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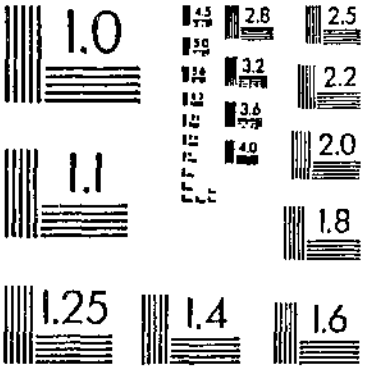

United States
Department of
Agriculture

Agricultural
Research
Service

Technical
Bulletin
No. 1684

Suppression and Management of Cabbage Looper Populations

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Suppression and Management of Cabbage Looper Populations

Abstract

Lingren, P.D., and G. L. Green, editors. 1984. Suppression and management of cabbage looper populations. U.S. Department of Agriculture, Technical Bulletin No. 1684, 152p.

This publication deals with a variety of factors important to the management and suppression of populations of cabbage looper, *Trichoplusia ni* (Hübner). Its primary purpose is to provide the reader with an overview of what is known concerning natural populations of the cabbage loopers and procedures or techniques that might be used to suppress populations. Special emphasis is given to the distribution and dispersal of natural populations in North America. The publication contains an updated bibliography of the pest and provides an analysis of research needs and problems associated with the development of more effective control procedures.

Key words: cabbage looper, population management and suppression, host plants, biology, ecology, behavior, dispersal, distribution, sampling, population dynamics, parasites and predators, microbial agents, chemical insecticides, host plant resistance, cultural control, attractants, sterilization, handling and shipment of live specimens, research needs, bibliography.

The year in italic, when it follows the author's name, refers to Literature Cited at the end of each chapter. Data presented in the references, figures, and tables are reproduced essentially as they were supplied by the author(s) of each chapter.

Preface

During the 1960's and early 1970's, government research agencies (Federal and State) applied a major research effort toward the development of better control procedures for the cabbage looper, *Trichoplusia ni* (Hübner). This effort resulted in several major research developments relevant to a basic understanding of insect behavior, population dynamics, and suppression procedures. One of the achievements strongly influenced the development of a new suppression procedure (confusion by sex pheromones) that is receiving considerable attention in today's insect control picture. Other results of this research effort are commonly being used in current and emerging control strategies.

This bulletin reviews much of the research that has been conducted on the cabbage looper with a special emphasis on results obtained during the 1960's and 70's that are relevant to population management and suppression. It also includes a great deal of previously unpublished information and philosophies of several authors relevant to an areawide suppression effort against the cabbage looper along the eastern seaboard. We hope that information presented will prove useful to scientists, producers, research managers, and students interested in entomology and related sciences.

This bulletin was originally intended for publication in 1976. This was not accomplished for reasons beyond our control. Therefore, each chapter (where relevant new information has evolved since 1975) has been either rewritten or an addendum attached covering information up to mid-1981. A bibliography is included, covering the period of 1969 to early 1975, which updates one published by Sutherland and Sutherland (*1972*). Many pertinent publications since 1975 are included in the literature citations associated with each chapter presented.

P.D. Lingren, U.S. Department of Agriculture (USDA), Agriculture Research Service (ARS), Western Cotton Research Laboratory, Phoenix, Ariz., and G. L. Green, Kansas Agricultural Experimental Station, Garden City, are primarily responsible for selection of senior authors and in coordinating the collation of this bulletin. Many scientists were involved in the research presented and reviewed herein, and their contributions are very significant and deeply appreciated; however, we must not overlook the leaders involved in any effort. Therefore, we dedicate this technical bulletin to three of the primary leaders of the research that was conducted on the cabbage looper during the 1960's and 70's: E. F. Knipling and T. J. Henneberry of USDA, ARS, and H. H. Shorey, University of California, Riverside.

Contents

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Part I. Natural Populations

Chapter 1. Cultivated and Wild Host Plants

By Douglas W. S. Sutherland[1] and G. L. Greene[2]

Abstract

The cabbage looper, *Trichoplusia ni* (Hübner), is listed as feeding on over 160 species of plants in 36 families. Cultivated crucifers are preferred. In addition, some 50 host species were checked for looper development in Florida. Twenty of these produced adults whereas 23 were not suitable hosts.

The cabbage looper, *Trichoplusia ni* (Hübner), has a diverse host range as is indicated by the species and family range of hosts. It has been reported on at least 160 species, varieties, or cultivars of plants in 36 families even though cultivated crucifers appear to be favored when available (Riley, *1881*, *1883*; Wene and Otey *1955*; Brett et al. *1958*; Genung *1960*; David *1960*). In greenhouses, many ornamentals and a few vegetables, such as lettuce, are attacked during late fall and winter (Sirrine *1897*; Britton *1910*; Smith et al. *1952*). Weeds have only been shown to be important hosts of the cabbage looper in the southwestern United States (McKinney *1944*) and in Israel (Avidov and Harpaz *1969*).

A number of authors have evaluated cabbage varieties and other crucifers for resistance to the cabbage looper. Harrison and Brubaker (*1943*) concluded that no crucifer cultivar was resistant to attack and that differences were due to the amount of foliage, stage of maturity, height, and general physical condition of the plant. Harcourt (*1954*) stated that a red cabbage (Red Acre) was preferred by *T. ni* to nine other green varieties. Chalfant and Brett (*1967*) showed that Mammoth Red Rock cabbage consistently had higher numbers of *T. ni* eggs and young larvae than other cabbage varieties, but fewer older larvae survived and less damage resulted. Wolfenbarger (*1967*) listed four resistant and five susceptible cabbage varieties, based upon the mean feeding scars per leaf made by *T. ni*.

Nonpreference was considered the primary resistance mechanism among the cabbage varieties tested against the cabbage looper by Radcliffe and Chapman (*1966a*). Chinese cabbage, mustard, rutabaga, and turnip were the most resistant to oviposition by *T. ni* and of the 43 crucifer varieties representing 11 Brassica crops [Radcliffe and Chapman (*1966b*)]. In field-cage studies, Boling and Pitre (*1971*) found *T. ni* preferred collards and cotton to broccoli, cabbage, and cauliflower for oviposition. Greene (*1970*) tested 14 crucifer varieties under medium to high looper population densities and found egg and larval numbers were similar on the reported resistant and preferred varieties at high population densities in the field.

Elsey and Rabb (*1967*) determined that the density and gumminess of trichomes on tobacco leaves reduced the survival of early instar cabbage loopers. Radcliffe and Chapman (*1966b*) suspected that the hairiness of the leaves of Chinese cabbage and turnip may be a factor in their resistance to oviposition, and that the comparative resistance of kohlrabi may be due to its small total leaf surface.

Radcliffe and Chapman (*1965a*, *1965b*, and *1966b*) found no correlation between plant size and susceptibility of the various cabbage varieties to looper oviposition. Significant differences in ovipositional preference on broccoli and cauliflower plants of different ages were noted by Boling and Pitre (*1971*). The stratification of *T. ni* oviposition sites and larval distribution on cabbage were studied by Sutherland (*1966*) and Greene (*1968*).

Sutherland (*1966*) found differences in larval development of *T. ni* on peppers as compared with that on cabbage, lambsquarters, lima bean, and tomato grown in field cages. A separate preliminary study indicated that hosts also affected adult longevity and egg production (Sutherland *1966*). Shorey et al. (*1962*) showed that *T. ni* developed more rapidly on lima bean foliage than on cabbage at 73.4° F. Larvae seldom develop beyond the second or third instar on cantaloupe in Arizona (Anonymous *1957*, *1960a*, *1962a*).

Greene and Shelburne (*1970*) conducted field-cage studies on St. George Island, located 4 miles off the Florida coast, during July and August 1970. No crops were grown on the island, and no naturally occurring *T. ni* larvae were collected during the experiment.

Ten third instar larvae were introduced into cages placed over a single species of plant growing naturally on St. George. The following results were obtained:

1. Adults were reared from the following plants:

   Amaranthaceae

   Amaranthus spinosus L. – spiny amaranth

[1]Entomologist, 125 Lakeside Drive, Greenbelt, Md. 20770.

[2]Professor of Entomology, Univ. of Fla., Agric. Res. and Educ. Center, Quincy, FL 32351; Current affiliation; Station Director, Kans. Agric. Expt. Stn., Garden City, Kans. 67846.

Anacardiaceae

Rhus copoallina L. - shining sumac

Chenopodiaceae

Chenopodium sp.

Compositae

Baccharis angustifolia Michx.
Pluchea sp.
Xanthium strumarium L. - heartleaf cocklebur

Ebenaceae

Diospyros virginiana L. - common persimmon

Guttiferae

Hypericum sp.

Labiatae

Teucrium sp.

Lauraceae

Sassafras albidum (Nutt.) Nees - sassafras

Leguminosae

Desmodium tortuosum (Sw.) DC. - Florida beggarweed
Pueraria thunbergiana (Sieb. and Zucc.) Benth. = *P. lobata* (Willd.) Ohwi
Vigna luteola (Jacq.) Benth.

Polygonaceae

Polygonum pensylvanicum L. - Pennsylvania smartweed
Rumex floridanus Meissn. = *R. pulcher* L.
Rumex sp.

Rosaceae

Aronia melanocarpa (Michx.) Elliott - black chokeberry

Rubiaceae

Cephalanthus occidentalis L. - common buttonbush

Vitaceae

Ampelopsis arborea Koehne - peppervine
Vitis rotundifolia Michx. - muscadine grape

II. Larval feeding was observed, but no adults emerged from the following:

Aquifoliaceae

Ilex glabra (L.) Gray - fallberry

Compositae

Baccharis halimifolia L. - eastern baccharis
Eupatorium sp.
Iva sp.

Euphorbiaceae

Croton punctatus Jacq.

Fagaceae

Quercus sp. - oak

Leguminosae

Cassia obtusifolia L. - sicklepod
Pisum sp. - field pea

Liliaceae

Smilax auriculata Walt.

Rosaceae

Rubus argutus Link

Scrophulariaceae

Agalinis sp.

Solanaceae

Nicotiana tabacum L. - tobacco

Verbenaceae

Lantana camara L. - lantana

III. Larval feeding was not observed and no adults emerged from the following:

Alismataceae

Sagittaria lancifolia L.

Aquifoliaceae

Ilex vomitoria Ait. – yaupon

Compositae

Ambrosia artemisiifolia L. – common ragweed
Eupatorium rugosum Houtt. – white snakeroot
Heterotheca subaxillaris (Lam.) Britt. and Rusby – camphorweed
Iva sp.
Verbesina sp.

Fagaceae

Quercus laurifolia Michx. – laurel oak
Quercus virginiana Mill. – live oak

Gramineae

Zea mays L. – corn

Labiatae

Conradina canescens (Torr. and Gray) Gray
Teucrium nashii Kearney = *T. canadense* L. var. *hypoleucum* Griseb.

Leguminosae

Pueraria lobata (Willd.) Ohwi – kudzu

Malvaceae

Kosteletzyka althaeifolia (Chapm.) Rusby
Sida rhombifolia L. – arrowleaf sida

Myricaceae

Myrica cerifera L. – southern waxmyrtle

Phytolaccaceae

Phytolacca sp.

Polypodiaceae

Pteridium aquilinum (L.) Kuhn – bracken

Rosaceae

Prunus americana Marsh. – American plum
Rubus cuneifolius Pursh

Salicaceae

Salix caroliniana Michx. – ward willow

Verbenaceae

Callicarpa americana L. – American beautyberry

The following list of recorded hosts has been divided into cultivated plants and weeds. In the literature, hosts are frequently listed by common name; therefore, a few inaccuracies may exist in designating a scientific name (Holstun et al. *1971*; Magness et al. *1971*; Wyman *1971*). There is no intent to include all references to each host listed here. The selected references, particularly for the more common hosts, are considered representative or unusual enough to be included. A number of references cited in the introduction also contain host records and may not be cited in the following list:

I. Cultivated Plants

Araceae

Philodendron sp. – (Eichlin *1975*)

Araliaceae

Hedera helix L. – English ivy (Smith *1962*)

Boraginaceae

Heliotropium sp. – heliotrope (Sirrine *1899*)

Cannaceae

Canna – cannas (Sirrine *1899*)

Caryophyllaceae

Dianthus barbatus L. – sweet William (Sutherland *1966*)
Dianthus caryophyllus L. – carnation (Sirrine *1899*, *1900*; Chittenden *1902*; Weigel and Sasscer *1923*; Blauvelt *1938*; Eichlin *1975*)
Dianthus sp. – pinks (Blauvelt *1938*)
Gypsophilia sp. – (Anonymous *1971c*)

Chenopodiaceae

Beta vulgaris L. – beet (Caudell *1902*; Chittenden *1902*; McKinney *1944*; Eichlin *1975*)
– sugarbeet (Forbes and Hart *1900*; Caudell *1902*)
Beta vulgaris (Cicla group) – Swiss chard (Severin *1919*; Ratcliffe et al. *1961*; Wressell *1970*; Anonymous *1971d*; Eichlin *1975*)

