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Inherited sterility induced by gamma radiation in a laboratory population of Ostrinia nubilalis (Hübner)

Raymond A. Nabors

To the Graduate Council:

I am submitting herewith a thesis written by Raymond A. Nabors entitled "Inherited sterility induced by gamma radiation in a laboratory population of Ostrinia nubilalis (Hübner)." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Biology.

Charles D. Pless, Major Professor

We have read this thesis and recommend its acceptance:

Lyle E. Klostermeyer, Edward E. Burgess

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Accepted for the Council:

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Vice Chancellor
Graduate Studies and Research

INHERITED STERILITY INDUCED BY GAMMA RADIATION IN A LABORATORY POPULATION OF *OSTRINIA NUBILALIS* (HÜBNER)

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Raymond A. Nabors

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I am grateful to my wife, Janet. Without her constant encouragement this thesis could not have been completed.

ABSTRACT

Male European corn borer pupae were exposed to a substerilizing dose of gamma radiation. Treated males were as successful as nonirradiated males in spermatophore transfer and production of offspring when allowed to mate with nonirradiated females. The progeny of irradiated males inherited sterility and produced no offspring when allowed to mate with normal corn borers.

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CHAPTER I

INTRODUCTION

The European corn borer, *Ostrinia nubilalis* (Hübner), was accidentally introduced into Boston, Massachusetts, about 1910 and was detected by Vinal (1917). Vinal believed the borer arrived in shipments of hemp to a Boston cordage company. He observed tunneling in barnyard grass, pigweed, foxtail, and dahlias but stated that corn was the preferred host. Today the European corn borer is found in forty states from the Canadian boarder to North Florida and from the Atlantic seaboard to the Eastern most counties of Montana, Wyoming, Colorado, and Texas. It is most abundant in Iowa, Nebraska, Minnesota and Missouri (USDA 1977). The host range of the corn borer includes more than two hundred species of herbaceous plants. Losses to U. S. corn crops from 1968 to 1974 have been estimated as high as $210,000,000.00 annually (Burkhardt 1978).

The life history of the European corn borer was reviewed by Bradley (1952). *O. nubilalis* passes the winter as a diapaused larva. Pupation and eclosion occur in the spring. In the North there is one generation per year. As far south as South Carolina there are three complete generations per year (Durant 1969). Female moths lay their eggs in masses on the underside of the corn leaf. After hatching, the larvae feed on the leaf surface before tunneling into the stalk. When cornstalks are heavily infested, lodging often occurs, resulting in a poor harvest.

Current effective control measures include cultural and chemical practices. Fall plowing is of value if all weeds and stubble can be completely buried to prevent moth emergence. Resistant varieties of corn have been developed for the corn belt states (Guthrie et al. 1960). Planting early can reduce damage because the more mature corn can better tolerate infestation. The effectiveness of cultural control is sometimes erratic. Systemic soil insecticides have proven to be useful for borer control on field corn. Foliar applied insecticides require good coverage and proper timing so larvae will be killed before they can enter the stalks.

In recent years the use of insecticides has come under attack for several reasons. First, insects have been known to develop resistance to insecticides. Secondly, there are environmental concerns over the effects of chemical pesticides on wildlife and residues in water, food and air. Total dependence on any single method of control should be avoided. It is desirable that alternative methods of pest control be developed.

One alternative method is the release of sterile male insects into the field to suppress a population of pest insects. This method is host specific and nonpolluting. The technique is also compatible with other control measures. Some success has been achieved using radiation as a sterilizing agent for lepidopterous insects (North 1975). Lepidopterans require relatively large doses (16,000 to 50,000 rads) of radiation to induce sterility (LaChance et al. 1967). Mating competitiveness and longevity are adversely affected with such large doses of radiation. A more competitive moth is obtained when the dose of radiation is substerilizing. The treated individuals produce offspring, but these offspring are nearly or completely sterile. This phenomenon is known as inherited sterility or F_1 sterility. Because the chromosomes of lepidopterans are holocentric rather than monocentric the effects of substerilizing doses of radiation are not apparent in the treated generation but are manifested in their progeny.

The effects of gamma radiation are pronounced in the reproductive cells of insects for the same reason human malignant carcinomas are more susceptible to radiation damage than normal tissues. Rapidly dividing cells are more easily damaged by radiation energy than are more slowly dividing cells. When a holocentric chromosome is present, radiation damage is passed on to the progeny if less than a sterilizing dose is given to the parent.

This thesis will describe experiments with the phenomenon of inherited sterility using a laboratory colony of the European corn borer. The feasibility of releasing irradiated males to suppress a feral population of corn borers will be discussed.

