics of aphids on potatoes and the spread of the leaf roll virus in South Africa. J. Ent. Soc. S. Africa, 25(2):157-169.

105. Daiber, C.C. 1963. Notes on the host plants and winged dispersal of Macrosiphum euphorbiae. J. Ent. Soc. S. Afr., 26(1): 14-33.

106. Davies, W.M. 1936. Studies on aphids infesting the potato crop. Ann. Appl. Biol., 23:401-408.

107. Dickson, R.C. & E.F. Laird, Jr. 1967. Fall dispersal of green peach aphids to desert valleys. Ann. Ent. Soc. Amer., 60(5):1088-1091.

108. Close, R & K.P. Lamb. 1961. Trapping study of some winged aphid vectors of plant virus diseases in Canterbury, New Zealand. N.Z. J. Agric. Res., 4(5): 1-4.

109. Medler, J.T. & P.W. Smith. 1960. Greenbug dispersal and distribution on barley yellow dwarf virus in Wisconsin. J. Econ. Ent.,,53(3):473-474.

110. Ruggles, A.G. & F.M. Wadley. 1927. The greenbug in Minnesota. J. Econ. Ent., 20(2):321-327.

111. Dickson, R.C., E.F. Laird & G. Pesho. 1955. The spotted alfalfa aphid. Hilgardia, 24(5): 93-118.

112. Smith, R.F., J.E. Swift & J. Dibble. 1956. Rapid spread of alfalfa pest. Calif. Agric., 10(1):5,15.

113. Tuttle, D.M., O.L. Barnes, M.W. Neilson, V.D. Roth & M.H. Schanhorst. 1958. The spotted alfalfa aphid in Arizona. Univ. Ariz. Agric. Exp. Sta. Bull. No. 294, 10 pp.

114. Stearns, L.H. & D. MacCreary. 1938. Leafhopper migration across Delaware Bay. J. Econ. Ent. 31(2):226-229.

115. Annand, P.M., T.C. Chamberlain, C.F. Henderson & H.A. Waters 1932. Movement of the beet leafhopper in 1930 in southern Idaho. U.S.D.A. Circ. No. 244. 24 pp.

116. Romney, V.E. 1939. Breeding areas and economic distribution of the beet leafhopper in New Mexico, southern Colorado and western Texas, U.S.D.A. Circ. No. 518,14pp.

117. Pienkowski, R.L. & J.T. Medler. 1966. Potato leafhopper trapping studies to determine local flight activity. J. Econ. Ent., 59(4):837-843.

118. Maxwell-LeFroy, H. 1901. The scale insects of the Lesser Antilles, Part I. Comm. Agric. Imperial Dept. Agric. West Indies. Pamphlet Series, No. 7, 61pp.

119. Newstead, R. 1901. Monograph of the Coccidae of the British Isles. Vol. 1. The Roy. Soc., London, 220 pp.+39 pl.

120. Quayle, H.J. 1916. Dispersal of scale insects by the wind. J. Econ. Ent., 9(5):486-493.

121. Quayle, H.J. 1911. Citrus fruit insects. Calif. Agric. Exp. Sta. Bull. No. 214:443-512.

122. Waterston, J.M. 1947. Report of the plant pathologist (Bermuda) for the year 1946. Hamilton Dept. Agric., 18 pp.

123. Ashmead, W.H. 1880. Orange insects. A treatise on the injurious and beneficial insects found on the orange trees of Florida. Ashmead Bros., Jacksonville, Florida, 78 pp.

124. Ebeling, W. 1959. Subtropical fruit pests. Univ. Calif. Div. Agric. Sci., 436 pp.

125. Wolcott, G.N. & S. Francisco, Jr. 1933. A year's experience with the cottony cushion scale in Puerto Rico. J. Dept. Agric. Puerto Rico, 17(3):199-221.

126. McKenzie, H.L. 1967. Mealybugs of California with taxonomy, biology and control of North American species (Homoptera: Coccoidea: Pseudococcidae). Univ. Calif. Press, Berkeley, 526 pp.

127. Clausen, C.P. 1915. Mealybugs of citrus trees. Calif. Agric. Exp. Sta. Bull. No. 258:19-48.

128. Peterson, A. 1923. The blackberry psyllid, Trioza tripunctata Fitch. N.J. Agric. Exp. Sta. Bull. No. 378, 32 pp.

129. Newcomer, E.J. 1966. Insect pests of deciduous fruits in the west. U.S.D.A. Agric. Hdbk. No. 306, 57 pp.

130. Brower, A.E. 1930. An experiment in marking moths and finding them again (Lepid.: Noctuidae). Ent. News, 41(1):10-15.

131. Brower, A.E. 1930. An experiment in marking moths and finding them again (Lepid.: Noctuidae). Ent. News, 41(2):44-46.

132. Collins, C.W. 1917. Methods used in determining wind dispersions of the gypsy moth and some other insects. J. Econ. Ent., 10(1):170-176.

133. Felt, E.P. 1925. Dispersal of butterflies and other insects. Nature (Lond.), 116:365-368.

134. Newman, L.J. 1927. Armyworms, cutworms and webworms. J. Dept. Agric. West Austr. (2nd ser.), 4:227-239.

135. Stultz, H.T. 1943. Studies in codling moth biology and behavior. Rep. Comm. Codling Moth, U.S.D.A. Bur. Ent. Pl. Quar., 85 pp. mimeo.

136. Walker, J.J. 1921. A summary of butterfly migrations Proc. Ent. Soc. London, 1921: 20-25.

137. Williams, C.B., G.F. Cockbill, M.E. Gibbs & J.A. Downes. 1942. Studies in the migration of lepidoptera. Trans. Roy. Ent. Soc., Lond., 92:101-281 + 2 pl.