Compositae

Ageratum conyzoides L. – (Tietz *1957*; Eichlin *1975*)
Calendula officinalis L. – calendulas (Dietz *1922*; Weigel and Sasscer *1923*; Smith *1962*; Eichlin *1975*)
Carthamus tinctorius L. – safflower (David *1960*)
Chrysanthemum hybrids – chrysanthemum (Weed *1889*; Sirrine *1897*; Smith *1962*; Sutherland *1966*; Anonymous *1971c*; Eichlin *1975*)
Cichorium endivia L. – endive (Weed *1889*; Hills and Taylor *1951*)
Cynara scolymus L. – artichoke (Jones *1918*; Lange *1941*)
Dahlia hybrids – dahlia (Weed *1889*; Tenhet *1931*; Brimley *1938*)
Helianthus annuus L. – sunflower (David *1960*; Hawthorne et al. *1975*)
Helianthus sp. – (Eichlin *1975*)
Lactuca sativa L. – lettuce (Riley *1883*; Weed *1889*; Sirrine *1894*, *1897*; Townsend *1942*; McKinney *1944*; Linkfield and Damiano *1963*; Sutherland *1966*, *1968*; Avidov and Harpaz *1969*; Wressell *1970*; Kishaba et al. *1973*; Hawthorne et al. *1975*)
Senecio cruentus (Masson) DC. – cineraria (Weigel and Sasscer *1923*; Gibson and Ross *1940*; Smith *1962*; Capizzi *1965*; Eichlin *1975*)
Senecio mikanioides Otto ex Walp. (scandens) – German ivy (Riley *1883*; Chittenden *1902*; Weigel and Sasscer *1923*; McDaniel *1924*; Smith *1962*; Eichlin *1975*)
Senecio sp. – (Hawthorne et al. *1975*)

Convolvulaceae

Ipomoea batatus (L.) Lam. – sweet potato (Middleton *1963*; Ratcliffe and Dupree *1964*; Canerday and Arant *1966*; Anonymous *1968c*)

Cruciferae

Armoracia lepathifolia Gilib. ex Usteri = *A. rusticana* Gaertn., Mey. and Scherb. – horseradish (Morris *1959*; Mason *1959*)
Brassica campestris L. = *B. rapa* L. (Pekinensis group) – Chinese cabbage (Reinhard *1935*; Landis *1936*; Sutherland *1966*)
Brassica campestris L. = *B. rapa* L. (Rapifera group) – turnip (McQueen *1963*; Kaatz *1964*; Walla *1964*; Eichlin *1975*)
Brassica juncea (L.) Czern. and Coss. – mustard (Chittenden *1902*; McKinney *1944*; Hawthorne et al. *1975*)
Brassica napus L. – rape (Osborn *1893*; Sirrine *1899*; Milliron *1958*; Eichlin *1975*)
Brassica napus L. (Napobrassica group) – rutabaga (Caudell *1902*; Chittenden *1902*; Severin *1919*; Wressell *1970*)
Brassica oleracea L. (Acephala group) – collard (Harrison and Brubaker *1943*; Harcourt et al. *1955*; Genung *1956*; Sutherland *1966*; Kouskolekas and Harper *1973*)
– flowering kale (Smith *1962*)
– kale (Riley *1883*; Sirrine *1899*; Harrison and Brubaker *1943*; McKinney *1944*; Sutherland *1966*)
Brassica oleracea L. (Botrytis group) – cauliflower (Weed *1891*; Sirrine *1897*; Harrison and Brubaker *1943*; McKinney *1944*; Sutherland *1966*; Hawthorne et al. *1975*; Eichlin *1975*)
Brassica oleracea L. (Capitata group) – cabbage (Riley *1870*; Sirrine *1894*; Garman *1904*; Compton *1925*; McKinney *1944*; Sutherland *1966*; Avidov and Harpaz *1969*; Hawthorne et al. *1975*; Eichlin *1975*)
Brassica oleracea L. (Gemmifera group) – Brussels sprout (Sirrine *1899*; Harrison and Brubaker *1943*; Milliron *1958*; Sutherland *1966*; Eichlin *1975*)
Brassica oleracea L. (Gongylodes group) – kohlrabi (Severin *1919*; Harrison and Brubaker *1943*; Harcourt et al. *1955*)
Brassica oleracea L. (Italica group) – broccoli (Sirrine *1899*; Harrison and Brubaker *1943*; McKinney *1944*; Sutherland *1966*; Hawthorne et al. *1975*; Eichlin *1975*)
Mathiola sp. – stocks (Smith *1962*; Sutherland *1966*)
Raphanus sativus L. – radish (Chittenden *1902*; Severin *1919*; McKinney *1944*; Eichlin *1975*)

Cucurbitaceae

Citrullus lanatus (Thunb.) Matsum and Nakai - watermelon (McKinney *1944*; Anonymous *1960b*; Burbutis and Evans *1963*; Sutherland *1966*; Adlerz *1971*; Hawthorne et al. *1975*; Eichlin *1975*)
Cucumis melo L. - muskmelon and cantaloupe (Quaintance *1901*; McKinney *1944*; Anonymous *1957*; Sutherland *1966*; Anonymous *1970d*; Anonymous *1971a*; Eichlin *1975*)
Cucumis sativus L. - cucumber (Anonymous *1908*; McKinney *1944*; Smith et al. *1952*; Sutherland *1966*; Avidov and Harpaz *1969*; Hofmaster *1973*, *1975*; Hawthorne et al. *1975*; Eichlin *1975*)
Cucurbita maxima Duch. and *moschata* (Duch.) Duch. ex Poir. - squash (McKinney *1944*; Milliron and Conard *1957*; Eichlin *1975*)
Cucurbita pepo L. - pumpkin (Milliron and Conrad *1957*; Burbutis and Mason *1959*) - zucchini squash (Eichlin *1975*)

Euphorbiaceae

Euphorbia pulcherrima Willd. ex Kl. - poinsettia (Eichlin *1975*)

Geraniaceae

Erodium cicutarium (L.) L'Her. ex Ait. - redstem filaree (McKinney *1944*; Eichlin *1975*)
Erodium sp. - heronsbill (Eichlin *1975*)
Geranium sp. - geranium (Eichlin *1975*)
Pelargonium sp. - pelargonium (Sirrine *1899*)

Gramineae

Sorghum bicolor (L.) Moench - sorghum (Anonymous *1956a*)
Zea mays L. - corn (Avidov and Harpaz *1969*; Anonymous *1970b*; Janes and Greene *1970*; Eichlin *1975*)

Iridaceae

Gladiolus hybrids - gladiolus, after weeds (*Chenopodium* sp.) had been hoed (Hungerford *1931*; Anonymous *1971c*)

Labiatae

Coleus sp. - coleus (Eichlin *1975*)
Menthax piperita L. - peppermint (Hocking *1941*; Landis *1965*)
Metha spicata L. - spearmint (Klostermeyer *1973*)
Metha sp. - mint (Davis *1952*; Anonymous *1962b*; Eichlin *1975*)
Salvia sp. - sage or salvia (Weed *1889*; Tenhet *1931*; Hawthorne et al. *1975*; Eichlin *1975*)

Leguminosae

Arachis hypogaea L. - peanut (Anonymous *1956b*; Johnson *1957*; Boyd *1963*; Canerday and Arant *1966*; Pike *1970*)
Glycine max (L.) Merr. - soybean (Leiby *1926*; Lyle *1936*; Burbutis and Mason *1959*; Anonymous *1965*; Canerday and Arant *1966*; Roberts *1974*; Carner et al. *1974*)
Lathyrus odoratus L. - sweet pea (Severin *1919*; McKinney *1944*; Eichlin *1975*)
Lupinus sp. - lupine (Eichlin *1975*)
Medicago sativa L. - alfalfa (Johnson *1957*; Anonymous *1957*; McCreary and Conrad *1958*; Anonymous *1964a*; Anonymous *1970a*; Eichlin *1975*)
Melilotus sp. - sweet clover (Walkden *1950*; Anonymous *1960b*)
Phaseolus aureus - Roxb. = *Vinga radiata* (L.) Wilczek - mung bean (Anonymous *1969a*)
Phaeseolus lunatus L. - lima bean (Milliron *1956*; McCreary and Conrad *1958*; Burbutis and Mason *1960*; Sutherland *1966*; Hofmaster *1975*; Hawthorne et al. *1975*; Eichlin *1975*)
Phaseolus vulgaris L. - pole bean, snap bean, kidney bean, and/or bean (Knowlton *1928*; Watson *1931*; Mason *1959*; Anonymous *1964b*; Avidov and Harpaz *1969*; Anonymous *1970c*; Hofmaster *1975*; Eichlin *1975*)
Phaseolus sp. - (Hawthorne et al. *1975*; Eichlin *1975*)
Pisum sativum L. - pea (Caudell *1902*; Chittenden *1902*; Dustan *1932*; McKinney *1944*; Anonymous *1973*; Eichlin *1975*)
Trifolium incarnatum L. - crimson clover (Johnson *1957*; Canerday and Arant *1966*)
Trifolium pratense L. - red clover (McCreary and Conrad *1958*)
Trifolium sp. - (Riley *1883*; Weed *1891*; Chittenden *1902*; Eichlin *1975*)
Vicia sp. - vetch (Garner *1954*; Hawkins *1957*; Irvin *1962*)
Vigna sinensis (L.) Savi ex Hassk. = *V. unguiculata* (L.) Walp., subsp. *unguiculata* - field pea, cowpea, and/or blackeyed pea (Chittenden *1902*; Guyton *1958*; Genung *1961*; Anonymous *1963a*; Anonymous *1968a*; Eichlin *1975*)

Liliaceae

Allium cepa L. (Common onion group) – onion (Bechtel and Lauderdale *1957*; Anonymous *1962c*; Anonymous *1968b*)
Asparagus officinalis – asparagus (Chittenden *1902*; McDaniel *1924*; Drake and Harris *1932*; Eichlin *1975*)
Smilax rotundifolia L. – common greenbrier, smilar, or horsebrier (Tietz *1957*; Eichlin *1975*)
Smilax sp. – (Sirrine *1899*; Fletcher *1901*; McDaniel *1931*)

Linaceae

Linum sp. – flax (Anonymous *1963b*)

Malvaceae

Althaea rosea (L.) Cav. = *Alcea rosea* L. – holiyhock (McKinney *1944*; Bechtel and Ferraro *1965*; Eichlin *1975*)
Gosspium hirsutum L. – cotton (Folsom *1936*; Gaines *1937*; McKInney *1944*; Hargreaves *1948*; Parencia et al. *1957*; Canerday and Arant *1966*; Davis et al. *1973*; Hawthorne et al. *1975*; Eichlin *1975*)
Hibiscus esculentus L. = *Abelmoschus esculentus* (L.) Moench – okra (Anonymous *1969b*; Hawthorne et al. *1975*; Eichlin *1975*)
Hibiscus sp. – (Seibels and Simms *1964*)
Malva sp. – mallow (Eichlin *1975*)

Orchidaceae

Orchids (Anonymous *1961*; Hawthorne et al. *1975*)

Papaveraceae

Argemone platyceras Link and Otto var. *hispida* (Gray) Prain = *Argemone hispida* Gray – crested prickle-poppy (Tietz *1957*; Eichlin *1975*)

Eschscholtzia californica Cham. – California poppy (McKinney *1944*; Eichlin *1975*)
Papaver somniferum L. – opium poppy (Okuni *1920*; Fletcher, in David *1960*)
Papaver sp. – poppy (Eichlin *1975*)

Resedaceae

Reseda odorata L. – mignonette (Riley *1883*; Chittenden *1902*; Smith *1962*; Eichlin *1975*)

Rosaceae

Chaenomeles japonica (Thunb.) Lindl. ex Spach – Japanese quince (Riley *1883*; Chittenden *1902*; Eichlin *1975*)
Fragaria hybrids – strawberry (Hawthorne et al. *1975*; Eichlin *1975*)
Rosa sp. – rose (Gesell *1957*; Miller *1971*)

Rutaceae

Citrus sinensis (L.) Osb. – sweet orange (Eichlin *1975*)
Citrus sp. – citrus (Woglum and Lewis *1935*; Atkins *1960*; Anonymous *1966*; Avidov and Harpaz *1969*; Hawthorne et al. *1975*; Eichlin *1975*)

Salicaceae

Populus sp. – cottonwood (Chittenden *1901*)

Saxifragaceae

Bergenia sp. – (Eichlin *1975*)

Scrophulariaceae

Antirrhinum hybrids – snapdragon (Tenhet *1931*; McKinney *1944*; Smith *1962*; Naegele, personal communication, *1963*; Sutherland *1966*; Anonymous *1971c*; Eichlin *1975*)

Solanaceae

Capsicum annum L. – chili pepper, pimento, sweet pepper, bell pepper, or ornamental pepper (Milliron *1955*; Ratcliffe et al. *1961*; Elmore *1961*; Buttram *1962*; Anonymous *1963c*; Sutherland *1965*, *1966*)
Lycopersicon esculentum Mill. – tomato (Riley *1883*; Britton *1896*; Sirrine *1899*; Milliron and Conrad *1957*; Milliron *1958*; McKinney *1944*; Canerday and Arant *1966*; Sutherland *1966*; Wressell *1970*; Creighton et al. *1971*; Eichlin *1975*)
Nicotiana tabacum L. – tobacco (Howard *1899*; Girault *1913*; Gibson and Ross *1940*; Chamberlin and Madden *1942*; Nettles et al. *1965*; Strickland and French *1970*; Hawthorne et al. *1975*; Eichlin *1975*)
Petunia hybrids – (Tenhet *1931*; Hawthorne et al. *1975*; Eichlin *1975*)
Solanum melongena L. – eggplant (Anonymous *1963d*; Avidov and Harpaz *1969*)