CHAPTER II

LITERATURE REVIEW

Experiments of Bushland and Hopkins (1951) introduced a new concept of insect control. They tested the screwworm, *Cochliomyia hominivorax*, as the first candidate for control by the release of radiation sterilized male screwworm flies. In 1955 Baumhover et al. published a report on the eradication of the screwworm from Curacao Island. Knipling (1955) explained how sterile male release causes a population decline and postulated that eradication would occur in four generations. The technique was successfully applied to the screwworm on the Florida peninsula (Baumhover et al. 1959). The screwworm population has been suppressed in Texas with sterile male releases (Hightower et al. 1965). Successful suppression and eradication of the screwworm has fostered interest in sterile male release for control of other economically important insects. The evolution of sterile male release for control of lepidopterous insects will be reviewed in the following paragraphs.

Laspeyresia pomonella (Linnaeus)

The first attempt at sterile male release for control of a lepidopterous insect was made with the codling moth. Proverbs and Newton (1962) found that the release of radiation sterilized males could reduce the reproductive potential of that insect. They noted that males given a dose of 40,000 rads were not as competitive as normal males. A release ration of 20:1 sterile males to normal males was suggested as a way to overcome the lack of competitiveness in sterilized males. In 1964 and 1965 the release of sterile males reduced apples injured from 60% to 1.6% and .3% respectively (Proverbs et al. 1967). In 1964 271,000 moths were released into a 2 hectare isolated orchard. In 1965 478,000 moths were released. Release ratios were estimated to be 20:1 in 1964 and 45:1 in 1965.

The codling moth was controlled between 1966 and 1968 in a commercial apple orchard by releasing radiation sterilized males (Proverbs et al. 1969). The technique was employed in British Columbia in combination with timed chemical sprays (Proverbs et al. 1977). Keeping moth populations below the economic threshold (1% of the apples injured) with sterile male release requires too many sterile moths for this technique to be economically competitive with current chemical methods (Proverbs et al. 1977).

Heliothis zea (Boddie)

An attempt to eradicate the corn earworm from St. Croix Island was reported by Snow et al. (1971). Moths of both sexes were treated with 33,000 rads the morning after eclosion. The ratio of treated males to feral males was maintained above 20:1. *H. zea* was kept under control but not eradicated from St. Croix. Snow et al. (1971) found that 60% of the mating pairs failed to separate after copulation. North et al. (1975) found that radiosterilized males of *H. zea* had sperm of poor quality. The poor quality of sperm evidently resulted in remating of female moths.

Ephestia cautella (Walker)

Cogburn et al. (1973) irradiated all metamorphic stages of the almond moth with doses between 5,000 and 100,000 rads. Eggs and larvae did not develop when treated with 30,000 and 20,000 rads respectively. Adults which emerged from treated pupae had a shorter lifespan than those which emerged from untreated pupae. Adult females were sterilized with 30,000 rads. Males required 100,000 rads to induce complete sterility. Irradiated adults paired with untreated adults produced fewer eggs than pairs of untreated moths. Progeny of irradiated adults inherited genetic damage which affected their reproductive ability.

In 1977, Amoako-Atta and Mills reported that doses of 10,000 or 20,000 rads did not significantly affect the mating frequency of male *E. cautella* whereas a dose of 30,000 rads did reduce their mating frequency. Increasing doses of radiation accentuated the reduction in male reproductive potential.

Diatrea saccharalis (Fabricius)

During irradiation experiments with male and female sugarcane borers Walker and Quintana (1968) found that parents given a less than sterilizing dose of radiation could produce sterile offspring. Population models for suppression of the sugarcane borer were proposed by Walker and Pederson (1969). They concluded that the release of males treated with a substerilizing dose of radiation might be a more effective control measure than sterile male release. Substerile males could give the maximum effect with the minimum effort and expense. They pointed out in their models that the release of males treated with a substerilizing dose of radiation would become relatively more effective than sterile male release as the natural population increased.

Pectinophora gossypiella (Saunders)

Ouye et al. (1964) reported that 55,000 rads was the sterilization dose for 7 day old male pupae of the pink bollworm. They determined that 40,000 rads would sterilize female pupae of the same age. They observed less than 3% egg hatch when the parents were treated with 30,000 rads. Richmond and Graham (1970) found that moths treated with 25,000 rads were as effective in reducing the population as moths treated with 40,000 rads. The moths treated with 25,000 rads were more competitive and therefore could better suppress a field population. Adults which developed from eggs produced by treated moths were sterile. Because of the high rate of population increase in the F_2 generation following the release of irradiated moths, Richmond and Graham (1970) suggested the need for continuous releases of treated insects throughout the season. The release ratio used by Richmond and Graham (1970) was 50:1.

Cheng and North (1972) found that male pink bollworms treated with 20,000 rads and paired with normal females produced four male progeny for every female. The F_1 males were not competitive. Caged females irradiated with 25,000 rads were as attractive to native males as caged unirradiated females in field tests (Flint et al. 1973). Females receiving 30,000 rads mated as frequently as nontreated females. Sperm transfer was reduced by 30% when untreated males mated with treated females instead of untreated females. The longevity of moths treated with 25,000 rads was not significantly different from unirradiated moths.