138. Minott, C.W. 1922. The gypsy moth on cranberry bogs. U.S.D.A. Bull. No. 1093, 19 pp.

139. Price, D.W. & F.M. Summers. 1961. Cyclical changes in numbers of moths and larvae of the peach twig borer in California. J. Econ. Ent., 54(5):933-936.

140. Vereshchagina, V.V. & Zagulyaer. 1961. The fruit moth (Anarsia lineatella Z.)—A facultative predator of the plum shoot mite. Trud. Moldavsk. navchno-issled Inst. Sadovod, 7:35-45.

141. Common, I.F.B. 1952. Migration and gregarious aestivation in the bogong moth, Agrotis infusa. Nature (Lond.), 170(4336):981-982.

142. Common, I.F.B. 1954. A study of the ecology of the adult bogong moth, Agrotis infusa (Boisd.)(Lepidoptera: Noctuidae), with special reference to its behaviour during migration and aestivation. Austr. J. Zool., 2 (2):223-263 + 4 pl.

143. Scott, A.W. 1873. On the "Agrotis vastator," a species of moth, now infesting the sea-board of New South Wales. Trans. Ent. Soc. N.S.W., 2:40-48.

144. Fletcher, T.B. 1925. Migration as a factor in pest outbreaks. Bull. Ent. Res., 16(2):177-181.

145. Walker, J.J. 1931. Insects at sea. Ent. Mon. Mag., 67: 211-232, 254-268.

146. Anonymous. 1948. Plant diseases and pests in Denmark. Tidsskr. Planteall, 51:373-437.

147. Anonymous. 1948. Plant diseases and pests in Denmark. Tidsskr. Planteall, 52:236-292.

148. Heddergott, H. 1963. On the mass occurrence of Autographa gamma in the year 1962. Gesunde Pflanzen, 15 (1):5-10.

149. Peerdeman, 1961. Autographa gamma flight south of of Amsterdam, Neth.,March-November. Ent. Ber., 22:149-151.

150. Currie, [illegible]. 1930. The brown cutworm (Euxoa radians Guen.). [illegible]ensl. Agric. J., 34(1):10-16.

151. Currie, [illegible]. 1930. The brown cutworm (Euxoa radians Guen.). [illegible]nsl. Agric. J., 34(2):138-163.

152. Currie, [illegible]. 1930. The brown cutworm (Euxoa radians Guen.). [illegible]nsl. Agric. J., 34(4):383-390.

153. Currie, [illegible]. 1930. The brown cutworm (Euxoa radians Guen.). [illegible]nsl. Agric. J., 34(5):488-495.

154. Currie, [illegible]. 1931. The brown cutworm (Euxoa radians Guen.). [illegible]nsl. Agric. J., 35(1):18-33.

155. Glover, [illegible], K.R. Hardy, T.G. Konrad, W.N. Sullivan & A.S. M[illegible]els. 1966. Radar observations of insects in fligh[illegible] Science. 154(3752):967-972.

156. Walton, [illegible] & C.M. Packard. 1951. The armyworm and its control. [illegible]D.A. Farmer's Bull. No. 1850, 10 pp.

157. Faure, [illegible]. 1943. Phases of the lesser armyworm. Farming in [illegible] 18(203):69-78.

158. Newcome[illegible] J. 1931. Control of the codling moth in the Paci[illegible] Northwest. U.S.D.A. Farmer's Bull. No. 1326, 26 [illegible]

159. Van Leeu[illegible] E.R. 1940. Activity of adult codling moths as [illegible]icated by captures of marked moths. J. Econ. Ent[illegible] 33(1):162-166.

160. Worthley[illegible] N. 1932. Studies of codling moth flight. J. Econ. [illegible] 25 [illegible]:559-565.

161. Frost, [illegible] 1931. Some habits of the adults of the oriental [illegible] moth with reference to baits. J. Econ. Ent., 24 [illegible]302-309.

162. Summers, [illegible]. 1966. The oriental fruit moth in California. Calif. A[illegible] Exp. Sta. Circ. No. 539, 17 pp.

163. Yetter, [illegible] Jr. & L.F. Steiner. 1932. Efficiency of bait [illegible] for the oriental fruit moth as indicated by th[illegible] release and capture of marked adults. J. Econ. Ent[illegible] 25(1):106-115.

164. Dupree, M[illegible] T.L. Bissell & C.M. Beckham. 1955. The picklewor[illegible] and its control. Bull. Ga. Agric. Exp. Sta. (N.S.), No[illegible] 34 pp.

165. Strelnikov, I.D. 1936. Die Wanderung von Loxostege sticticalis. Bull. Inst. Sc., Lesshaft. Leningrad, 19: 77-120.

166. Melnichenko, A.N. 1935. Regularities of mass flying of the adult Loxostege stricticalis L. and the problems of the prognosis of their flight migrations. Bull. Plant Prot. Leningrad, Ent. No. 17, 55 PP.

167. Saunders, L.G. 1938. Migration of moths of the beet webworm. Can. Ent., 70(8): 176.

168. Neiswander, C.R. & J.R. Savage. 1931. Migration and dissemination of European corn borer. J. Econ. Ent., 22(2): 389-393.

169. Stirrett, G.M. 1938. A field study of the flight, oviposition and establishment periods in the life cycle of the European corn borer, Pyrausta nubilalis Hbn., and the physical factors affecting them. Sci. Agric. 18(7) :355-369, 462.

170. Brindley, T.A. & J.C. Chambers. 1958. The pea weevil and the methods for its control. U.S.D.A. Farmer's Bull. No. 1971.

171. Larsen, A.O., T.A. Brindley & F.G. Hinman. 1933. The local dispersal of the pea weevil. J. Econ. Ent., 26:1063-1068.