Solanum tuberosum L. – potato (Fletcher *1901*; Caudell *1902*; McKinney *1944*; Anonymous *1963e*; *Sutherland 1966*; Avidov and Harpaz *1969*; Schulz *1973*; Hawthorne et al. *1975*; Eichlin *1975*)

Tropaeolaceae

Tropaeolum majus L. – garden nasturtium (Tietz *1957*; Eichlin *1975*)
Tropaeolum hybrids – nasturtium (Tenhet *1931*: McDaniel *1931*; Smith *1962*)

Umbelliferae

Apium graveolens L. var. *dulce* (Mill.) Pers. – celery (Riley *1883*; Weed *1889*; Sirrine *1899*; McKInney *1944*; Anonymous *1964c*; Desin *1965*; Wressell *1970*; Anonymous *1971b*; Eichlin *1975*)
Daucus carota L., subsp. *sativus* (Hoffm.) Arcang. – carrot (Burbutis and Mason *1959*; Kaatz *1964*; Hawthorne et al. *1975*; Eichlin *1975*)
Pastinaca sativa – parsnip (Crumb *1956*; Eichlin *1975*)
Petroselinum crispum (Mill.) Nym. ex A. W. Hill – parsley (Britton *1910*; McKinney *1944*)

II. Weeds

Amaranthaceae

Amaranthus sp. – pigweed (Chittenden *1902*)

Asclepiadaceae

Asclepias sp. – milkweed (Eichlin *1975*)

Chenopodiaceae

Chenopodium album L. – common lambsquarters (Tietz *1957*; Eichlin *1975*)
Chenopodium sp. (Riley *1883*; Chittenden *1902*; Crumb *1956*; Sutherland *1966*)
Salsola kali L. var. *tenuifolia* Tausch – Russian thistle (Goeden and Ricker *1968*)

Compositae

Chaenactics stevioides Hook. and Arn. – morning bride (McKinney *1944*; Eichlin *1975*)
Crepis sp. – hawksbeard (Riley *1883*; Eichlin *1975*)
Encelia farinosa Gray – white brittlebush (McKinney *1944*)
Pectis papposa Harv. and Gray – chinchweed (McKinney *1944*; Eichlin *1975*)
Lactuca canadensis L. – tall lettuce (Tietz *1957*; Eichlin *1975*)
Lactuca sp. – wild lettuce (Caudell *1902*; McKinney *1944*; Hawthorne et al. *1975*; Eichlin *1975*)
Taraxacum officinale Wiggers – common dandelion (Tietz *1957*; Eichlin *1975*)
Taraxacum sp. – dandelion (Riley *1883*; Weed *1891*; Chittenden *1902*)

Convolvulaceae

Ipomoea purpurea (L.) Roth – tall or common morning glory (Eichlin *1975*)

Cruciferae

Brassica campestris L. = *B. Rapa* L. – wild turnip or field mustard (Eichlin *1975*)
Brassica hirta (alba) Moench = *Sinapis alba* L. – white mustard (Tietz *1957*; Eichlin *1975*)
Brassica kaber (DC.) Wheeler = *Sinapis arvensis* L. – wild mustard (Sirrine *1889*)
Brassica nigra (L.) Koch – black mustard (Tietz *1957*; Eichlin *1975*)
Cresses (Sirrine *1899*)
Five species of wild crucifers (McKinney *1944*)
Raphanus raphanistrum L. – wild radish (Sirrine *1899*; Chittenden *1902*)

Labiatae

Glechoma hederacea L. – ground ivy or gill-over-the-ground (Eichlin *1975*)

Leguminosae

Acacia greggi Gray – catclaw acacia (Eichlin *1975*)
Crotalaria rotundifolia (Walt.) Poir. – (Eichlin *1975*)

Malvaceae

Several species of mallow (McKinney *1944*)

Plantaginaceae

Plantago sp. – plantain (Chittenden *1902*; Eichlin *1975*)

Polygonaceae

Rumex sp. - dock (Riley *1883*; Weed *1891*; Chittenden *1902*; McDaniel *1924*)

Scrophulariaceae

Verbascum sp. - mullein (Chittenden *1902*)

Solanaceae

Nicotiana glauca Grah. - tree tobacco (McKinney *1944*; Eichlin *1975*)
Nicotiana trigonophylla Dunal. - desert tobacco (McKinney *1944*; Eichlin *1975*)
Solanum sp. - (David *1960*)
Solanum sp. - nightshade (Kirby *1897*)

Urticaceae

Urtica sp. - nettle (David *1960*; Kirby *1897*)

Zyglophyllaceae

Tribulus sp. - (Eichlin *1975*)

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Chapter 2. Biology, Behavior, and Dispersal of Adults

By Everett R. Mitchell[1] and Richard B. Chalfant[2]

Abstract

The biology, behavior, and habits of the adult cabbage looper, *Trichoplusia ni* (Hübner), are discussed in relation to various environmental factors. Temperature appears to be the major factor regulating the population and distribution of this important pest.

The adult cabbage looper, *Trichoplusia ni* (Hübner), is a grayish to chocolate-colored moth about 2.5 cm long with a wingspan of about 3.8 cm. The forewings have a silver mark near the middle resembling a torch or fire pot. Similar markings occur on the other Plusiinae. Crum (*1956*) described the basic taxonomic characters, and McEwen and Hervey (*1960*) discussed sex differences. The adults are strong fliers, seminocturnal, and active mostly in the dark except in cloudy weather (McKinney *1944*). During the day, the moths rest in protected areas, such as the undersides of host plants, in the debris at the base of the plants, or in the vegetation bordering the field. They begin feeding and ovipositing one-half hour before sunset (Sutherland *1966*). Most copulation occurs between 1 a.m. and 3:30 a.m. (Shorey et al. *1962*). Ultraviolet light trap (BL) studies by Shorey et al. (*1962*) indicate adult activity in California declines after 11:00 p.m.; however, studies by Graham et al. (*1964*) in Texas show most activity occurs between 1:30 a.m. and 3:30 a.m.

Adult survival is related to conditions that affect food sources. Moths feed on nectar of various wild and cultivated hosts where they obtain water and dissolved nutrients, particularly sugars. These plants may or may not be larval hosts. A list of adult hosts is given by Sutherland (*1966*). Other hosts are *Aster spinosus* (Shorey et al. *1962*), *Abelia grandiflora* (Grant *1971*), and nectaries of southern peas (personal observation). Food obtained from nectaries of cotton increases reproductive potential (Lukefahr and Rhyne *1960*). Because a successfully inseminated female will lay her own body weight in eggs, water and sugars are needed for maximum longevity and fecundity (Shorey *1963*). Moths also utilize sugars for sustained flight (Kishaba et al. *1967*). Moisture is an important adult stimulus and may attract moths over long distances in the desert areas of Arizona (McKinney *1944*).

[1]Research entomologist, Insect Attractants, Behavior, and Basic Biology Research Laboratory, Agric. Res. Serv., USDA, P.O. Box 14565, Gainesville, Fla. 32604.

[2]Associate Professor of Entomology, Entomology-Fisheries Department, Georgia Coastal Plain Experiment Station, Tifton, Ga. 31794.

Ovipositing females respond to several stimuli, particularly moisture. In the laboratory, moths will lay more eggs on moist than on dry filter paper and as many on moist filter paper as on cabbage leaves (Shorey *1964*). Presence of a substrate suitable for oviposition has little effect on frequency of mating and does not strongly influence oviposition (Shorey *1963*). Similarly, Saario et al. (*1970*) observed that females do not aggregate near cole crops prior to mating. Chemicals such as allyl isothiocyanate and sinigrin (substances common to crucifers), sucrose, and ascorbic acid do not elicit and ovipositional response; however, yellow substrate is preferred over other colors for oviposition (Shorey *1964*). Ovipositing females prefer certain plants. Hosts that are severely defoliated lost attractiveness (Smith and Brubaker *1938*), and mature cabbages are less preferred than younger plants (Sutherland *1966*).

Changes in temperature have marked effects on adult behavior, viability, and fecundity. At temperatures below 15.6° C, flight and mating activity are drastically reduced (Sutherland *1966*, Elsey and Rabb *1967*). During the winter months in the overwintering zone (fig. 1), females begin calling and males respond to pheromone shortly after sunset. As the seasons change and the nights become warmer, the period of peak female calling and male responsiveness to pheromone occurs later in the evening and is extended over a longer period (Mitchell *1973*). As temperatures rise to about 27° C, frequency of mating increases (Henneberry and Kishaba *1967*) and oviposition and longevity decrease (Canerday *1967*). At high temperatures (about 32° C), egg production and hatch decrease (Toba et al. *1973*). High temperatures also interfere with metabolism of fatty acids, thereby resulting in abnormal wing development (Grau and Terriere *1967*).

Various studies of the biology of the adult cabbage looper (Shorey et al. *1962*; Shorey *1963*; Sutherland *1966*; Canerday *1967*; Henneberry and Kishaba *1967*) show that after adults emerge from the pupal stage, there is a preovipositional period of 4 days after which mating begins.

Most mating occurs after 3 to 4 days and can continue up to 16 days. Oviposition can begin before mating shortly after emergence, but the eggs are infertile. Oviposition of viable eggs reaches a peak at 3 to 6 days, depending on ambient conditions, and can continue throughout the mating period (14 to 16 days). Workers have given various reports of fecundity ranging from about 300 eggs per female (McEwen and Hervey *1960*) to about 1,400 eggs per female (Sutherland *1966*). Hatch ranges from 50 to 80 percent during peak oviposition periods when most females have mated.

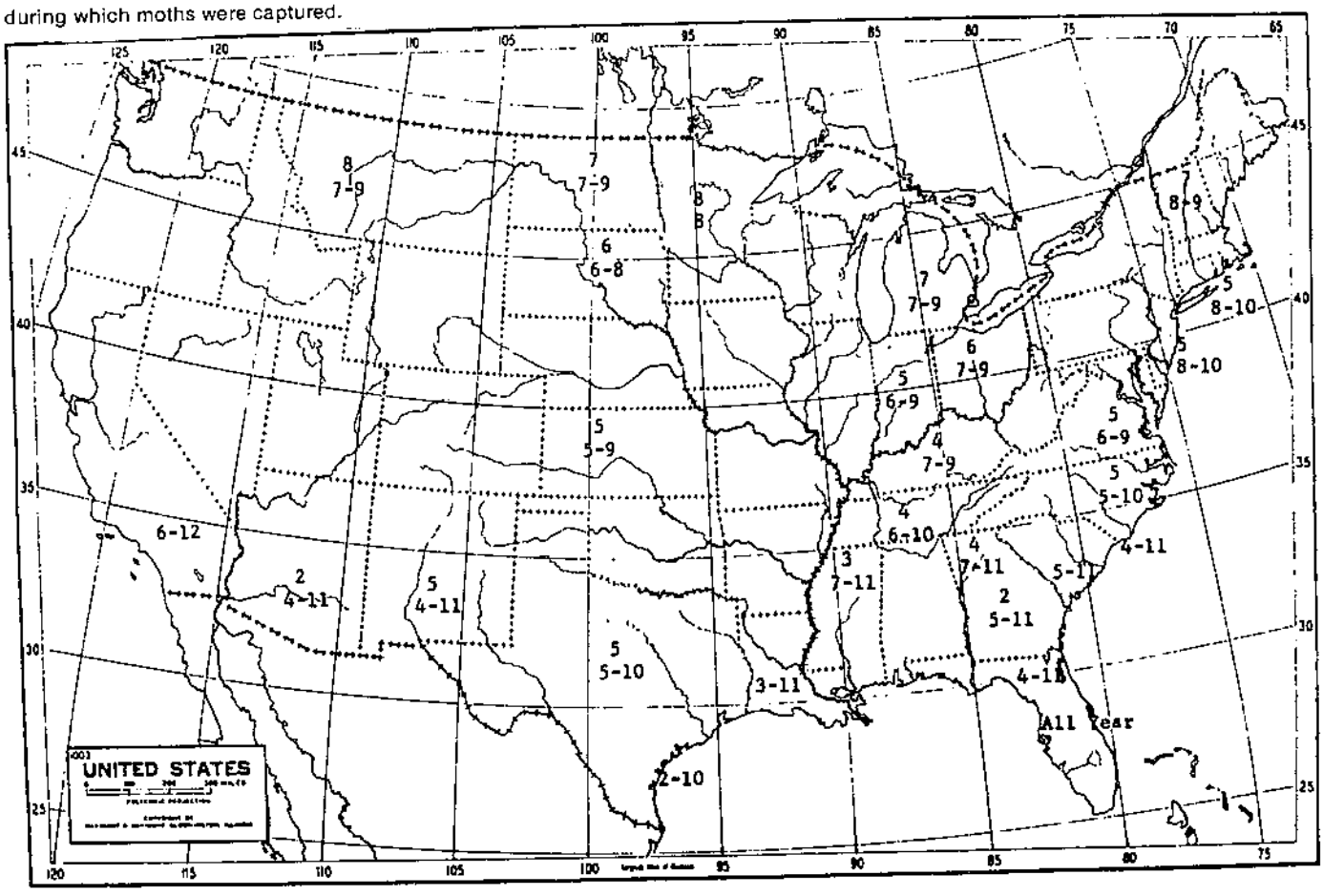
The cited data demonstrate that the cabbage looper has a high reproductive potential. Given temperate weather,

adequate drinking water, and dissolved nutrients from various cultivated and wild hosts, a single female can be responsible for well over 1,000 viable eggs. Very little has been reported on the factors responsible for regulation of the adult population. Birds and bats feed on moths in flight (McKinney *1944*; Sutherland *1966*), and earwigs feed on moths that rest beneath host plants (personal observation); however, temperature appears to be the major factor regulating the population and distribution of the cabbage looper.