LaChance et al. (1978) found no significant difference in the frequency of mating between male moths given 20,000 rads and nonirradiated moths. The amount of sperm and proportion of abnormal sperm transferred were significantly different. Fewer sperm bundles matured in the testes of radiation-treated males than in the testes of untreated males (LaChance et al. 1979).

Plodia interpunctella (Hübner)

The life span of radiation treated adults or pupae of the Indian-meal moth was not significantly shortened after exposures of 13,000; 17,000; 25,000; 45,000; and 100,000 rads (Cogburn et al. 1966). There was a significant reduction in progeny produced by treated pairs, which varied inversely with the dose of radiation. Genetic damage, as evidenced by reduced reproduction, was transmitted to the F_1 generation. Treated males suffered less damage than females treated with the same dose. The progeny of treated males, however, had a lower reproduction rate than the progeny of treated females.

Ashrafi et al. (1972) irradiated fifth instars of *P. interpunctella* with 3,500 rads. This treatment caused a 72% reduction in the F_1 generation. When F_1 males of the treated line were mated with normal females there was an 82% reduction in the F_2 generation. Males treated with 3,500 rads as fifth instars were found to be competitive with normal males.

Irradiation of newly eclosed adults resulted in rupture of sperm bundles, and flagellar abnormalities were inherited more intensely by the progeny of treated males than treated females (Ashrafi and Roppel 1973). Brower (1978) found that males and females given 35,000 rads (a substerilizing dose) were more competitive than moths given 50,000 rads (a sterilizing dose). He found the irradiated females to be fully competitive but the males were less than fully competitive.

Heliothis virescens (Fabricius)

Flint and Kressin (1967) reported 99% sterility among male tobacco budworm pupae given 35,000 rads of gamma radiation. Females from pupae given this same dose produced few viable eggs. The emergence and the longevity of the moths was reduced. Flint and Kressin (1968) stated that treated females were as competitive as untreated females. Treated males were found to be less competitive than untreated males. An untreated female allowed to mate with a treated male and then an untreated male was fertile in 50% of the cases. When females mated first with untreated males then subsequent matings with treated males had no effect on fecundity. Males treated with 35,000 rads failed to transfer sperm in 50% of their matings whereas untreated males failed to transfer sperm in 20% of their matings (Flint and Kressin 1969).

Proshold and Bartell (1970) demonstrated inherited sterility in *H. virescens*. When P_1 males were given a dose of 15,000 rads, one-third of their F_1 male progeny failed to mate. Of those which mated, one-half failed to transfer sperm. Female progeny of treated males mated as often as untreated females but their fecundity was greatly reduced. A delay in development time and a skewed sex ratio (2 males: 1 female) were noted. The treated males were more competitive than their progeny. Proshold and Bartell (1972) reported that the fertility of F_1 males and F_1 females was less than 5% and 10% respectively. They noted 20% fertility in the F_2 generation and a return of normal fertility levels in the F_3 generation.

Trichoplusia ni (Hübner)

When normal female cabbage loopers were allowed to mate with males treated with 20,000 rads, 15-20% of their eggs hatched (North and Holt 1968). The progeny of these crosses were sterile when mated with untreated moths of the opposite sex. The sterility inherited by the F_1 generation was attributed to the induction of large numbers of reciprocal chromosome translocations. The frequency of induced translocations was said to probably result from the holocentric chromosome structure (North and Holt 1968). The release of males given a substerilizing dose of radiation is advantageous because they are competitive with feral moths (North and Holt 1969). Since the progeny of treated males were sterile, it was projected that 92% control could be obtained over 3 generations.

Galleria mellonella (Linnaeus)

Nielsen (1976) irradiated all four metamorphic stages of the greater wax moth with sterilizing and various substerilizing doses of gamma radiation. He found that males given a sterilizing dose were not competitive with untreated males. Reproduction was more adversely affected when the offspring of irradiated moths were allowed to mate with untreated moths. He concluded that the release of moths given a substerilizing dose of radiation might suppress a population of wax moths sufficiently to avoid economic damage by wax moth larvae. In a theoretical appraisal Nielsen (1976) used a 5:1 ratio of radiated males to feral males. This low ratio would be more economic than the 20+:1 ratio that has been employed with most sterile male release programs involving lepidopterous insects.

Ostrinia nubilalis (Hübner)

Experiments with radiation control of the European corn borer were begun by Walker and Brindley (1963). They treated 1-day-old male moths with 32,000 rads of x-rays. The treated males mated with untreated females and 1% of the resulting eggs hatched. They observed competitiveness by caging 8 treated males with 4 untreated males and 8 untreated females. The percent of eggs which hatched was 39.4% of that of the control. Walker and Brindley (1963) also irradiated pupae and noted a significant reduction in egg hatch which varied inversely with the dose. Female pupae were found to be more radiosensitive than male pupae.