172. Smith, C.E. & N. Allen. 1932. The migratory habit of the spotted cucumber beetle. J. Econ. Ent., 25(1):53-57.

173. Arant, F.S. 1929. Biology and control of the southern corn rootworm. Alabama Agric. Exp. Sta. Bull No. 230, 46 pp.

174. Dominick, C.B. 1943. Life history of the tobacco flea beetle. Va. Agric. Exp. Sta. Bull. No. 355, 39 pp.

175. Wolfenbarger, D.O. 1940. Relative prevalence of potato flea beetle, Epitrix cucumeris Harr., injuries in fields adjoining uncultivated areas. Ann. Ent. Soc. Amer., 33 (2):391-394.

176. Tower, W.L. 1906. An investigatio f evolution in chrysomelid beetles of the genus Leptinotarsa. Publ. Carnegie Inst. Wash., 48:320 pp. + 30 pl.

177. Manson, G.F. 1963. The cereal leaf beetle in North America. Ent. Newsl., 41(7):1-2.

178. Steiner, H.M. & H.M. Worthley. 1941. The plum curculio problem on peach in Pennsylvania. J. Econ. Ent., 34 (2):249-255.

179. Prokopy, R.J. & G.G. Gyrisco. 1963. A fall flight period of the alfalfa weevil in New York. J. Econ. Ent., 56(2):241.

180. Cartwright, O.L. 1929. The maize bill-bug in South Carolina. S. Carolina Agric. Exp. Sta. Bull. No. 25., 35 pp.

181. Landis, B.J. & J. A. Onsager. 1967. Wireworms on irregated lands in the West: How to control them. U.S.D.A. Farmer's Bull. No. 2220, 14 pp.

182. Holmes, N.D. & L.K. Peterson. 1963. Effects of variety and date of seeding spring wheats and location in the field on sex ratio of the wheat stem sawfly, Cephus cinctus. Canad. J. Zool., 41(7):1217-1222.

183. Wheeler, W.M. 1910. Ants, their structure, development and behavior. Columbia Univ. Press, N.Y., 663 pp.

184. Schlinger, E.I., personal communication, 1969. Dept. of Entomology, University of California, Riverside, Cal., 92502.

185. Jones, E.T. 1937. Dispersal of hessian flies from field reservoirs. Unpubl. rep. of Bureau of Ent. & Pl. Quar.

186. McCullouch, J.W. 1917. Wind as a factor in the dispersion of the hessian fly. J. Econ. Ent., 10(1):162-168.

187. Osborn, H. 1898. The hessian fly in the United States. U.S.D.A. Div. Ent. Bull., 16:1-57.

188. Frick, K.E., H.G. Simkover & H.S. Telford. 1954. Bionomics of the cherry fruit flies in eastern Washington. Tech. Bull. Wash. Agric. Exp. Sta., No. 13, 66 pp.

189. Phipps, C.R. & C.O. Dirks. 1932. Dispersal of the apple maggot. J. Econ. Ent., 25(3):576-582.

190. Ehrenberg, L., A. Gustafsson, A. Levan & U. von Wettstein. 1949. Radiophosphorus, seedling lethality and chromosome disturbances. Hereditas, 35:469-489.

191. Scossiroli, R.E. & S. Pellegrini-Scossiroli. 1963. Analysis of phenotypic variability in progeny obtained from seeds treated with x Rays and seeds not treated of T. durum. Atti Assoc. Genet. Ital., 8:303-313.

192. Vasilev, I.M., O.I. Parfenova & N.D. Rybalka. 1959. The effect of exposure to x rays on the content of nitrogenic substances in wheat plants. Doklady Akad. Nauk SSSR, 124:928-929.

193. Mohamed, H.A., A.A.M. Omar & M.N. El-Barhamtoushy. 1964. Effect of radioactive cobalt on wheat. I. Effect on some morphological characters. Tech. Bull. Egypt. Agric. Organ., No. 76, 56 pp.

194. Strazhevskaya, N.B. 1960. Effect of ionizing radiation on protein metabolism in nuclei, mitochondria and ergastaplasm of the plant organism. Biophysics (USSR) (Eng. Trans.), 5(3):397-406.

195. Hoopingarner, R.A., S. Kumararaj & A.L. French. 1965. Gametogenesis and radiation effects in the cereal leaf beetle, Oulema melanopa. Ann. Ent. Soc. Amer., 58: 777-781.

196. Sydorenko, I.D. 1962. The effect of ionizing radiation and ultraviolet radiation on corn seeds. Ukr. Bot. Zh., 19(2):3-12.

197. Erdelsky, K. 1960. Influence of gamma irradiation on the germination and first developmental stages of maize. Biologia, 15:890-894.

198. Walker, J.R. 1962. Evaluation of control of European corn borer, Ostrinia nubilalis (Hübner) by x-ray induced sterility. Diss. Abstr., 23:761.

199. Walker, J.R. 1963. Effect of x-ray exposure on the European corn borer, J. Econ. Ent., 56:522-525.

200. Sparrow, A.H. & E. Christensen. 1949. I[illegible]sed seed germination following x-ray treatment of potato tubers. A.E.C.U.-484, 3 pp.

201. Sparrow, A.H. & E. Christensen. 1950. Effects of x-ray, neutron, and chronic gamma irradiation on growth and yield of potatoes. A.E.C.U.-898, 1 p.

202. Avakyan, V.A., L.A. Gukasyan & I.S. Sisakyan. 1965. Effect of x-irradiation on the yield of potatoes. Izv. Akad. Nauk Arm. SSR., Biol. Nauki, 18(5):52-56.

203. Heiken, A. 1961. Induction of somatic changes in Solanum tuberosum by acute gamma irradiation. Hereditas, 47:606-614.

204. Kuzin, A.M., A. Kasymov & L.M. Kryukova. 1964. Mechanism of the stimulating and depressing action of radiation in potato tubers. Radiobiologiya, 4:144-149.