Populations of moths are estimated directly by BL traps (baited or unbaited with pheromone) and indirectly by inferences from eggs and larvae on host plants. Both methods have inherent errors, and factors other than local population densities may influence counts. BL trap catches are highest between midnight and 3:30 a.m. (Graham et al. *1964*) on days preceded and followed by higher temperatures (Sutherland *1966*), in seasons favored by combinations of low rainfall in early spring and high rainfall in early summer (King *1966*), and in the presence of nearby hosts (Sutherland *1966*). Trap efficiency and misidentification are also factors. Lunar phase does not appear to influence trapping of the cabbage looper (Hills *1969*; Gentry and Davis *1973*). Finally, high egg and larval densities do not necessarily result from large adult populations (McKinney *1944*).

The cabbage looper is distributed throughout Eurasia and North America but is subtropical in origin and, in the United States, overwinters only in Florida and the coastal plain of Georgia (Chalfant et al. *1974*), the lower coastal plain of South Carolina (Reid and Bare *1952*), Louisiana (Smith and Brubaker *1938*), the Rio Grande Valley of Texas (Glick and Graham *1965*; Wolfenbarger *1967*), Arizona (McKinney *1944*), and southern California (Oatman *1966*). During winter, significantly large adult populations occur only in peninsular Florida in the United States. Sporadic captures occur in the remaining overwintering zone (fig. 1).

Figure 1.—Blacklight trap catches of the cabbage looper. The top numeral represents the month during which adults were first captured, and the lower numerals represent the months during which moths were captured.

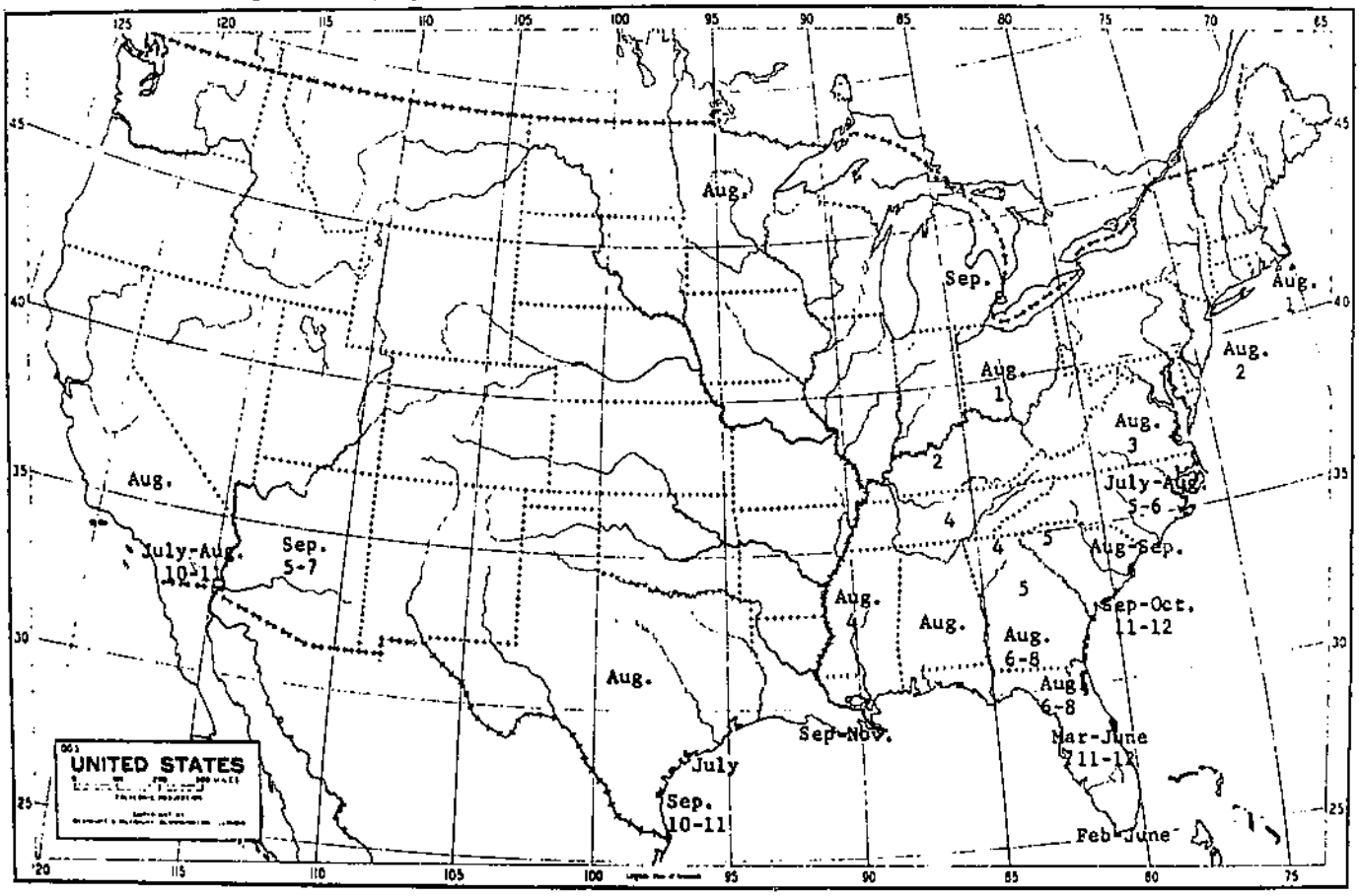


Adults in the overwintering zone follow the advancing spring season and move northward. Figure 1 shows the first reported BL captures of cabbage looper moths at various locations outside the overwintering zone and the months during which captures occur. Figure 2 shows the month during which peak capture occurs and the estimated number of generations per year. Both are based on various accounts (Smith and Brubaker *1938*; Merkl and Pfrimmer *1955*; Hofmaster *1961*; Oatman *1966*; Sutherland *1966*; C herday *1967*; Elsey and Rabb *1967*; Falcon et al. *1967*; W lfenbarger *1967*; Anonymous *1970-74*). As one moves north, the month of initial capture occurs later, the season of significant adult capture is shorter, and the interval between first capture and development of a significant adult population is shorter.

Although there are large differences in length of adult activity among the climatic zones, peak catches occur mostly in August in most areas outside the southernmost overwintering zones (fig. 2). In the winter vegetable areas of South Carolina, Texas, and California, peak catches usually occur in September, coinciding with the crop development. In the peninsula of Florida, peak catches occur in spring.

Different peaks of adult catches usually represent different generations and are about 1 month apart during the winter (Oatman *1966*; Chalfant et al. *1974*). The number of generations, based on BL trap catches, ranges from about 12 in the southernmost United States to 1 per year in the northern States (fig. 2). With 11 to 12 generations and significant populations throughout the year, the southern States, particularly the peninsula of Florida, are the principal breeding grounds for cabbage loopers that appear later in other parts of the United States. Any measures directed toward areawide population suppression must be concentrated in this area. Because of its high reproductive potential, absence of significant predators, and possible migratory behavior (Chalfant et al. *1974*), these efforts should be directed principally against the adult.

Figure 2.—Blacklight trap catches of the cabbage looper showing the month of peak captures and the number of generations per year.



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Addendum

The migratory habits of the cabbage looper and other Plusiinae are discussed by Lingren et al. (*1979*). Based upon personal research, observations, and a review of the literature, these workers concluded that the cabbage looper has the inherent capability for rather long-range movements by flight. Such movements appear to account for much of the spread of cabbage looper populations northward in the United States each year in spring and early summer and southward in late summer and fall.

Flight by the adults, however, is not the only means by which cabbage loopers are able to extend their northerly range each season. Lingren et al. (*1979*) also cited examples where immature forms (eggs, larvae, and pupae) of the cabbage looper are transported northward from areas of production in Florida and southeastern Alabama on produce (for example, cabbage heads) and plant sets used to establish home gardens and commercial plantings. In some years, the cabbage looper may survive the winter season outside its usual overwintering refugia by feeding on ornamental plants located in urban areas in protected sites next to heated residences. Given the high reproductive potential of the cabbage looper, these residual populations could result in the appearance of significant numbers of this pest much earlier than expected under usual circumstances. Such residual populations may also contribute to the spead of cabbage loopers into uninfested areas further north.

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Chapter 3. Release, Recovery, and Dispersal of Adults

By Jack W. Debolt,[1] T. J. Henneberry,[2] W. W. Wolf,[3] and P. D. Lingren[2]

Abstract

Adult cabbage loopers, *Trichoplusia ni,* (Hübner), are capable of flying long distances and have been caught 161 km from land in the Gulf of Mexico, whereas over land, marked moths have been recaptured up to 14.5 km from the release point the same night of release. This insect is very mobile and readily moves from cultivated areas into adjacent areas such as the deserts of the southwestern United States. Passive and active marking techniques provide coded marked moths for release. Preacclimating moths above 15° C produced the best recaptures. Anesthetizing moths with CO_2, ether, or 10° C chilling reduced mating for at least one night.

Knowledge of flight potential of the cabbage looper, *Trichoplusia ni,* (Hübner), is critical in the development of efficient, effective, and compatible pest management systems. McKinney (*1944*) observed that the cabbage looper was a strong flier and postulated that the species was capable of flying long distances. Reports by several English authors imply that the cabbage looper may be capable of moving from southwestern Europe via North Africa to locations in the British Isles (Dannreuther *1953*; French *1953*; Rossel *1957*). Hills (*1968*) concluded that the main source of the insect in south-central Arizona was irrigated-cultivated crop areas because increased catches of the moths in light traps, placed various distances into the desert away from cultivated areas, appeared to correlate well with increases in cultivated areas when the desert areas were devoid of cabbage looper host plants. Moreover, migration northward seems to be an important factor in the seasonal distribution of the insect. Although Sirrine (1894) indicated that the cabbage looper could overwinter in the pupal stage in northern and central United States, Sutherland (*1966*) reported that the insect could not overwinter near Long Island, N.Y., and Elsey and Rabb (*1970*) reported that the looper probably did not often overwinter in North Carolina. Indeed, Chalfant et al. (*1974*) indicated that continuous reproduction and development in the southeastern United States probably occurs only where average winter temperatures exceed 16° C.

[1] Entomologist, Biological Control of Insects Laboratory, Agric. Res. Serv., USDA, 2000 East Allen Rd., Tucson, Ariz. 85719.

[2] Research entomologists, Western Cotton Research Laboratory, Agric. Res. Serv., USDA, 4135 E. Broadway Rd., Phoenix, Ariz. 85040.

[3] Agricultural engineer, Grain Insects Research Laboratory, Agric. Res. Serv., USDA, Georgia Coastal Plain Experiment Station, Tifton, Ga. 31793.

Marking Techniques

Marking-recapture techniques have been used extensively in animal studies to estimate total populations and dispersal. One assumes that the marked, released segment of the population behaves and is sampled in the same ratios as the unmarked natural segment. Vail et al. (*1966*) found that the longevity of cabbage looper moths was not affected and the marking lasted the life of the insect if rhodamine B dye was applied in aqueous sprays.

Cabbage looper moths can be effectively marked with petroleum-based inks (Wolf and Stimmann *1972*), or with water soluble food coloring dyes (Henneberry et al. *1967*), though the dyes are not as permanent as the inks, which penetrate the scales to permanently mark the integument. (With all these materials, various colors are available for coding treatments, such as release locations or release dates). Best results with the ink were obtained by automatically applying a short burst of spray to the moths as they were being transferred to a release cage (Wolf and Stimmann *1972*). This method minimized overspraying and exposure to solvent fumes. When moths were confined in a cage while they were sprayed, some were marked excessively, some were not marked, and some became glued to the cage. Such exterior marking invariably reuires extra handling or exposing the insects to abnormal conditions. For example, anesthetizing cabbage looper moths at 10° C or exposure to CO_2 for as little as 10 minutes can reduce mating the first night after treatment (Henneberry and Kishaba *1967*).

A strain of cabbage looper exhibiting a black body phenotype was found and reported by Toba et al. (*1970*). These moths are readily identifiable and have been used successfully in release-recovery experiments (Stimmann et al. *1973*). Butler et al. (*1975*) studied the dark strain and found that larval and pupal development times over a range of 15° C to 30° C were similar to those of the normal strain. Adult longevity was also about the same as that of the normal strain, but eggs require slightly longer to hatch. Although genetic markers eliminate the handling necessary with exterior marking, the number of useful mutations is small. North and Holt (*1968*) used a yellow-eyed mutant in studying radiation-induced sterility in the cabbage looper, and Morgan and Mitchell (*1973*) reported a white cabbage looper mutant.

Other passive markers include materials that may be fed to the larvae or adults. Berry et al. (*1972*) proposed applying rubidium to foliage in the field to mark native insects: Larvae feeding on the plants retained enough rubidium so that it could be detected in the adults. Rubidium can also be fed in artificial diets (Stimmann et al. *1973*). Radioactive isotopes have been used successfully to mark various lepidopteran insects (Flint et al. *1975*) and should be equally useful for cabbage loopers.