Raun et al. (1967) irradiated diapausing and nondiapausing larvae of *O. nubilalis* with 4,000 and 5,000 rads of gamma radiation. They found that nondiapausing larvae suffered too much radiation damage for use in a sterile male release program. The number of eggs laid and the number which hatched were significantly different from the numbers produced by nonirradiated insects. There was a 63% emergence following treatments of 5,000 rads (Anwar 1968). There fertility level was 12%

and their lifespan was reduced. Anwar (1968) concluded that it would be advantageous to release both irradiated male and female moths.

Nagy (1971) discussed the release of sterile males for control of the European corn borer. His population estimate for Hungary was 1,000 moths per ha of corn during the spring moth flight. He recommended releasing sterile moths at a ratio greater than 20:1 over a short period of time during May, June and July when the first (spring) moth flight occurs. He noted that relatively few release sites might be needed because the moths are strong fliers.

From the results cited in this review the following conclusions can be drawn. The easily handled pupal stage has fewer radiation induced deformities after eclosion than does the egg or larval stages. Also, female pupae are more radiosensitive than male pupae. The lifespan and competitiveness of male moths is improved with a substerilizing dose of radiation instead of a sterilizing dose. The release ratio could, therefore, be reduced if control by inherited sterility were the goal. The males could pass viable sperm to feral females. These females could then produce a generation of sterile moths.

CHAPTER III

MATERIALS AND METHODS

Rearing

European corn borer egg masses were obtained from the Corn Insects Research Lab of the United States Department of Agriculture in Ankeny, Iowa, to start a colony of corn borers at The University of Tennessee, Knoxville. The rearing method was modified from the technique described by Raun (1966). The egg masses, which had been laid onto wax paper, were placed in plastic dishes containing moist toweling. Upon hatching, two neonatal larvae were transferred to 5 cm plastic petri dishes containing ca 10 ml of diet, which was sufficient for both larvae to complete development. The Custom Southwestern Corn Borer Diet (Table I), as formulated by Bio-Serv® Inc. and prepared according to their direction, was used. A sterile cotton cord was pressed between the lid and base of the dish to prevent escape of young larvae.

Pupae were removed from the diet and sexed using the technique described by Villard (1975). Female pupae are distinguished by the notch on the fourth ventral sternite caudad from the wing pads (Fig. 1). Pupae were separated by sex and placed on moistened cotton in 1 liter plastic screw cap containers until adults emerged. On the morning following emergence two males and two females were placed into each oviposition cage.

Oviposition cages (Fig. 2) were constructed of 3mm (1/8 inch) hardware cloth formed into cylinders, 30 cm in diameter and 30 cm

TABLE I

COMPOSITION OF CUSTOM SOUTHWESTERN CORN BORER DIET

	gms/L
Agar	17.2
Wheat Germ	21.1
Casein, Vitamin Free	25.0
Sucrose	25.0
Salt Mixture Wesson	7.0
Linseed Oil	0.2
Cholesterol	0.1
Corn Cob Grits	37.0
Methyl Para-hydroxybenzoate	1.5
Sorbic Acid	0.5
Vanderzant Vitamin Mixture	5.3
Ascorbic Acid	2.1

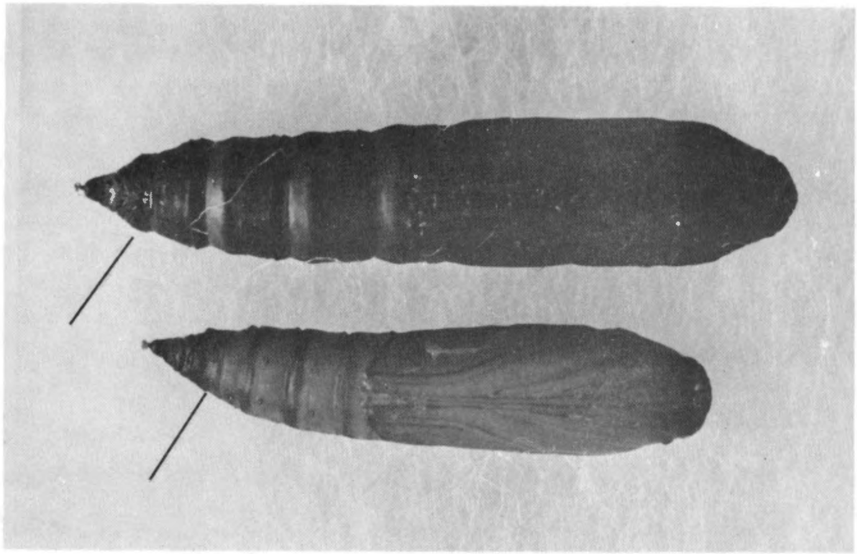

Figure 1. European corn borer pupae: female with notch on the fourth ventral sternite (top), male without notch (bottom).