205. Burton, W.G. & W.H. deJong. 1959. The irradiation of ware potatoes. Intern. J. Appl. Rad. & Isotopes, 6: 167-170.

206. Elbadry, E.A. 1963. The effect of gamma radiation on host-parasitoid relationships. Thesis, Univ. Calif., Berkeley, 100 pp.

207. Elbadry, E.A. 1965. Some effects of gamma radiation on the potato tuberworm, Gnorimischema operculella (Lepidoptera: Gelechiidae). Ann. Ent. Soc. Amer., 58:206-209.

208. Breslavets, L.P., N.M. Berezina, G.I. Shchibria, M.L. Romanchikova, V.A. Iazykova & Z.F. Mileshko. 1960. Increase in the yield of radishes and carrots by x- or gamma-irradiation of the seeds before sowing. Biophysics (USSR) (English Trans.), 5:86-87.

209. Mamedov, T.G. & F. Khalisi. 1965. Some regularities of changes in plants after gamma irradiation. Radiobiologiya, 5:730-731.

210. Gottschalk, W. 1962. Studies of the selection value of radioinduced mutants. Z. Vererbungsleher, 93:185-202.

211. Avramenko, B.I., A.N. Ipatev, L.G. Mushinskaya & A.P. Savchenko. 1965. Morphological and biological changes in plants induced by gamma radiation. Dokl. Akad. Nauk BSSR, 9:340-343.

212. Moh, C.C. & J.J. Alan. 1965. Bean mutant induced by ionizing radiation. II. Yellow mosaic mutant. Turrialba, 14:199-201.

213. Mamedov, T.G. 1960. The influence of the state of plant cells on their radiosensitivity to gamma irradiation. Tsitologiya, 2(2):

214. Spalding, J.F., S.B. Hawkins & U.A. Sayeg. 1958. Relative biological effect of 14-Mev neutrons with the broad bean root (Vicia faba) as a test system. Rad. Res., 9:548-551.

215. Lozeron, H., A. Maggiora & W. Jadassohn. 1964. Protection of Vicia faba equina against x rays by seretonin. Experientia, 20:390-391.

216. Huque, H. 1963. Preliminary studies on irradiation of some common stored grain insects in Pakistan. I.A.E.A. Preprint SM-40/18, 1? pp.

217. Henneberry, T.J., F.F. Smith & W.L. McGovern. 1964. Some effects of gamma radiation and a chemosterilant on the Mexican bean beetle. J. Econ. Ent., 57(6):813-815.

218. Brock, R.D. & W.D. Andrew. 1965. X ray-induced variation in Medicago polymorpha var. vulgaris. Austr. J. Biol. Sci., 18:1119-1128.

219. Sumarukov, G.V. 1962. Correlation between the magnitude of the oxidation-reduction potential of the hemolymph of the cricket, and the radiosensitivity of the cricket. Radiobiologiya, 2:374-377.

220. Burgess, E.E. & S.E. Bennett. 1966. Sterilization of the male alfalfa weevil (Hypera postica: Curculionidae) by x radiation. J. Econ. Ent., 59:268-270.

221. Vlasyuk, P.A. 1964. Effect of ionizing radiation on the physiological-biochemical properties and metabolism of agricultural plants. Akad. Nauk Moldavsk. SSR, Inst. Fiziol. i Biokhim. Rast., 1964:24-31.

222. Breslavets, L.P., N.M. Berezina, G.I. Shchibrya & M.L. Romanchikova. 1956. Action of ionizing radiations on the growth and development of certain agricultural plants. Biofizika, 1:628-632.

223. Rasulov, F.K., 1963. Effedt of x rays on the sterility of the cotton moth, Laphygma exigua. Khlopkovodstvo, 7:41-42.

224. McClanahan, R.J. 1965. Sterilization of the carrot rust fly by irradiation with 137 Cs. Can. Ent., 97:1042-1045.

225. Lapins, K. 1965. Compact mutants of apple induced by ionizing radiation. Can. J. Plant Sci., 45:117-124.

226. Proverbs, M.D. & J.R. Newton. 1960. Influence of gamma radiation on the development and fertility of the codling moth, Carpocapsa pomonella (L.) (Lepidoptera: Olethreutidae). Can. J. Zool., 40:401-420.

227. Proverbs, M.D. 1962. Sterilization of the codling moth by gamma irradiation. Nature (Lond), 194:1297.

228. Mitlin, N., A.C. Bartlett & I.C. Keller. 1965. Elimination rate and effect on reproduction of ingested radiophosphorus in the boll weevil. J. Econ. Ent., 58:119-121.

229. Mayer, M.S. & J.R. Brazzel. 1961. Certain biological effects produced in the boll weevil by tagging it with P^{32}. J. Econ. Ent., 54:1197-1203.

230. Nelson, D.J., S.I. Auerbach, B.G. Blaycock, et al. 1965. Clinch River and related aquatic studies. Oak Ridge Nat'l. Lab., Tenn., ORNL 3697, pp. 95-104.

231. Stroemnaes, O. 1962. Mutagenic effect of C^{14} and H^3 labelled DNA precursors ingested into *Drosophila melanogaster* males. Can. J. Genet. Cytol., 4:440-446.

232. Grosch, D.S. 1960. The genetic and developmental effects of ingested radioactives in *Habrobracon*. Final Rep., Contract AT(40-1)-1314, 10 pp.

233. Martin, A., Jr. 1950. The significance of the action of radioactive phosphorus on *Habrobracon juglandis* Ashmead. Proc. Penn. Acad. Sci., 24:60-64.

234. Smith, J.C. & D.J. Kimeldorf. 1963. The bioelectrical response of the insect eye to beta radiation. NRDL (AD 42910), 30 pp.