The main disadvantage of the use of markers such as rubidium or isotopes is the sophisticated detection equipment required. Simple passive markers such as Calco Oil Red dye can be used to mark the adults and eggs laid by marked females (Wilkinson et al. *1972*). The oil dye (0.05 percent w/v) is fed in diet to the larvae, the adults can be visibly identified without special equipment, and eggs laid by marked females can be identified with about 90 percent accuracy.

Preacclimation of Moths for Release

The number of cabbage loopers recaptured is affected both by the handling and the preacclimation. Stimmann and Wolf (*1973*) used looplure-baited electric grid traps to recover 37 percent of moths preacclimated at near ambient field conditions (15° to 42° C) and only 13 percent of those preacclimated at 11° C. The effect was not apparent the second night after release, when recaptures of all moths were similar.

Moths preacclimated before release at temperatures below 15° C lost fewer scales and appeared physically more sound that moths preacclimated at higher temperatures.

Dispersal of Cabbage Looper Moths

Field Releases

Henneberry et al. (*1967*) made three releases of male cabbage looper moths in a 1704-hectare (ha) area at Homes Gardens, Calif. Moths were marked with food colors or rhodamine B dye, and collections were made from 26 blacklight (BL) traps that were unbaited or baited with virgin female cabbage loopers. Released moths were recovered as far as 3.2 km from the release point. The percentage of released moths recovered ranged from 8.33 to 17.32 percent. Of the moths recaptured, 95 percent were caught within 3.0 to 4.3 days after release. Extrapolation of the regression line of recaptures vs. distance indicated that theoretically no moths would have been recaptured beyond 4.6 km and that 90 percent of the estimated recaptures would occur within 1.2 km of the release point. Likewise, R. Gentry, G. H. Smith, and D. F. Johnson, ARS, Quincy, Fla. (unpublished data), released 5,252 male cabbage loopers over a period of 33 days in the center of a 1581-ha area that contained 58 looplure-baited BL traps. Of the moths released, 37 percent were recaptured, and 96 percent of these were caught within 1.6 km of the release point. No moths were recovered beyond 2.4 km. Harstack et al. (*1971*) released marked cabbage loopers at various distances from 40 BL traps to determine trap spacings required to control insect populations. Recaptures were made up to 2.88 km from the release point. They determined that at 488 m, recoveries of released cabbage loopers would be expected to be less than 0.01 percent.

In a 16,576-ha area near Chandler, Ariz., 25 BL traps were arranged in a 5 by 5 grid with 3.2 km between traps. Over a span of 2 1/2 years, 109,311 cabbage looper moths were released near the center of this grid to study their dispersal. Numbers of moths released at one time ranged from 210 to 10,200. The nearest trap was 402 m south of the release point, and the furthest traps were 2.9 km away. No pheromone baits were used.

The first series of releases, totaling 75,676 moths, began May 21, 1965, and continued until March 31, 1966. Trap collections were made daily through March 31, 1966. Until November 13, 1965, the moths were marked with a spot of model enamel placed on the dorsal surface of each wing on the day of eclosion. They were anesthetized with CO_2 for counting and marking and were then provided with 10 percent sucrose solution and held at about 13° C until release. After November 13, the moths were anesthetized, counted, and held as before until the day of release and were then sprayed with food color or rhodamine B dye solutions according to the techniques of Henneberry et al. (*1967*). Thus, these moths were 1 to 4 days old at the time of release.

The percentage of released moths caught was low but generally higher during the warmer months when more native cabbage loopers were being caught (table 1). Thus, the highest recapture rate, 1.39 percent, occurred during September 1965 when the native catch was also the highest. None of the 29,289 moths released during December and January were recovered, and only 6 moths were caught during February and March. Of all 75,676 cabbage loopers released, 0.139 percent were caught the night of release; this represented 70 percent of all marked moths recaptured. An additional 12 percent were caught the next night.

The number of moths captured at various distances and directions from the release point is shown in table 2. Of the released moths recaptured, 113 were caught in the closest trap (402 m south of the release point), 17 at 3.2 km, 8 at 4.5 km, 6 at 6.4 km, 10 at 7.2 km, and 10 at 9.2 km. Of those captured 9.2 km from the release point, two females and one male were captured the nights of release. After nearly all releases, more moths were caught in the single trap located 402 m from the release point (south) than in any other trap.

When one considers the direction of flight of the released moths, the catches in the trap 402 m away must be discounted because this trap was the closest to the release point (of course, some of these moths might have been caught in more southerly traps had they not been stopped). When this was done, there was a definite tendency for the released moths to move east and spread

Release dates	$\bar{X}$ native moths/trap/night	No. released	Percent of released moths captured on indicated nights after release								
			0	1	2	3	4	5	6	7	Total
1965											
May 21-26	58.30	1,230	0	.081	0	0	0.081	0.081	0	0	0.244
June 4-24	31.90	3,983	.025	.050	.050	.025	0	0	0	0	.151
July 1-27	34.17	6,784	.044	.162	.014	.044	0	.014	.088	.014	.383
Aug. 4-26	71.60	2,921	0	.034	0	0	0	0	.034	.034	.103
Sept. 1-28	151.50	6,260	1.309	.031	.015	.015	0	.015	0	0	1.390
Oct. 8-29	11.41	5,336	.187	.018	.018	.018	0	.018	0	0	.262
Nov. 4-26	1.00	4,142	.097	0	0	0	.024	0	0	0	.121
Dec. 3-31	0.04	15,000	None recaptured								
1966											
Jan. 7-31	0.001	14,289	None recaptured								
Feb. 5-26	0.004	7,580	.013	0	0	0	0	0	.013	0	.026
March 4-31	0.780	8,151	.049	0	0	0	0	0	0	0	.049
Totals	—	75,676	.139	.022	.007	.008	.001	.004	.001	.003	.198

Table 1.—*Recovery of cabbage looper moths released at the center of a 16,576-hectare area with 25 blacklight traps, Chandler, Ariz.*

north and south. When the study area is divided by a north-south line running through the center and catches on the line are discounted, 34 released moths were captured to the east of the line; only 8 were captured to the west of it.

In late 1966, three special releases were made to determine whether looplure baits on sand (Wolf et al. *1967*) for the first two releases, and in wick dispensers (Debolt *1970*) for the last release could increase the catches of released cabbage looper moths in the BL traps during periods of low native catches. Unsexed laboratory-reared moths were anesthetized, sprayed with food coloring, and released at the central point as before. The number released, the percentage recaptured, and the mean captures of native males are shown in table 3. The catch of native female moths in the traps was quite low and no released females were recaptured; however, the looplure resulted in higher native male catches and recaptures of released males when populations were quite low.

A second series of tests was made at Date Creek, Ariz., in a 4-ha lettuce field from February 24 to May 12, 1968. Before March 19, two looplure-baited BL traps were located approximately 91 m south and 3.2 km southeast of the lettuce, and after that date, four looplure-baited maze traps (Killinen and Ost *1971*) were located approximately 46 m northwest, 0.8 m south, 3.2 km east-southeast, and 3.2 km northeast of the lettuce. Light traps were operated 3 nights weekly and maze traps captured moths continually. Unsexed moths 2 to 4 days after eclosion were sprayed with an aqueous solution of food color or rhodamine B dye containing 1 percent tepa. After 24 hours, the moths were chilled to about 4.5° C, packed in 3.8-L ice cream cartons with layers of moths separated by paper toweling, and transported to the field at this temperature. (Thus, the moths were held at about 4.5° C for 3 to 4 hours.) A total of 145,350 moths were released. Numbers released and numbers recaptured at various locations are reported in table 4. Three releases, totaling 41,000 moths made between March 2 and March 15 for which there were no recoveries, are not shown in the table.

As at Chandler, most moths were recovered from the traps (maze and BL) closest to the release point. Recaptures again increased as the native catches increased. Eleven released moths were caught in traps 3.2 km from the release point. One male cabbage looper was captured 19 to 22 days after its February 24 release, and another male was captured 28 to 31 days after release on March 28. Only three released females were recaptured from the BL trap 91 m south of the lettuce field.

A third series of tests was made on a 7682-ha lettuce ranch at Red Rock, Ariz. where from March 1967 through November 1969, 415 looplure-baited BL traps were operated (Wolf et al. *1969*; Ford et al. *1972*). Three special releases of marked cabbage looper moths were made during August and September 1969 at a site about 8 km northwest of the BL trap installation. For these releases, pupae were sexed and placed in emergence cages described by Seay et al. (*1971*). The moths emerging (thus collected without cold or CO_2 anesthesia) over 4 days were supplied with 10 percent sucrose solution and held at 21° to 29° C. Adult males and females were kept about 12.9 km apart to prevent possible male habituation to the female sex pheromone). A chromatograph sprayer was used to spray the moths with colored inks (Wolf and Stimmann *1972*). On the day of release, the moths were brought to ambient temperatures by placing them outside in the shade. Collections were made for 2 nights from 36 survey-type BL traps on the ranch and 9 located about 1.6 km outside the ranch. The numbers of cabbage loopers released, numbers recovered on the lettuce ranch, and the approximate distances flown are shown in table 5. One male was captured about 14.5 km from the release point on the night of release. Many recaptured moths had

Table 2.—*Numbers of released cabbage looper moths captured in blacklight and maze traps at different distances and directions from a central release point, Chandler, Ariz.*[1]

From release point: km and direction	No. released cabbage looper moths captured in month indicated[2] [3]																							
	M	J	J		A		S		O		N		F	M	A	Totals								
			♂	♀	♂	♀	♂	♀	♂	♀	♂	♀				♂+♀								
0.4 S	1	3	9	1	1		43	30	6	4	1	1	2	3	8	113								
3.2 S			1	1				1								3								
3.2 E	1	1	6	1				1								10								
3.2 N			1					1								2								
3.2 W			1					1								2								
4.5 SE												1				1								
4.5 NE		1	2		1										1	5								
4.5 NW								1		1						2								
4.5 SW																0								
6.4 S								1			1				2	4								
6.4 E			1	1												2								
6.4 N																0								
6.4 W																0								
7.2 SSE							1	2								3								
7.2 ESE			1									1				2								
7.2 ENE								1								1								
7.2 NNE										1						1								
7.2 NNW									1							1								
7.2 WNW																0								
7.2 WSW																0								
7.2 SSW								1						1		2								
9.2 SE								2				1			1	4								
9.2 NE			1		1		1		1						1	5								
9.2 NW																0								
9.2 SW															1	1								

[1]No moths recovered during December and January.
[2]Order of month from left to right is May, June, July, August, September, October, November, February, March, and April.
[3]Moths captured in May, June, February, March, and April were not sexed.

either passed over a larger number of light traps to reach the trap in which they were caught or had to fly past the ranch and approach from a southerly direction after random flight.

From 1970 to 1973, movement of cabbage loopers between St. George Island, Fla., and the mainland (6.4 km distant) was studied by making releases of marked moths of the Riverside strain, laboratory-reared for over 100 generations. (The researchers included P. D. Lingren, T. J. Henneberry, A. H. Baumhover, H. H. Toba, D. T. North, G. G. Holt, F. I. Proshold of USDA, and D. L. Williamson, G. L. Greene, and P. B. Martin of the University of Florida.) Throughout 1970, several releases were made on both the island and the mainland. Only 1 released moth was trapped on the mainland of more than 20,000 moths released on the island through relatively large numbers (5 to 213) were recovered on the island. Likewise, 2 moths were trapped on the island as a result of mainland releases of over 9,000 moths. From February through July 1972, only 2 marked (sterile) moths were trapped on the mainland from island releases of about 1.5 million moths. From August 1 to 14, approximately 380,000 moths were released on the island and 13 were caught on the mainland. At almost the same time, the catches of native moths in traps on the mainland increased from 3.5 moths/trap night to 8.7/trap night. Two days later, on the island, catches of native moths increased from 1.2 moths/trap night to 126.3 moths/trap night. Native and marked moths were also recovered in traps from the center of the bay, about 3.2 km from land, during August and September.

From March 26 to May 28, 1973, 950,000 marked cabbage loopers, of a strain selected from St. George Island during the winter, were released on the island. A total of 40 marked moths, some from each release, were trapped on the mainland. The larger number of released moths caught on the mainland during the spring of 1973 (40 moths) vs. the 2 moths in 1972 may reflect a difference between the Riverside and St. George Island strains.

Long Distance Movement

A. N. Sparks, R. D. Jackson of ARS, and C. L. Allen (personal communication) operated BL traps on oil platforms 32, 74, 106, and 161 km from shore in the Gulf of Mexico

Table 3.—*Recovery of cabbage looper moths released at the center of a 16,576-hectare area with 25 sex pheromone-baited blacklight traps, Chandler, Ariz., 1966*

Release dates	$\bar{X}$ native catch/trap/night		No. released	Percent of released moths captured on indicated nights after release[1]							
	♀	♂		0	1[1]	3	4	6	8	15	Total
10/14	0.19	2.38	3,350	0	0	0	0	0.358	0	0.03	0.388
10/21	.004	2.08	2,300	0	0	.043	.043	0	.174	0	.26
12/04	.06	10.17	10,200	.157	.01	.02	0	0	0	0	.187

[1]All moths recaptured were ♂.
[2]Only nights when released moths were caught are shown.