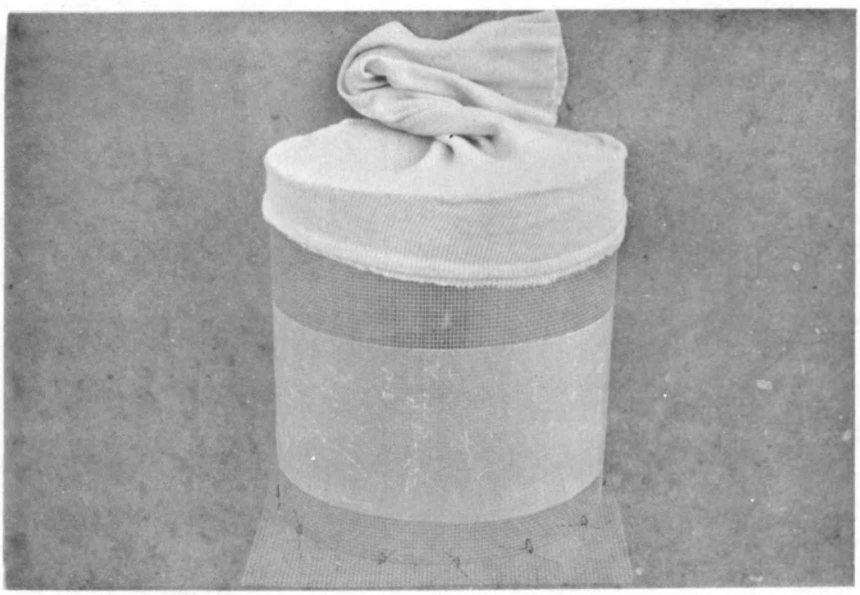

Figure 2. Oviposition cage for European corn borer with wax paper for oviposition sites.

long. A flat sheet of hardware cloth was wired to one end. The other end was closed with 20 cm (8 inch) orthopedic stockinette, 1 meter in length. The outside of the cylinder was covered by wax paper to serve as oviposition sites. Moist cotton provided a source of water for the adults.

All life stages were held under the following conditions. The temperature was maintained at 21° ± 2° C. A 68 liter capacity humidifier was operated continuously to maintain a relative humidity of 75% ± 10%. The colony was maintained on a 16 hour photophase. This photoperiod was used to discourage larval diapause (Beck 1962). Adults were active during the 8 hour scotophase.

Treatments

Radiation treatments were administered to male pupae at the Oak Ridge National Laboratories. Pupae between 7 and 9 days old received a dose of 15,000 rads from a cobalt 60 source emitting 111 rads per minute. Pupae were transported and irradiated in plastic petri dishes. Moist cotton cushioned the pupae and maintained a high humidity. Adults were assigned to treatments as follows:

(1) Nonirradiated males × Nonirradiated females;

(2) Radiated males × Normal females;

(3) Nonirradiated males × F_1 females (progeny of treatment 2); and

(4) F_1 males (progeny of treatment 2) × Nonirradiated females.

Each treatment was replicated 10 times. Replicates consisted of 2 adult males and 2 adult females per cage.

The wax paper was removed from the cages and eggs were counted daily. One hundred eggs from each cage in treatments 1 and 2 and all eggs from treatments 3 and 4 were dipped for 1 sec in an aqueous 1:20 dilution of chlorine bleach to prevent bacterial growth. The number of eggs that hatched was recorded. Fifty newly hatched larvae from each replicate were placed on diet. When less than fifty larvae were produced in a replicate all larvae were placed on diet. The number of larvae to pupate was recorded for each replicate. All pupae from each treatment were separated by sex and the number of adults that emerged was recorded. To determine if the two females in each replicate had successfully mated, the bursa copulatrix was removed and examined for the presence of spermatophores (Fig. 3).

Data were analyzed using analysis of variance. Data recorded as percentages were transformed using an Arcsine transformation prior to analysis. Means were compared using Duncan's multiple range test.

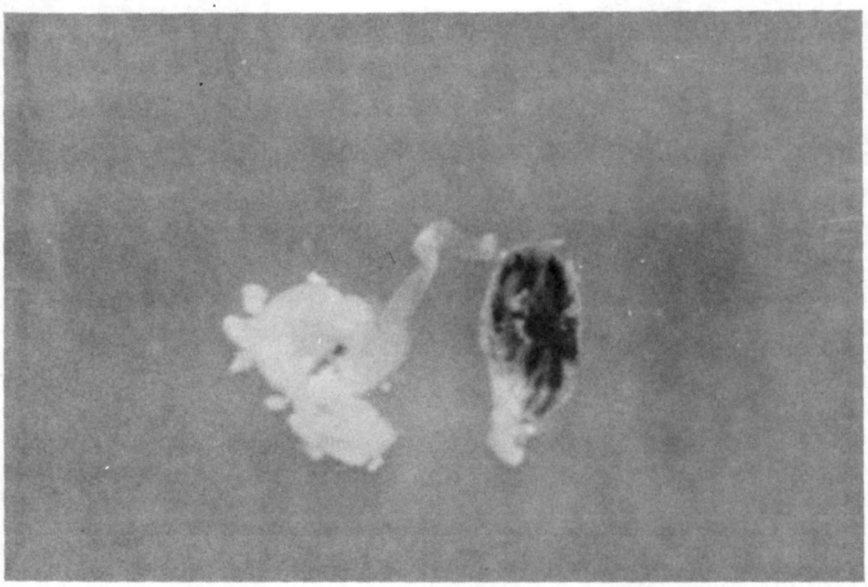

Figure 3. European corn borer bursa copulatrix with spermatophore (right), without spermatophore (left).