235. Erdman, H.E. 1962. Developmental arrest of irradiated *Ephestia* larvae. (HW-72500), pp. 102-103.

236. Wharton, D.R.A., M.L. Wharton & J.E. Lola. 1965. Weight and blood volume changes induced by irradiation of the American cockroach. Rad. Res., 25:514-525.

237. Abdel-Malek, A.A. & K.K. McKevan. 1961. Inhibited oviposition by females of *Gryllus assimilis* (F.), induced by radioactive males, using L-methionine-methyl-^{14}C. Nature (Lond.), 192:618-621.

238. Anderson, T.W. & H.L. Cromroy. 1968. Effects of beta radiation on eggs of *Blatella germanica*. M.S. Thesis, University of Florida, 35 pp.

239. Sidorov, V.E. & I.M. Grokhovskaya. 1964. The effect of x rays on adult *Hyalomma asiaticum*. Communication I. Med. Parazitol. i Parazitarn Bolezni., 5:560-563.

240. Melville, C. 1958. An apparent beneficial effect of gamma radiation on the flour mite. Nature (Lond.), 181:1403-1404.

241. Henneberry, T.J. 1964. Effects of gamma radiation on the fertility of the two-spotted mite and its progeny. J. Econ. Ent., 57:672-673.

242. Farkas, J. 1964. Investigations into the radiation resistance of Tribolium confusum (Duval) and Tyrophagus dimidiatus (Hermann). Acta Microbiol. Acad. Sci. Hung., 12:15-28.

243. Bychkovskaya, I.B. & G.K. Ochinskaya. 1964. Study of the oxygen effect at different irradiation rates. Radiobiologiya, 4:63-66.

244. Abdul-Matin, A.S.M., A.D. Bhuiya & Z.A. Khan. 1966. Attempt to obtain sterility of male rice hispa through gamma radiation. Proc. Agric. Symp., Dacca, Pakistan, pp. 155-156.

245. Pesson, P. 1963. Some experimental data on cobalt radiation doses capable of arresting insect infestation of cereals and flour. Food. Irradiation, 3(4):A18-A21.

246. Quraishi, M.S. & M. Metin. 1963. Radiosensitivity of various stages of Callosobruchus chinensis L. IAEA Preprint, SM-40/19, 7 pp.

247. Neharin, A.,M. Calderon & O. Yacobi. 1964. Susceptibility of Callosobruchus maculatus to high-dose-rate gamma irradiation. Ia-IOIO, 2 pp.

248. Viado, G.B. & E.C. Manoto. 1963. Effects of gamma radiation on three species of Philippine insect pest. IAEA Preprint SM-40/24, 16 pp.

249. Davich, T.B. & D.A. Lindquist. 1962. Exploratory studies on gamma radiation for the sterilization of the boll weevil. J. Econ. Ent., 55:164-167.

250. Mayer, M.S. 1963. Biological and histopathological effects of gamma radiation on three life stages of Anthonomus grandis Boheman. Thesis, Texas State A & M Univ., 154 pp.

251. Mayer, M.S. & J.R. Brazzel. 1966. Laboratory studies to sterilize the boll weevil with radiation. Ann. Ent. Soc. Amer., 59:284-290.

252. Nardon, P. 1963. Possibilities of use of radiation in the control of insects. Phytoma, 15:7-12.

253. Andreer, S.V., B.K. Mortens, V.A. Molchanova & A.S. Stepanov. 1962. Studies of dose-dependence on the survival rate and the sexual sterilization of the granary weevil (Calandra granaria). Radiobiologiya, 2:758-762.

254. Bychkovskaya, I.B. & G.K. Ochinskaya. 1964. Analysis of the dependence of the protective action of hypoxia on the radiation dose. Radiobiologiya, 4:203-209.

255. Blazek, J., J. Dockal & J. Kolin. 1964. The possibility of using Co^{60} radioisotope against grain storage insects. Mlynsko-Pekarsky Prumysl, 10:436-439.

256. Zakladnoi, G.A. 1966. Influence of the gamma irradiation dose rate on the lifetime of granary weevils. Radiobiologiya, 6:478-479.

257. Bychkovskaya, I.G. & G.K. Ochinskaya. 1966. Concerning the system in the reaction of biological objects to radiation experiments on granary weevils. Zool. An., 45:134-137.

258. Hoover, D.L., E.H. Floyd & H.D. Richardson. 1963. Effects of 300 kv x ray radiation on Sitophilus oryzae. J. Econ. Ent., 56:584-585.

259. Abdul-Matin, A.S.M. 1966. Susceptibility of adult rice weevil, Sitophilus oryzae (L.) to gamma radiation. AECD/AG-15, 7 pp.

260. Laviolette, P. & P. Nardon. 1963. Effects of irradiation on mortality and reproduction of a cereals pest, Sitophilus sasakii Takahashi (Curculionidae) and study of the influence of treatment on offspring. IAEA Preprint SM-40/4, 12 pp.

261. Upadhya, M.D., J.L. Brewbaker & E.A. Macion. 1966. Effect of gamma irradiation on mango fruits and mango seed weevil (Sternochetus mangiferae Febricus). UH-235P5-I, pp. 39-46.

262. Ross, E. 1966. Dosimetry, tolerance and shelflike extension related to disinfestation of fruits and vegetables by gamma irradiation. Conf.-641002, pp. 49-52.

263. Walker, J.R. 1966. Reproductive potential of the sweet potato weevil after exposure to ionizing radiations. J. Econ. Ent., 59:1206-1208.

264. Tilton, E.W., W.E. Burkholder & R.R. Cogburn. 1966. Mating competition of gamma irradiated and non-irradiated male Trogoderma glabrum Herbst. J. Econ. Ent., 59:168-169.

265. Carney, G.C. 1959. Differential response of male and female adults of Trogoderma granarium Everts towards sterilizing doses of gamma radiation. Nature (Lond.), 183:339-339.