Table 4.—*Recaptures of chemosterilized cabbage looper males released at Date Creek, Ariz. 1968*

Date	$\bar{X}$ native ♂ catch/trap/night[1]		Marked released moths							
					No. ♂ recaptured in					
					BL[2] traps		Maze traps			
	BL traps	Maze traps	No. released	Percent recaptured	91 m S	3.2 km SE	46 m NE	0.8 km S	3.2 km ESE	3.2 km NE
2/24	78		12,000	0.042	4					
3/22	27	139	16,900	.006	1					
3/28	104	128	12,200	.041	3		2			
4/06	95	180	8,300	.096			6	2		
4/12	114	66	14,800	.135	4	1	7	1	2	4
5/04	150	28	5,600	.804	19	4	19	2		
5/12	30	8	18,300	.066	6		6			

[1]For period during which moths from each release were being recaptured.
[2]Blacklight traps.

Table 5.—*Recovery of cabbage looper moths released near Red Rock, Ariz., 1969*

Number released	Number recovered	Approximate distance flown (km)
	Aug. 7	
363 ♂	1	6.4
	1	9.7
	1	10.1
	Aug. 21	
379 ♂	1	11.3
	1	12.1
	1	14.5
1805 ♀	1	12.9
	Sept. 4	
561 ♂	1	10.1
	16	6.4
	3	8.0

south of Jeanerette, La. Traps located 32 and 161 km from shore were operated from September 11 to October 26.

Of the looper moths caught, most were cabbage loopers, but some soybean loopers were also present. The numbers caught at 32, 74, 106, and 161 km from shore were 163, 89, 526, and 631, respectively. Thus, since these flights were over water, large numbers of cabbage loopers appear to be able to travel at least 161 km in a single flight.

Laboratory Studies

A flight mill was developed by Kishaba et al. (*1967*) to study flight characteristics of the cabbage looper. With this apparatus, they determined that individual cabbage loopers flew as far as 196 km. The maximum duration of a single flight was 7 hours, traveling a distance of 4.8 km. The average and maximum speeds were 4.9 and 9.7 km/hour respectively. Female moths were capable of flying greater distances than males, and food in the form of a sucrose solution allowed both males and females to fly further.

Summary and Discussion

These results appear to support other circumstantial evidence that the cabbage looper can and does disperse over long distances. Although no actual migrations have been observed, adults can move at least 161 km, and long distance movements are probably aided by prevailing winds or weather fronts. Laboratory flight mills have shown sustained flight durations that would account for long distance movements in such weather fronts. Population control strategies must, therefore, account for the introduction of fertile insects into a region by atmospheric effects and normal dispersal.

Recaputres of marked moths have detected movements up to 14.5 km in a single night. Such recaptures indicate the flight capability of the release laboratory-reared moths to disperse and do not represent the maximum distance native moths might move.

A variety of marking materials and techniques have been used for cabbage looper release-recovery studies. Marking techniques that do not require anesthetizing probably produce a better (more analogous to the native population) moth for release. Prerelease temperature acclimation of cabbage looper moths can significantly increase recaptures. More research should be done on the effects of prerelease handling and acclimation of cabbage looper and on the effects of various marking techniques, especially when combinations are to be used in a coding system.

Although local movement of cabbage looper may thus be profitably studied with released moths, studies of long range movements have a low probability of success due to rapid dropoff of recaptures with increased distances from release points. The factors influencing long range dispersal of cabbage loopers and the proportions of a population that take part in these dispersal flights are unknown.

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Addendum

An excellent review of the mechanics and pitfalls of tagging lepidopterous insects with external markets is given in a recent publication by Raulston (*1979*). The reader should seek out this article for a more recent update of external marking techniques. An excellent new technique for internally marking dipterous insects has been reported recently by Coppedge et al. *1979*. This technique involves feeding adults a sodium fluorescein dye, which J. R. Raulston (personal communication) has shown works very well with lepidopterous species.

Long range movement of the cabbage looper has been demonstrated in two recent studies (Lingren et al. *1979*; Sparks *1979*). We refer the reader to these articles for an update on more current knowledge on dispersal of the cabbage looper. Also, a recent study by Debolt et al. (*1979*) evaluates the potential of light and sex pheromone traps for control of the cabbage looper on lettuce and gives some information on the dispersal of the species.

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Chapter 4. Potential for Dispersal by Winter Shipments of Vegetables, Ornamental Plants, and Cut Flowers

By S. L. Poe[1] and R. B. Workman[2]

Abstract

Dispersal of cabbage loopers, *Trichoplusia ni* (Hübner), into northern areas where it does not overwinter outdoors is considered. Based on the presence of loopers on vegetables and ornamental cut flowers in Florida and the Gulf States during winter and the large volume of these plants shipped northward during early spring, as well as on personal communication with entomologists in northern areas, a passive intraurban dispersal route is highly probable; however, evidence indicates that cabbage loopers overwinter inside enclosed greenhouse ranges in northern areas where plant production is maintained year round.

Preliminary investigation to determine the sources of early spring populations of cabbage loopers, *Trichoplusia ni* (Hübner), in areas where they are not known to overwinter implicated migration or displacement from areas where the species flourishes year round. One of the possible avenues for this northward movement of the looper is via commodities grown in warm areas and shipped north for consumption.

This portion of the report discusses the potential for such a displacement of the looper on vegetables, ornamental plants, and cut flowers, exclusive of bedding plants, shipped from three major areas where loopers thrive on winter crops grown for use in northern areas. The three regions are central and southern California, central and southern Florida, and southern Texas. Although winter crops are produced along the gulf coast from Texas to Florida and the cabbage looper undoubtedly overwinters in this area, the number of plants shipped is dwarfed by the much greater volume shipped from the major areas.

Sources of Information

Data were collected from correspondence with State agriculture departments, entomologists, county agents, regional plant inspectors, nurserymen, flower producers, shippers, consumers, and from personal investigations. Numerical data were obtained from (1) Marketing Florida Ornamental Crops Summary 1971 Season, USDA, Consumer and Marketing Service and Florida Department of Agriculture and Consumer Services and (2) Flower and Foliage Plants, Statistical Report Service, Crop Report Board USDA, Production and Sales, 1971 with intentions for 1973.

Vegetables

Although published reports on the transport of cabbage loopers on vegetables from one area to another in North America are lacking, several workers indicated that transport on vegetables was feasible and some had observed it (personal communications: R. B. Chalfant, Univ. of Georgia; L. W. Getzin, Washington State Univ.; G. L. Greene, Kansas State Univ.; R. N. Hofmaster, Virginia Polytechnic Institute and State Univ.; and R. B. Workman, Univ. of Florida). Life stages included mostly eggs and larvae shipped on transplants between different areas and on the wrapper leaves of cabbage in the market. In spite of these observations, adult migration was thought the main source of the loopers in more northern areas; however, cabbage looper infested transplants may furnish a nucleus for early populations when shipped to distant growing areas in early spring. In the fall, cabbage transplants are shipped from North Carolina and Georgia southward. In spring, cabbage, cauliflower, pepper, tomato, and other transplants are shipped from Florida, Georgia, and North Carolina to northern States and Canada. Alabama cabbage transplants are shipped to cabbage growing areas of the Midwest. There is little shipment of crucifer transplants on the U.S. West Coast; however, Paul Gerhardt (personal communication) reported that some California grown vegetable transplants are sold at plant nurseries in Arizona for homeowner use.

Volume shipments of produce that may carry cabbage looper eggs, larvae, or pupae include cabbage, crucifer, lettuce, and other leafy vegetables. These shipments may travel long distances from the harvesting area to a consumer area, often when host crops are being grown where the produce is consumed. Disposal methods of the unsaleable plant portions, such as wrapper leaves and trimmings, removed before sale might serve to inoculate crops in the area.

If research of numbers of cabbage loopers at points of destination proves transport to be an important source of cabbage looper populations, harvesting and packing without the nonsaleable or outer plant portions would help to reduce not only insects, but also insect damage, insecticide residues, shipping costs, and removal and disposal costs at the destination.

Woody Ornamentals

In general, wood (containerized) ornamentals were not considered to be a significant means of dispersal for the looper. In Florida and California, the hardy ornamental plants are grown for local intrastate consumption and are usually of tropical or semitropical origin and therefore

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[1]Professor and Head of Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg, Va. 24061.

[2]Associate Professor of Entomology, University of Florida Agriculture Research Center, Hastings, Fl. 32045.

unfit for use in northern landscapes. Plants grown in central and south Florida are shipped no further than Jacksonville or Tallahassee except where a few were used as houseplants. Most nurserymen and producers did not consider the looper as a serious pest of their commodities and many did not even recognize the larva.

Cut Flowers

Several species of cut flowers are known to host cabbage loopers and are grown commercially in California, Florida, and Texas. These include:

Aster	Gladiolus
Carnation	Gypsophila
Chrysanthemum	Snapdragon
Delphinium	Statice

Of these flowers, asters, carnation, and delphinium constitute a very minor portion of total volume grown outdoors in Florida, and although produced in greater quantities in California most production is enclosed or in greenhouses kept free of loopers. Due to the plant growth habit of *Gypsophila* (baby's breath) and statice, where only the flower, devoid of foliage, is harvested, use of these plants in looper dispersion was considered unlikely.

The three remaining species are excellent hosts for the looper. *T. ni* is a major pest on two of the three and readily completes its life cycle on these plants. These plants constitute the largest volume of cut flowers shipped and also provide the best potential for looper movement; thus, they will be considered further.

Culture of Cut Flowers Relative to Looper Development

Gladiolus is grown outdoors in California and in Florida from corms planted seasonally or held annually in the field. The flower spikes are produced quickly and are cut as the florets begin to show color. Then the flowers are graded, bunched, packed, and shipped. One spike is produced per corm, but the plant is left in the field for several weeks after the flowers have been harvested to permit the new corm to develop. This corm is then harvested for the following crop.

Cabbage looper eggs are deposited, and larvae consume foliage, flower spike, or floret of the gladiolus. Since the period of time between spike formation and its harvest is short, any loopers on these plants would be early instars or eggs. Large looper larvae are rarely observed in fields because of a rigorous spray schedule followed to protect the developing spike.

Chrysanthemum and snapdragon provide better accommodations for the looper due to the density of plants in beds under screen cages or in the open. These crops are grown on 3-foot wide raised beds 24 to 30 stems per square yard, supported with grid mesh. Lights are used at night to increase photoperiod and serve to attract many insects, including the looper. Eggs are deposited on the plants, and larvae mature rapidly and pupate in a cocoon prepared beneath a folded leaf.

Larvae and cocoons with pupae or cocoons from which moths have emerged are frequently observed on mature flowers in the field and in the sorting and packing areas. In spite of their frequency in these quarters, no numerical data are available to show actual shipment. Verbal verification from floriculture researchers and florists in northern areas has been obtained which attests to the presence of loopers on Florida grown flowers. Because most flowers are sent to areas where the looper is common, no quarantine inspection is made; hence data are not kept on infestations by this pest at shipping time.

Although no concrete data are available, the circumstantial evidence is overwhelming and the opportunities of shipment are multiple.

Cut flowers are shipped almost daily from fall until late spring. Peak seasons are holidays—Valentine's Day, Mother's Day, and Easter—which are key periods for shipments of flowers to northern areas from which populations of loopers may then subsequently develop in early spring.

The volume of gladiolus sent from California and Florida has increased steadily since 1949 (table 1) and now exceeds 200 million spikes per year. In recent years, more than 70 percent of these have gone to north-central and northeast markets (table 2).

The number of chrysanthemum grown as pompons and standards is no less staggering (table 3) and has increased from less than 20 million blooms in 1949 to almost 230 million in 1972. Records of 1969–71 (table 4) indicate that almost 90 percent of those shipped from Florida were sold in north-central and northeastern

Table 1.—*Gladiolus spikes sold in northern United States from California and Florida*[1]

Year	California number (X 1,000)	Florida number (X 1,000)	Total number (X 1,000)
1949	19,440	152,664	172,104
1959	29,868	181,092	210,960
1969	30,792	208,392	239,184
1972	30,912	181,488	212,400

[1]From USDA, Consumer and Marketing Service, and Fla. Dept. Agr. and Consumer Services, Marketing Florida Ornamental Crops Summary 1971 Season.

Table 2.—*Gladiolus spikes shipped to northern United States from Florida during 1969-71*[1]

Destination	1968-69 Number (X 1,000)	1968-69 percent	1969-70 Number (X 1,000)	1969-70 percent	1970-71 Number (X 1,000)	1970-71 percent
Conn., Maine, Mass., N.H., R.I., Vt.	13,750	7	12,250	7	13,500	8
N.J., N.Y. Pa.	40,750	22	38,500	23	40,250	23
N.Y., Pa.	16,750	9	12,500	8	11,000	6
Del., Md., Va., W. Va., D.C. N.C., S.C.	24,000	13	22,250	13	26,750	15
Ind., Mich., Ohio, Ill., Wis.	40,500	22	34,750	21	31,000	18
	135,750	73	120,250	72	122,500	70

[1]From USDA, Consumer and Marketing Service, and Fla. Dept. Agr. and Consumer Services, Marketing Florida Ornamental Crops Summary 1971 Season.

Table 3.—*Chrysanthemum blooms sold in northern United States from California and Florida.*[1]

Year	Pompons (X 1,000)		Standards (X 1,000)		Total (X 1,000)		
	CA	FL	CA	FL	CA	FL	Both
1949	10,716	156	7,842	84	18,558	240	18,798
1959	23,716	45,822	36,579	2,199	60,195	48,021	108,216
1969	57,426	80,682	70,654	10,042	128,080	90,724	218,804
1972	71,808	74,772	75,093	7,390	146,901	82,162	229,063

[1]From USDA, Consumer and Marketing Service, and Fla. Dept. Agr. and Consumer Services, Marketing Florida Ornamental Crops Summary 1971 Season.