CHAPTER IV

RESULTS

Ionizing radiation delivered to male pupae of the European corn borer had an adverse effect on the reproductive ability of their progeny. When progeny of irradiated males were crossed with nonirradiated females, the resulting loss of fecundity was significant ($P \leq 0.01$). The first measure of fecundity was derived from the number of eggs laid (Table II). Females which were allowed to mate with treated males (cross 2) produced the largest number of eggs. The mean number of eggs from matings of nonirradiated moths (cross 1) was not significantly different from the mean number of eggs from cross 2. The mean number of eggs per female dropped significantly when progeny of irradiated males (crosses 3 and 4) were involved. The number of eggs from female progeny of irradiated males (cross 3) was not significantly different from the number of eggs produced by females which were allowed to mate with male progeny of irradiated males (cross 4).

Egg masses of crosses 1 and 2 contained a significantly larger number of eggs than egg masses of crosses 3 and 4 (Table II). Male progeny of irradiated males allowed to mate with nonirradiated females (cross 4) did not produce any viable eggs (Table II). Only 2.9% of the eggs from cross 3 hatched. The control (cross 1) and treated parent (cross 2) matings had a significantly larger percent of eggs hatch than cross 3 or cross 4. Seventy-five percent of the eggs from crosses 1 and 2 hatched. Of the 1,758 eggs taken from all replicates of cross 3,

TABLE II

FECUNDITY OF FEMALES IN FOUR CROSSES OF IRRADIATED AND NONIRRADIATED EUROPEAN CORN BORERS

Cross	Eggs/♀	Eggs/Mass	% Hatch	# Eggs Observed
1. (nonirradiated moths)	245.6a*	13.6a	74.4a	1,000
2. (♂♂ irradiated with 15,000 rads × non-irradiated ♀♀)	268.6a	15.7a	76.1a	1,000
3. (♀ progeny of cross 2 × nonirradiated ♂♂)	87.9b	6.9b	2.9b	1,758
4. (♂ progeny of cross 2 × nonirradiated ♀♀)	56.1b	5.2b	0.0b	1,121

*Any two means followed by the same letter are not significantly different ($P \leq 0.01$, Duncan's New Multiple Range Test).

only 51 hatched. Sixty percent of the offspring from crosses 1 and 2 completed their development from egg to adult (Fig. 4). Eight individuals from cross 3 completed their development.

The reduced fecundity presented in crosses 3 and 4 could have been caused by inherited sterility and the inability of F_1 treated moths to successfully transfer a spermatophore. Upon dissection, each female moth from crosses 1 and 2 contained at least one spermatophore in the bursa copulatrix (Fig. 5). The progeny of irradiated males (crosses 3 and 4) were able to transfer a spermatophore in only 60% of the cases.

There was little direct affect of the radiation treatment on the treated males. Some deformities in the form of wrinkled wings were present in the F_1 treated moths.

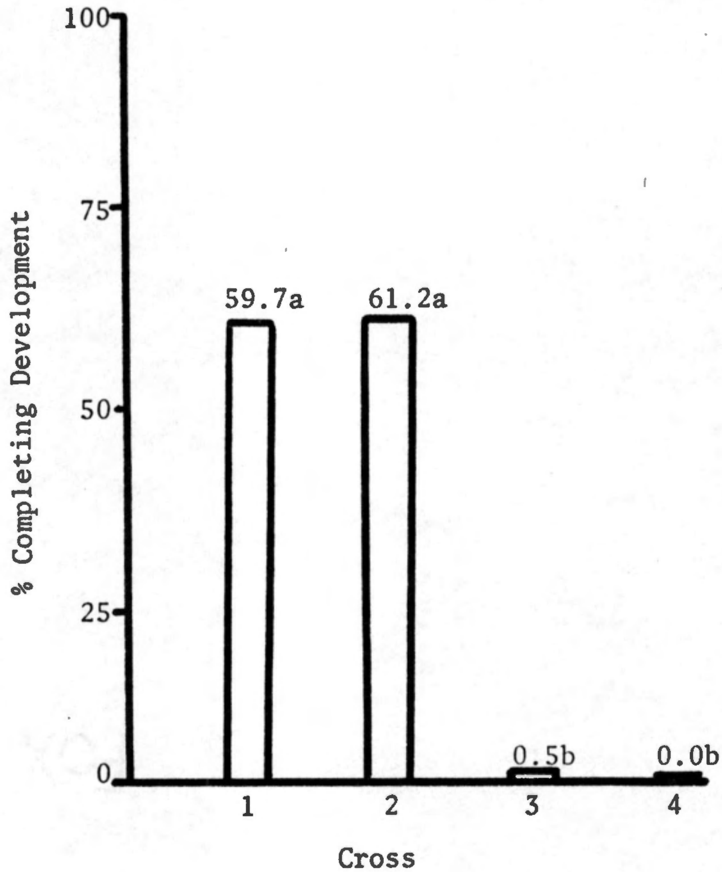

Figure 4. Development success (egg to adult) of European corn borers from 4 crosses.