266. Nair, K.K. & G.W. Rahalkar. 1963. Studies on the effects of gamma radiation on the different developmental stages of the khapra beetle, Trogoderma granarium Everts. IAEA Preprint SM-40/27, 18 pp.

267. Kansu, I.A. 1962. Preliminary experiments on the sterilization of the pupae of the khapra beetle by irradiation with gamma rays. Z. Angew Entomol., 49: 224-228.

268. Horber, E. 1963. Eradication of white grub (Melolontha vulgaris F.) by the sterile-male technique. IAEA Preprint SM-40/12, 24 pp.

269. Wood, D.L. & R.W. Stark. 1966. Effects of gamma radiation on the biology and behavior of adult Ips confusus (LeConte) (Coleoptera: Scolytidae). Can. Ent., 98:1-10.

270. Farkas, J. 1966. Investigations into the radiation resistance of Tribolium confusum (Duval) and Tyrophagus dimidiatus (Hermann). Acta Biol. Acad. Sci. Hung., 16: 207-215.

271. Harvey, J.M. 1964. Irradiation of fruits and vegetables in a mobile cobalt 60 unit. Tid-7684, pp. 55-57.

272. McDonald, D.J. 1961. X irradiation of the developing male germ cells of Tribolium confusum. Genetics, 46: 1511-1517.

273. Niaussat, P., A. Pascaud, C. Grenot & F. Pierre. 1963. Contingent relation between the resistance to gamma radiation of certain arthropods of the Sahara and the nucleic acid content of their tissues. Bull. Soc. Med. Mill. Franc., 57:295-299.

274. Erdman, H.E. 1963. The differential sensitivity of flour beetles, Tribolium confusum and T. castaneum to x ray: Alteration of reproductive abilities, induced dominant lethals, biomass and survival. HW-SA-2950, Contract AT (45-1)-1350.

275. Dennis, N.M. 1961. The effects of gamma ray irradiation of certain species of stored-product insects. J. Econ. Ent., 54:211-212.

276. Sokoloff, A. 1961. Irradiation experiments with Tribolium. Tribolium Info. Bull., 4:28-33.

277. Erdman, H.E. 1965. Dose ratio of x rays to fast neutrons in producing dominant lethals in flour beetles, Tribolium castaneum. Nature (Lond.), 205:99-100.

278. Bartlett, A.C. & A.E. Bell. 1962. The effect of irradiation in two strains of Tribolium castaneum Herbst. Rad. Res., 17:864-877.

279. Erdman, H.E. 1963. The differential sensitivity of flour beetles, Tribolium confusum and T. castaneum, to x ray alteration of reproductive abilities, induced dominant lethals, biomass, and survival. J. Exptl. Zool., 153:141-147.

280. Bushland, R.C. 1960. Male sterilization for the control of insects. Adv. Pest Control Res., 3:1-25.

281. Dixon, E.B. 1962. Some effects of irradiation on Cochliomyia hominivorax. J. Econ. Ent., 55:826-827.

282. Baumhover, A.H. 1963. Influence of aeration during gamma irradiation of screw-worm pupae. J. Econ. Ent., 56:628-631.

283. Gibbons, H.L., J. Robert, J. Dille & R.G. Cowley. 1965. Inhalant allergy to the screwworm fly: Preliminary report. Arch. Environ. Health, 10:424-430.

284. La Chance, L.E. 1963. Enhancement of radiation-induced sterility in insects by pretreatment in CO_2 and air. Intern. J. Rad. Biol., 7:321-331.

285. Crystal, M.M. 1965. First efficient chemosterilants against screw-worm flies (Diptera: Calliphoridae). J. Med. Ent., 2:317-319.

286. Flint, H.M. 1964. The effect of cobalt 60 gamma rays on the biology of the eye gnat, Hippelates pusio Loew. Thesis, Univ. Florida, Gainesville, Florida, 67 pp.

287. Flint, H.M. 1965. Effects of gamma radiation on the fertility and longevity of Hippelates pusio. J. Econ. Ent., 58:555-559.

288. Flint, H.M. 1966. The effects of gamma radiation on mating, competitiveness and fecundity of Hippelates pusio. Loew. J. Econ. Ent., 59:96-99.

289. Terzian, L.A. & N. Stahler. 1958. A study of some effects of gamma radiation on the adults and eggs of Aedes aegypti. Naval Med. Res. Inst., Bethesa, Md. 13 pp.

290. Dame, D.A. & C.H. Schmidt. 1962. The importance of competitiveness of radiosterilized males in mosquito control. Proc. Ann. Meeting N.J. Mosquito Exterm. Ass'n., 49: 165-168.

291. Dame, D.A., & D.N. Woodward, H.R. Ford & D.E. Weidhaas. 1964. Field behavior of sexually sterile Anopheles quadrimaculatus males. Mosquito News, 24:6-14.

292. Krishnamurthy, B.S., S.M. Ray & G.C. Joshi. 1962. A note on the preliminary field studies of the use of irradiated males for reduction of C. fatigans Wied. populations. Indian J. Malariol., 16:365-373.

293. Nickel, E. 1965. Effects of 2,4-dinitrophenol on the radioinduced dominant lethal factors in Drosophila melanogaster. Strahlentherapie, 126:;263-268.

294. Sacca, G. 1961. Studies on houseflies, sterilized with x-rays. Rend. 1st Super. Sanita., 24:5-12.

295. Sacca, G. 1961. Experiments on house flies sterilized with x-rays. Atti Accad. Naz. Ital., Ent., 8:91-98.

296. Nair, K.K. 1962. Preliminary studies on the effects of gamma radiation on housefly pupae with special reference to the critical periods in relation to the mechanism of emergence. Radioisotopes & Rad. in Ent., pp.207-211.