Table 4.—*Chrysanthemum blooms (85 percent pompons, 15 percent standards) shipped to northern United States from Florida during 1969-71*[1]

Destination	1968-69 Number (X 1,000)	1968-69 percent	1969-70 Number (X 1,000)	1969-70 percent	1970-71 Number (X 1,000)	1970-71 percent
Conn., Maine, Mass., N.H., R.I., Vt.	10,296	11	10,608	12	10,764	12
N.J., N.Y., Pa.	36,504	38	32,448	36	30,264	34
N.Y., Pa.	9,828	10	8,892	10	7,800	9
Del., Md., Va., W. Va., D.C. N.C., S.C.	12,480	13	13,260	15	15,600	18
Ind., Mich., Ohio, Ill., Wis.	15,912	16	14,040	16	11,544	13
	85,020	88	79,248	89	75,972	86

[1]From USDA, Consumer and Marketing Service, and Fla. Dept. Agr. and Consumer Services, Marketing Florida Ornamental Crops Summary 1971 Season.

markets. In addition, the seasonal shipping pattern reflects that half of these are shipped between February and May each year.

Personal communications from entomologists concerned with floricultural crops at Ohio State University (R. K. Lindquist) and at the University of Maryland (F. F. Smith and Ralph Webb) indicate that cabbage loopers overwinter inside glasshouses. Larvae are commonly observed on snapdragon, chrysanthemum, and lettuce as well as other crops during the winter months in these areas.

The presence of high levels of methomyl resistance in cabbage looper populations in New York (A. C. Davis, N.Y. Agric. Expt. Stn.; personal communication) in late 1972 then again in 1973 during early spring suggests that populations may overwinter in sheltered areas. This is especially meaningful since no methomyl resistance has been encountered in the Florida cabbage looper population.

Summary
The presence of looper infestations on Florida vegetables and ornamental flowers at maturity, their appearance in packing and shipping areas, their secretive pupation sites on their host, plus the multiple opportunities of being included with the large volume of plants shipped at the time of year when survival would be most likely provide incriminating circumstantial evidence that this source contributes to dispersion of loopers northward each spring. However, only verbal verification has been obtained that loopers were present in such shipments. No information is available on the survival and subsequent multiplication of any loopers dispersed northward in this fashion. The possibility, even probability, that loopers overwinter in greenhouses in northern areas is great.

Chapter 5. Seasonal Populations of Eggs and Larvae in North America

By G. L. Greene[1]

Abstract

A survey of published and unpublished data on immature infestations of cabbage looper, *Trichoplusia ni* (Hübner), in North America shows the primary population along the eastern and southern coasts. Populations are also reported from the northeastern United States and around the Great Lakes area of the United States and Canada. Few reports are available from the central United States, and limited information is available for populations on wild host plant. The immature forms appear to prefer cruciferous plants. Collards is the preferred crucifer and is recommended as the best plant for seasonal population estimates. The cabbage looper overwinters in southern United States and infestations occur northward as the summer progresses. Migration and transport via seedling plants and mature vegetables are suggested as possible reasons for seasonal infestation in northern areas.

The cabbage looper, *Trichoplusia ni* (Hübner), is a major pest of cruciferous crops in North America. It should make a good target for areawide population suppression programs because of its distribution and overwintering range. To know when to reduce populations, it is necessary to define the natural population cycles. This paper presents an attempt to bring together information on natural populations of cabbage looper eggs and larvae from North America. The paper contains published and previously unpublished data furnished by consent of the researchers who collected the data.

The previously unpublished data were furnished from southern Arizona by R. E. Fye (*1968*)[2], from south Florida by D. O. Wolfenbarger (*1971*)[3], from central Florida by G. L. Greene (*1970*)[4], and from north Florida by G. L. Greene and P. B. Martin (*1973*)[5]. The counts from Arizona were made on 200 to 1,200 cotton plants from several fields at about weekly intervals. The fields were treated with insecticides so populaton counts should be lower than one would normally find in untreated fields. The counts from south and north Florida were from weekly samples of 12 to 200 untreated collard plants, and those made in central Florida were from weekly samples of 100 untreated cabbage plants.

The sample units in each of the published and unpublished reports were not standardized in that some report numbers of eggs and/or larvae per plant, per 100 plants, per acre, per hour search, and so forth. To make samples comparable, the various reports have been converted to eggs or larvae per plant. The adjustments were not always totally accurate; therefore, one should seek the original reports for more accurate density assessments.

A map of the distribution of reports of immature cabbage looper and dates of the reports in North America are shown in figure 1. The map indicates fairly intensive reporting from the south and east coasts and southern California with a couple of reports around the Great Lakes. More effort needs to be given to sampling inland areas to better define the distribution and generation cycling of the species. Data on adult populations should be collected at the same time and correlated with immature forms to obtain a better assessment of the actual generation dynamics of populations throughout North America.

Population densities gleaned from several of the reports from various areas and host plants are graphed in figures 2 to 4. Reports of populations that are not graphed include Harcourt (*1965*), who reported cabbage loopers on crucifers during the summer in Canada; McKinney (*1944*), who reported the pest on lettuce and Arizona desert flora during the fall; Wilson (*1956*), who reported populations on commercially grown cabbage in central Florida during the winter; Elsey and Rabb (*1967*), who

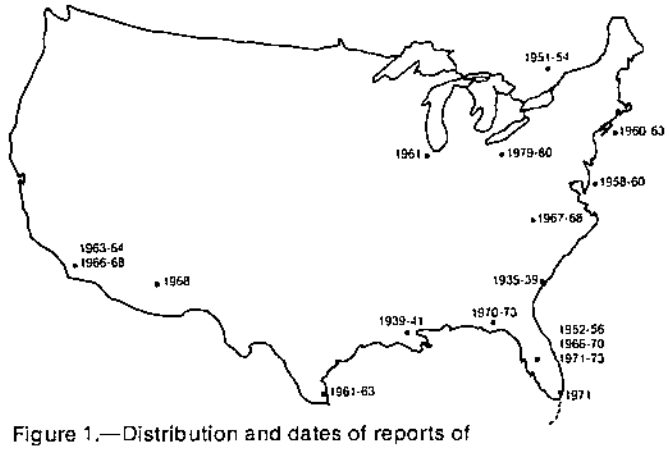

Figure 1.—Distribution and dates of reports of cabbage looper eggs and larvae in North America.

[1]Professor of Entomology and Station Director, Kansas Experiment Station, Garden City, Kans. 66506.

[2]Fye, R. B. 1968. The lepidopterous egg and larval densities in cotton in conjunction with the Red Rock Light Project in 1968. Special Rept. USDA, ARS, Tucson, Ariz.

[3]Wolfenbarger, D. O. 1971. Data collected at Univ. of Fla. Agric. Res and Educ. Center, Homestead, Fla.

[4]Greene, G. L. 1970. Progress reports. Univ. of Fla. Central Florida Experiment Sta., Sanford, Fla.

[5]Greene, G. L. and P. B. Martin (1973). Data collected at Univ. of Fla. Agric. Res. and Educ. Center, Quincy, Fla.

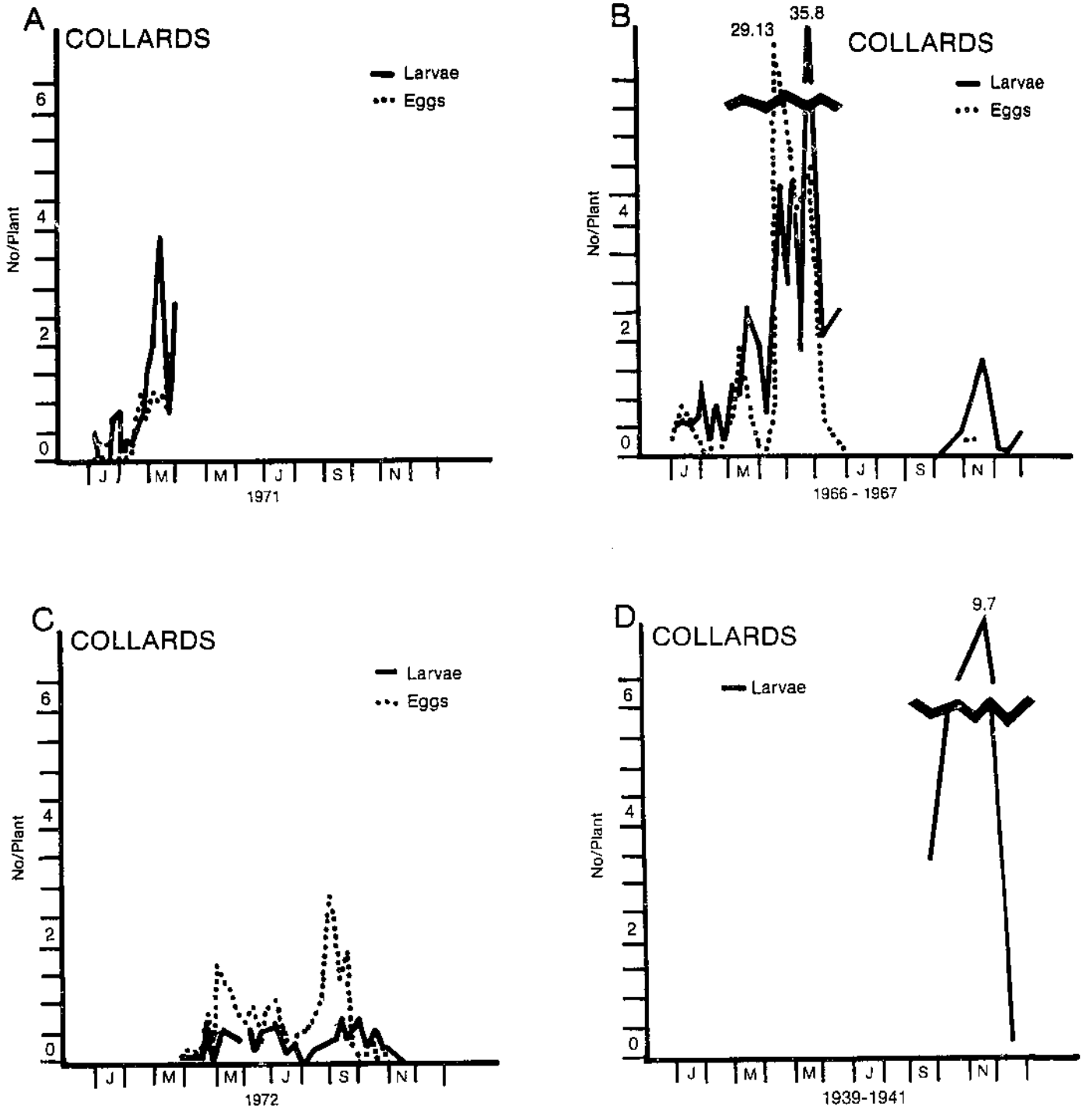

Figure 2.—Average numbers of cabbage looper eggs and larvae on collard plants receiving no or very limited insecticide treatment: A=(D. O. Wolfenbarger, Homestead, Fla., unpublished report); B=(G. L. Greene, Sanford, Fla., unpublished report); C=(G. L. Greene and P. B. Martin, Quincy, Fla., unpublished report); and D=Harrison and Brubaker (*1941*), Baton Rouge, La.