Crosses: (1) nonirradiated moths,
(2) males given 15,000 rads × nonirradiated females,
(3) nonirradiated males × female progeny of cross 2,
(4) male progeny of cross 2 × nonirradiated females.

Any two means followed by the same letter are not significantly different ($P \leq 0.01$, Duncan's New Multiple Range Test).

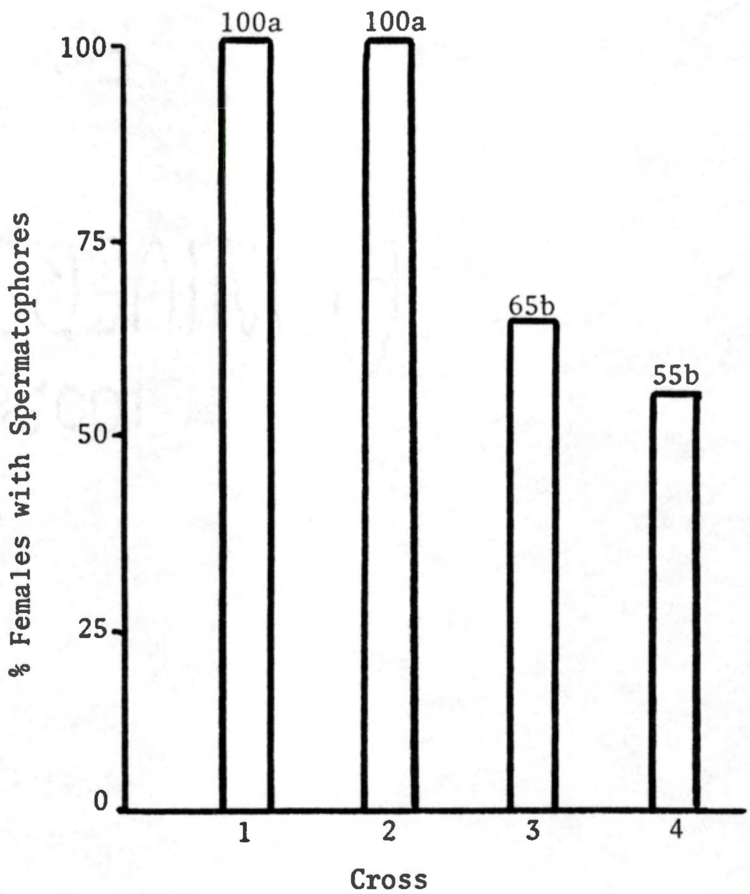

Figure 5. Percentage of European corn borer females from 4 crosses containing a spermatophore in the bursa copulatrix.

Crosses: (1) nonirradiated moths,
(2) males given 15,000 rads × nonirradiated females,
(3) nonirradiated males × female progeny of cross 2,
(4) male progeny of cross 2 × nonirradiated females.

Any two means followed by the same letter are not significantly different ($P \leq 0.01$, Duncan's New Multiple Range Test).

CHAPTER V

DISCUSSION

Ostrinia nubilalis is one of the most destructive insect pests of agriculture. It is difficult to control even with insecticides and cultural practices. Inherited sterility is expressed in the corn borer and a laboratory population can be eradicated using substerile male release. Population suppression of feral corn borers with release of radiation treated moths is a possibility.

There are many advantages to substerile moth release and many disadvantages as well. The effect of substerile moth release does not become apparent until the third generation following release. On the other hand, it is possible that a mass release of substerile moths could control the pest population for an entire season. Substerile moth release is host specific, which is a disadvantage if a complex of pests if involved. On the other hand, nontarget organisms such as wildlife, beneficial insects, and people are not harmed. There is no undesirable residue left on food, water, or soil when substerile moth release is employed.

The overwhelming problem with substerile moth release is one of expense. It is conceivable that the price of control might outweigh the benefits derived. In order for substerile moth release to work there must be more treated moths released than exist in the feral population. The price of a corn borer moth reared in the U.S.D.A. Corn Borer Laboratory is ca $0.01 (Guthrie 1980). Nagy (1971) estimated the feral population of the European corn borer in Hungary to be 1,000 moths per hectare of corn during the spring moth flight. Assuming that the population estimate for Tennessee is similar, there are about 352,000 hectares of corn in the State (Burgess 1980). Therefore there would be about 352,000,000 moths in the spring flight. Assuming that the sex ratio of the feral and laboratory moths is 1:1 and that both sexes would be released, a 10:1 release ratio would utilize 3,520,000,000 radiation treated moths at a cost of $35,200,000.