297. Dauer, M., P.L. Bhatnagar & M. Rockstein, 1965. x-irradiation of pupae of the house fly, Musca domestica L., and male survival. J. Gerontol., 20:219-223.

298. Schmidt, C.H., D.A. Dame & D.E. Weidhaas. 1964. Radiosterilization vs. chemosterilization in house flies and mosquitos. J. Econ. Ent., 57:753-756.

299. Lewis, L & G. Eddy. 1964. Some effects of gamma radiation on the horn fly. J. Econ. Ent., 57:275-276.

300. Drummond, R.O. 1963. Effects of gamma radiation on the fertility of the common cattle grub, Hypoderma lineatum (De Villers). Intern. J. Rad. Biol., 7:491-495.

301. Sakka, M. 1965. x ray induced shortening of life span of adult Sarcophaga peregrina and its modification by dose fractionation. Tohoku J. Exptl. Med., 86:325-333.

302. Benschoter, C.A. & J. Telich. 1964. Effect of gamma rays on immature stages of the Mexican fruit fly. J. Econ. Ent., 57:690-691.

303. Brownell, L.E. & M. Yudelovitch. 1962. Effect of radiation on Mexican fruit fly eggs and larvae in grapefruit. Intern. A.E.A., Radioisotopes & Rad. in Ent., pp. 193-206.

304. Katiyar, K.P. & F. Ferrer. 1965. Sterilization of the Mediterranean fruit fly and its application to fly eradication. NYO-2043-108, pp. 69-94.

305. Little, H.F. 1967. Midgut epithelium of adult Chelisoches morio (Dermaptera: Chelisochidae) and Ceratitis capitata (Diptera: Tephritidae) following ionizing irradiation. Ann. Ent. Soc. Amer., 60:412-414.

306. Katiyar, K.P. 1962. Possibilities of eradication of the Mediterranean fruit fly, Ceratitis capitata (Wied.), from Central America by gamma irradiated males. 4th Intern. Amer. Symp. on the Peaceful Applications of Nuclear Energy, vol. II, pp. 211-217.

307. Katiyar, K.P. & J. Valerio. 1965. Further studies on the possible use of sterile-male release technique in controlling or eradicating the Mediterranean fruit fly, Ceratitis capitata Wied., from Central America. 5th Inter-American Symp. on the Peaceful Application of Nuclear Energy, pp. 197-202.

308. Balock, J.W., A.K. Burditt, Jr., & L.D. Christenson. 1963. Effects of gamma radiation on various stages of three fruit fly species. J. Econ. Ent., 56:42-46.

309. Huque, H. & A. Hafiz. 1966. Control of fruit flies by gamma rays. Food. Irradiation, 6:28-32.

310. Balock, J.W., A.K. Burditt, Jr., S.T. Seo & E.K. Akamine. 1966. Gamma radiation as a quarantine treatment for Hawaiian fruit flies. J. Econ. Ent., 59:202-204.

311. Rhode, R.H., F. Lopez & F. Equisa. 1961. Effect of gamma radiation on the reproductive potential of the Mexican fruit fly., J. Econ. Ent., 54L202-203.

312. Thomou, H. 1963. Sterilization of Dacus oleae by gamma radiation. Radiation & Radioisotopes Applied in Insects of Agric. Importance, IAEA, pp. 413-424.

313 Baccetti, B. & R. de Dominicis. 1963. The effects of gamma radiations on the ovaries of Dacus oleae Gmel. IAEA Preprint SM-40/41, 40 pp.

314. Tzanakakis, M.E., JA.A Tsitsipis, M. Papageorgiou & E. Fytizas. 1966. Gamma radiation induced dominant lethality in the sperm of the olive fruit fly. J. Econ. Ent., 59:214-216.

315. Baldwin, W.F. 1963. Radiation induced sterility in the insect Rhodnius prolixus. Can. J. Zool., 41:637-648.

316 Gomez-Numez, J.C., A. Gross & C. Machado. 1964. Gamma radiation and the reproductive behaviour of male Rhodnius prolixus. Acta Cient. Benezolana, 15:97-104.

317. Courtois, G. & J. LeComte. 1959. The resistance to gamma radiation of the worker bee. Ann. abeille, 4: 5-290.

318. Lee, W.R. 1964. Partial-body radiations of queen honey bees. (TID-20299), Contract AT(30-1)-2315, 7 pp.

319. Lee, W.R. 1964. Partial body radiations of queen honey bees. J. Apicult. Res., 3:113-116.

320. Clark, A.M. 1958. Some effects of x rays on longevity of Habrobracon females. (TID-6053), Contract AT930-1)-1752, 21 pp.

321. DeBach, P & E.B. White. 1962. Irradiated parasitic wasps: the effect on progeny production and sex ratio. J. Heredit., 53:271-276.

322. Legay, J.-M. & P. Teulade. 1962. Sensitivity to x rays of the development time of Bombyx mori eggs when the irradiation is done several hours after the start of incubation. Compt. Rend., 255:1784-1785.

3??. Murakami,A. & S. Kondo. 1963. Relative biological effectiveness of 14. I Mev neutrons in killing dormant silkworm eggs. Ann. Rep. Nat. Inst. Genet., 14:106-107.

324. Strunnikov, V.A. 1960. The relative effect of primary radiation injuries to the nucleus and cytoplasm of sex cells of the silkworm. JPRS-7884, Tsitologiya, 2: 114-126.

325. Myburgh, A.C. 1963. Lethal and sterilizing effects of cobalt-60 gamma rays on Argyroploce leucothreta. Natl. Confr. Nuclear Energy. Applications of Isotopes and Rad. Pelindaba, S. Africa, pp. 514-525.

326. Ouye, M.T., R.S. Garcia & D.E. Martin. 1964. Determination of the optimum sterilizing dosage for pink bollworms treated as pupae with gamma radiation. J. Econ. Ent., 57:387-390.

327. Vasilyan, V.V. 1961. The effect of ionizing radiation upon the development of the mallow moth. Ent. Rev. (USSR) (Engl. Trans.), 39:42508.

328. Qureshi, Z.A. 1966. Effects of sub-lethal gamma radiation on the biology and behaviour of the angoumois grain moth, Sitotroga cerealella Oliver. Thesis, Kansas State Univ., 138 pp.

329. Rule, H.D., P.A. Godwin & W.E. Waters. 1965. Irradiation effects on spermatogenesis in the gypsy moth, Porthetria dispar (L.). J. Insect Physiol., II:369-378.

330. Andreer, S.V., Z.I. Samoilova & B.K. Martens. 1964. The potential application of gamma radiation for the sterilization of Chloridea obsoleta for the purpose of reducing its population. Radiologiya, 4:624-626.

331. Proverbs, M.D. & J.R. Newton. 1960. Could this be the death of the codling moth? Brit. Columbia Orchardist, I(4):13-16.

332. Whiting, A.R. 1950. Failure of pupation of Ephestia larvae following exposure to x rays. Paper presented at 47th Ann. Meeting Amer. Soc. Zool., Cleveland, Ohio.

333. Erdman, H.E. 1962. Effects of irradiation on the Mediterranean meal moth, Ephestia kuehniella Zeller, cultured on ^{89}Sr-spiked food. Intern. J. Rad. Biol., 5:331-338.

334. Mueller, I., E.A. Löbbecke & O. Oltmanns. 1962. Dose effect curve of somatic mutations in Ephestia kühniella Z. for low dose-range (o-200 r). Nature (Lond.), 194: 783-784.

335. Erdman, H.E. 1961. Arrested development in x rayed larvae of *Ephestia kuehniella* (Lepidoptera: Phycitinae). (HW-SA-2281) Contract AT (45-1)-1350, 8 pp.

336. Kritskii, G.A. & C. Chieivei. 1961. Nucleotide metabolism of *Galleria mellonella* L. caterpillars, normal and after x ray irradiation. Biochemistry, 26:224-227.

337. Piechowska, M.J. 1965. Effect of ionizing radiation on the endocrine system in insects. Bull. Acad. Polon. Sci.,Ser. Sci. Biol., 13:139-144.

338. Jacklin, S.W., F.F. Smith & A.L. Boswell. 1965. Egg mortality after gamma irradiation of adults of the omnivorous leaf roller. J. Econ. Ent., 58:1168-1169.

339. Jolly, P. & G. Biclimann, 1958. Effects of irradiation on *Locusta migratoria* L. Compt. Rend., 247:243-246.

340. Larson, W. 1963. Survival of isolated insect tissues following radiation. Ann. Ent. Soc. Amer., 56:720-721.

341. Nishita, H., E.M. Romney & K.H. Larson. 1965. Uptake of radioactive fission products by plants. In, E.B. Fowler (ed.), Radioactive Fallout, Soils, Plants, Foods, Man. Elsevier, N.Y., pp. 55-81.

342. Miller, C.F. 1963. Fallout nuclide solubility, foliage contamination, and plant part uptake contour ratios. S.R.I. Project No. IMU-4021, 30 pp.

343. Miller, C.F. 1965. Fallout models and radiological countermeasure evaluations. S.R.I. Project No. MU-5116, 15 pp.

344. Wong, P.W. 1967. Initial study of effects of fallout on simple selected ecosystems. OCD Work Unit 3145A, 43 pp.

345. Teresi, J.D. & C.L. Newcomb. 1966. An estimate of the effects of fallout beta radiation on insects and associated invertebrates. OCD Work Unit No. 3145A, USNRDL-TR-932, iv + 86 pp.

346. Rhoads, W.A., R.B. Platt, R.A. Harvey & E.M. Romney. 1969. Ecological and environmental effects from local fallout from Cabriolet. I. Radiation doses and short-term effects on the vegetation from close-in fallout. Project CEP-67.3 Under Contrack No. AT(29-1)-1183. In Press, Cleared Security, 1969. 60 pp.

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	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

INSECT PESTS OF MAJOR FOOD CROPS, THEIR REINVASION POTENTIAL AND THE EFFECTS OF RADIATION ON ARTHROPODS

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

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1969	198	346

8a. CONTRACT OR GRANT NO. N0022868C0157 b. PROJECT NO. OCD Work Unit No. 3145B 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

Distribution of this document is unlimited.

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

13. ABSTRACT

A literature survey of the major insect and mite pests attacking important food, forage and oil crops was compiled. It was impossible to obtain sufficient data to rely solely on widescale pesticide applications to construct models which would give predicted rates of insect recolonization into an area from which they might be theoretically eliminated by radioactive fallout. Other types of empirical data were used to construct indices of insect reinvasion into an area from which the pest species had been previously eliminated. These were largely based on published data and relate to the nature of the class Insecta, its excellent mobile and high reproductive capacities, and the biology and ecology of each pest species.

The data strongly indicate that the elapsed time for recolonization after theoretical elimination due to fallout will be quite short for many pest species. Thus, insects can be expected to be major competitors with man for food, forage and oil crops following a possible nuclear disaster. There are essentially no data to indicate whether radiation may differentially affect pest species in comparison to their natural enemies (i.e. insect predators and parasites). There are only a few references relating to the effects of beta particles on insects. Effects of gamma and X-radiation were analyzed and clearly show that most arthropods are highly resistant to radiation. Included are citations of 346 published papers as they specifically relate to this report.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Arthropod Pests						
Food, Forage and Oil Crops						
Severity of Pests						
Economic Threshold						
Dispersal and Migration						
Reinvasion Potential						
Nuclear Attack						
Pesticides Vs. Fallout						
Radiation Effects on Arthropods						
Radiation Effects on Crops						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

UNCLASSIFIED
Security Classification