The cost of substerile moth release is prohibitive when used alone. It might be advantageous if an insecticide application could be integrated with substerile moth release. In Table III a chemical spray used to kill 90% of the spring moths is compared to a 10:1 ratio of released substerile moths alone and the two techniques in combination. The use of an insecticide is most economic when the pest population is high. The use of substerile moth release becomes more economic as the pest population decreases. If the spring moth flight were reduced to 100 moths per hectare of corn then 1,000 moths released per hectare of corn would give a 10:1 ratio. The cost of moths released would be reduced from $35,200,000 for substerile moth release alone to $3,520,000 for the combination of techniques.

A further cost benefit might result after the first winter following the initiation of a substerile moth release program. If 125,000 overwintering larvae per hectare of corn yield 1,000 moths in the spring, then 12.5 overwintering larvae per hectare of corn could yield an average of 0.1 moths in the spring. One-tenth moth per hectare

TABLE III

THEORETICAL SEASONAL EFFECTS OF FOUR POPULATION SUPPRESSION TECHNIQUES ON AN ORIGINAL POPULATION OF 1,000 FERAL EUROPEAN CORN BORER MOTHS[a]

Generation	Feral Population Untreated	Substerile Release 10:1 Ratio	One Chemical Spray (90% Kill)	One Chemical Spray + Substerile Moth Release
P (before treatment)	1,000	1,000	1,000	1,000
(after treatment)	1,000	11,000	100	1,100
F_1	5,000	55,000[b]	500	5,500[c]
F_2	25,000	25	2,500	2.5
F_3	125,000	125	12,500	12.5

[a]Assumptions:
(1) a 5 fold increase in population per generation,
(2) the effects of radiation are lost in the F_2 generation,
(3) the ratio of sterile to fertile moths in the F_1 generation is 109:1,
(4) all moths are equally competitive,
(5) the sex ratio is 1:1.

[b]54,500 of these moths are sterile,

[c]5,450 of these moths are sterile.

would require the release of only 1 moth per hectare of corn at a cost of of $3,520.

Substerile moth release could be economical when the pest population density is low. The two means of control, insecticides and substerile moth release, compliment one another well. Insecticides could be used to control the pest population during severe outbreaks while substerile moth release would keep the population in check between insecticide applications. In the future, more efficient insect pest management could result from the integration of these techniques.

CHAPTER VI

SUMMARY

Radiation treatments of 15,000 rads were administered to male European corn borer pupae at the Oak Ridge National Laboratories. Comparisons of fecundity and progeny survival were made of females in 4 crosses:

(1) Nonirradiated males × Nonirradiated females;

(2) Irradiated males × Nonirradiated females;

(3) Nonirradiated males × F_1 females (progeny of treatment 2);

(4) F_1 males (progeny of treatment 2) × Nonirradiated females.

Ionizing radiation delivered to male pupae of the European corn borer had an adverse effect on the reproductive ability of their progeny. The F_1 progeny of irradiated male corn borers allowed to mate with nonirradiated moths of the opposite sex produced fewer eggs than their parents or crosses between nonirradiated moths. Very few eggs (2.9%) hatched when one of the parents was the offspring of an irradiated male. Eight progeny (.05%) of cross 3 females completed their development. The progeny of irradiated males were less likely to transfer a spermatophore than progeny of nonirradiated moths. The effect of radiation on the treated males was not apparent. Some deformities in the form of wrinkled wings were present in the progeny of treated moths. Inherited sterility is expressed in the corn borer and a laboratory population can be eradicated using substerile male release.

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VITA

Raymond A. Nabors was born on September 20, 1948, in Memphis, Tennessee. He attended Holy Rosary Elementary School and graduated from Christian Brothers High School of Memphis in 1966. He attended The University of Tennessee in Memphis and received a Certificate of Registration as an x-ray technologist in May of 1969. On February 2, 1970 he entered the United States Navy. On February 6, 1971 he married Janet Faye Scherer of Portageville, Missouri. He attended Florida Junior College in Jacksonville and received an Associate in Arts in May of 1974. Rachel Elizabeth Nabors, his first child, was born on June 16, 1974. Justin Scherer Nabors, his second child, was born on December 16, 1975. Raymond A. Nabors was honorably discharged from the United States Navy on January 15, 1976. He completed his Bachelor of Science degree at The University of Tennessee at Martin where he graduated with honors in May of 1978. He entered The University of Tennessee at Knoxville in June of 1978 and was awarded a graduate research assistantship in the Department of Entomology and Plant Pathology. He was elected to membership in Gamma Sigma Delta on May 7, 1980. On May 14, 1980 he was awarded the Chancellor's Citation for Extraordinary Academic Achievement. He received his Master of Science degree on June 10, 1980. He accepted a position as an extension entomologist for the University of Missouri Delta Center in Portageville, Missouri.