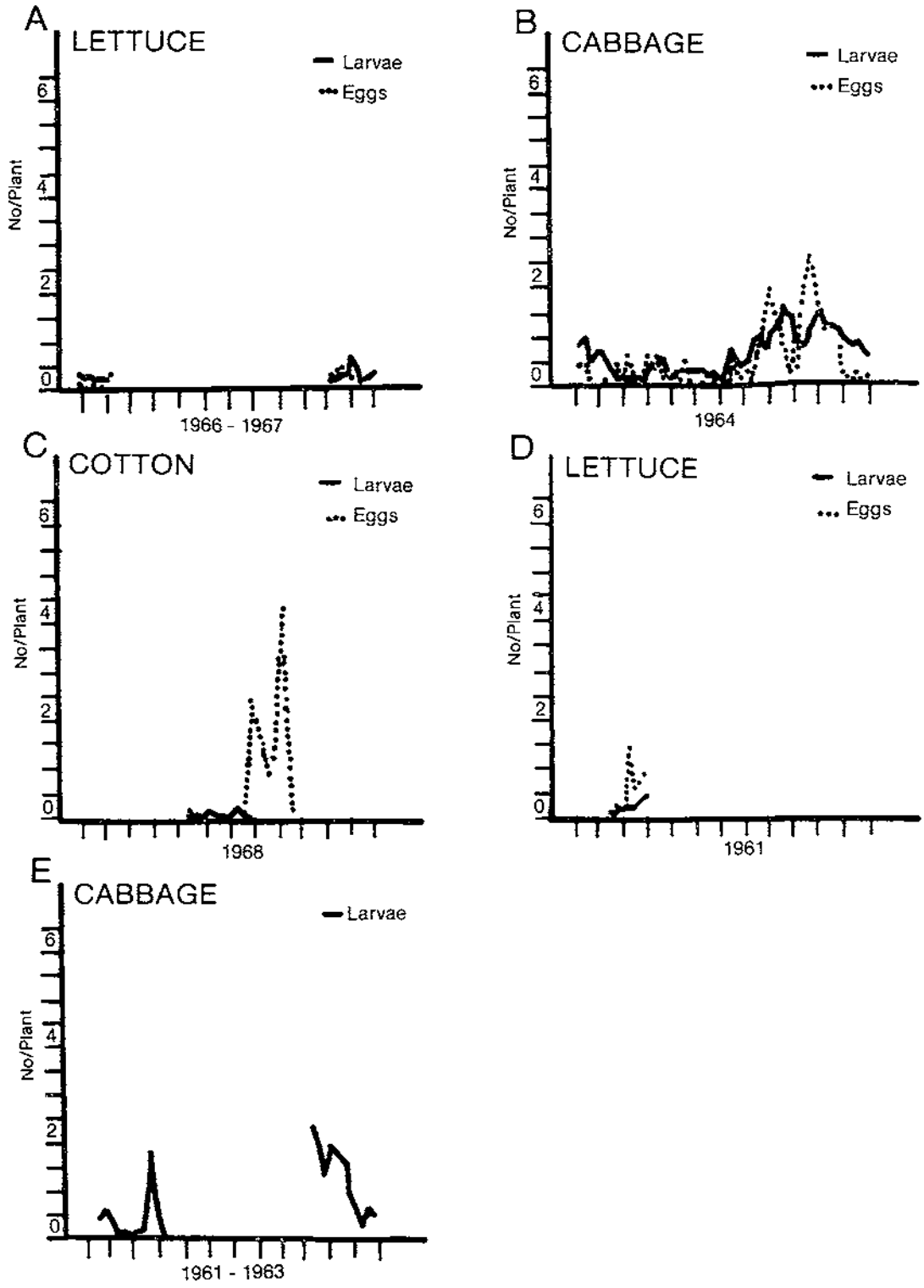

Figure 3.—Average numbers of cabbage looper eggs and larvae on several host plants in the southern United States: A=winter lettuce in southern California, Oatman and Platner (*1972*), untreated; B=Cabbage in southern California, Oatman and Platner (*1969*), untreated; C=Cotton in Arizona (R. B. Fye, Tucson, Ariz., unpublished report), commercially treated; D=Spring lettuce, Schuster (*1966*), untreated; and E=Winter cabbage, Wolfenbarger (*1967*), untreated.

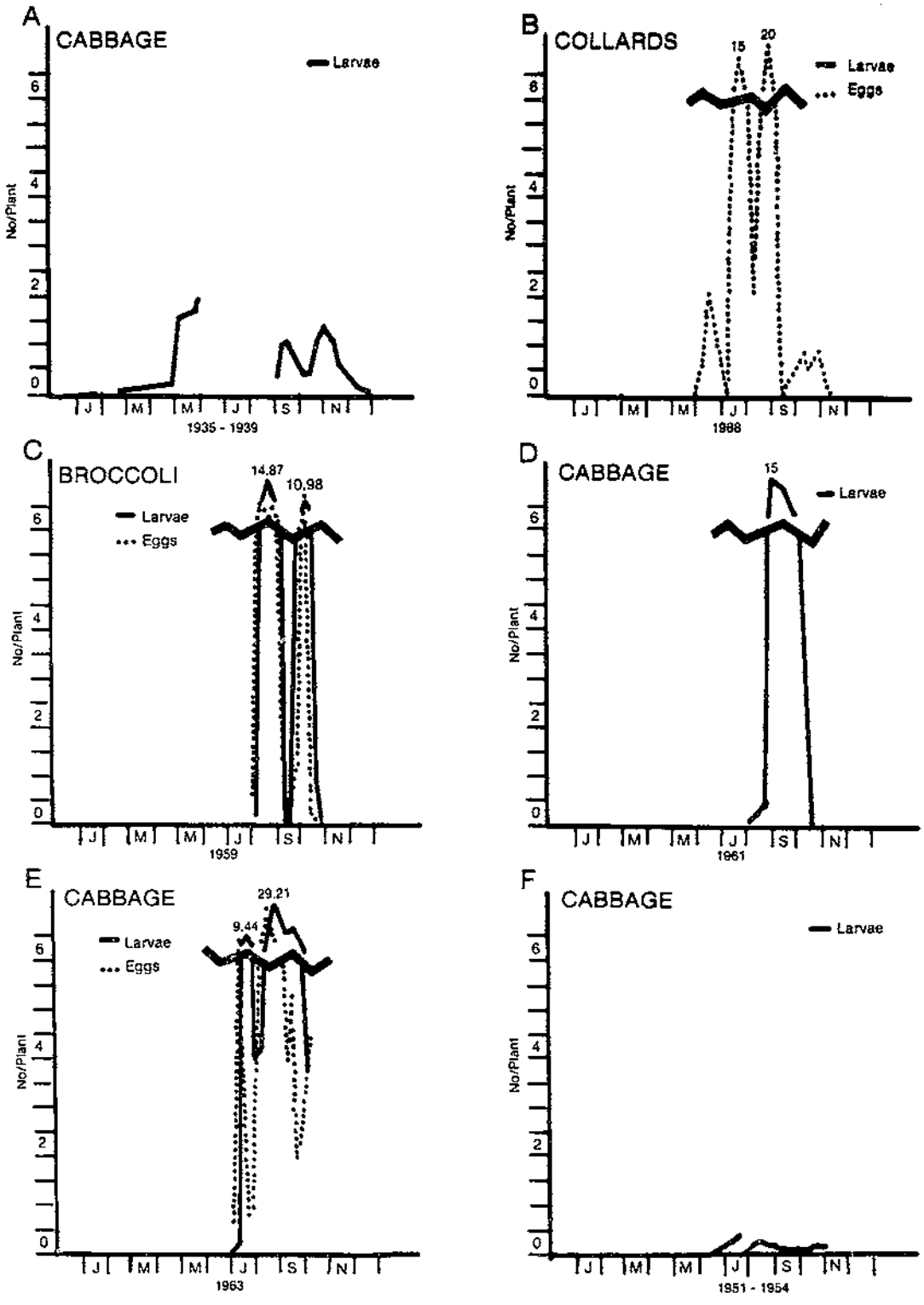

Figure 4.—Average numbers of cabbage looper eggs and larvae on cruciferous plants grown in several different areas: A=Cabbage in South Carolina, Reid and Bare (*1952*), varied insecticide treatments; B=Collards in North Carolina Elsey and Rabb (*1970*), untreated; C=Broccoli in Virginia, Hoffmaster (*1961*), untreated; D=Cabbage in Wisconsin, Radcliffe and Chapman (*1965*), untreated; E=Cabbage in New York, Sutherland (*1966*), untreated; and F=Cabbage in Canada, Harcourt et al. (*1955*), from untreated rows in treated fields.

reported populations on tobacco in North Carolina during the summer; Oatman and Platner (*1967*), who reported the pest on cabbage in southern California throughout the year; Simonet and Morisak (*1982*), who reported populations on cabbage in Ohio during the summer; and Parencia et al. (*1962*), who reported cabbage loopers on cotton during July in north-central Texas.

The reports in general show that the cabbage looper prefers cruciferous plants over other host plants. In addition, there appears to be limited published information on immature populations attacking wild host plant and ornamentals. More efforts should be given to defining populations on these types of plants and determining their influence on the overall population, especially in overwintering areas.

Several studies have been reported on preference within the cruciferous group (Greene *1970*; Sutherland *1966*; Elsey and Rabb *1970*; Harrison and Brubaker *1943*; Radcliffe and Chapman *1965*). The reports indicate that collards are among the most preferred crucifers. They appear to be the best plant for determining seasonal population dynamics. Obviously, the type and condition of the plant being sampled greatly affect the population density of immature cabbage loopers. Plants in a healthy growing condition yield more eggs and larvae than young or old plants. Elsey and Rabb (*1970*) resolved this problem by maintaining a relatively stable growth condition and leaf area in collards through removal of older leaves after each sampling interval.

Most reports of cabbage looper immature infestations show generation cycles even in areas where year around survival occurs (figs. 2*B*, *C* and 3*B*). This may be due to a host plant condition effect rather than a true population cycle because Sutherland (*1966*) found population peaks at similar times of the year regardless of the maturity of host plants. On the other hand, Greene (*1970*) found that plant maturity greatly influenced the time and occurrence of peak populations. The major difference in these two reports is that one was from New York where overwintering does not occur and the other was from central Florida where continuous generations can occur throughout the year. Therefore, it is likely that the limited growing season and lack of overwintering in northern areas tend to strongly influence population cycles.

The data shown in figures 2*B*, *C*, and 3*B* definitely show that the cabbage looper can overwinter in southern areas of the United States. There appears to be six or more generations in these areas. Elsey and Rabb (*1970*) demonstrated that the looper does not overwinter in North Carolina where a winter break in the population occurs and limits the generations to five or less. Further north in New York (Sutherland *1960*), in Wisconsin (Radcliffe and Chapman *1965*), and in Canada (Harcourt et al. *1955*), only three or less generations occur during the summer (fig 4). Therefore, adults probably move from the southern overwintering areas to infest areas to the north. Populations may also establish in northern areas through shipments of infested market vegetables and/or seedling plants grown in the infested overwintering areas of the southern United States. Certainly, the confinement of the cabbage looper population to southern overwintering zones makes it a good target for areawide pest control procedures.

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Chapter 6. Larval Population Sampling and Economic Thresholds

By Merle Shepard[1] and G. L. Greene[2]

Abstract

Basic sampling principles and economic thresholds are considered for larvae of the cabbage looper, *Trichoplusia ni* (Hübner). Factors such as budget, manpower, time, and precision are interrelated and dictate the sampling design for a given need. Larval feeding results in damage to the fruit of various crops, but for the most part market conditions have a direct influence on the quality ratings. Therefore, economic thresholds fluctuate widely and will continue to do so as long as a standard grading system is lacking.

Basic sampling principles for populations of the cabbage looper, *Trichoplusia ni* (Hübner), larvae are comparable to those for many other foliage dwelling insects. Practical considerations such as budget, manpower, and time available often dictate the degree of precision to which sampling programs can be developed or implemented. Determination of a specific sampling design depends entirely upon the objectives of the sampling effort, that is, whether extensive or intensive censusing of the population is required. Too few samples are often taken for studies involving indepth investigations of population dynamics, and more examples than necessary may be taken for descriptions of general trends in population fluctuations. A serious shortcoming in sampling methodology arises from lack of understanding of the cost (in time and money) involved in taking samples. Proper allocation of sampling resources can be decided upon only after determination of the degree of precision required for a particular study. Karandinos (*1976*) published a compilation of formulae relative to determination of optimum sample size for estimating insect populations.

Design of a sampling plan for the cabbage looper must rely on the best statistical procedures along with the most efficient sampling technique. Unless the actual mechanics of collecting the sample can be accomplished with relative ease and reliability, efforts to accomplish mathematical precision may be difficult to achieve.

The spatial arrangement of looper larvae and eggs in the field is important for development of sampling plans. Morris (*1960*) and Southwood (*1966*) presented a review of the subject of distribution of insects and pointed out necessary procedures for determining randomness (or nonrandomness) in a population.

After samples of cabbage loopers are taken, if field data are subject to analysis of variance techniques, transformation of these data is necessary when clumping is evident in order to stabilize mean and variance. For cabbage looper larvae, Harcourt (*1965*) suggested log $(X + K/2)$, $\sqrt{K}\ \mathrm{Sinh}^{-1}$, $\sqrt{X/K}$, Taylor's power law $X^{.37}$ (Taylor *1961*), or more conveniently, log $(X + 1)$. Distribution information is also essential for establishment of sequential sampling models, which are becoming increasingly popular and useful in pest management programs (Onsager *1976*).

The negative binomial distribution is characteristic of the mathematical distribution of *T. ni* in cauliflower, cabbage, broccoli, and brussel sprouts (Harcourt *1965*). This aggregated or clumped distribution was attributed to initial nonrandom deposition of eggs, and the tendency to clump was relaxed with development of the immature stages. This was reflected by the parameter K of the negative binomial, which ranged from 1.72 for eggs to 2.42 for pupae. In soybeans, Shepard and Carner (*1976*) suggested that the distribution of loopers (*T. ni* and *Pseudoplusia includens* (Walker)) follows a Poisson series.

Because of the heterogeneous larval populations of *Heliothis* spp. in cotton, Kuehl and Fye (*1970*) suggested stratification of the fields into a grid with one or more samples taken from each block of the grid. This procedure increased relative sampling efficiency and reduced sampling costs by one-third. Stratified random sampling can provide estimates of population size as well as random sampling, and no evidence is available that indicates that purely random samples give different (or better) estimates of total insect populations in the field. J. U. McGuire, Jr., Biometrical Services Staff, ARS, USDA, retired, suggested that randomization of samples for insects in the field is probably not necessary (personal communication). Yates and Finney (*1942*) reported that stratified random samples were usually preferred. In essence, this method is not strictly systematic because all units in the sample universe have an equal chance of being selected. On a practical basis, blocks created by stratification should be sufficiently small to provide an adequate estimate of the mean and variance of a population but large enough for optimum allocation of sampling time.

Determination of the number of samples required to answer questions about a population has always been vexing to entomologists. One may be concerned with either (1) indepth investigations of population dynamics or (2) the detection of general population trends or changes in population size; the choice between these two

[1]Professor of Entomology, Dept. of Entomology, Fisheries, and Wildlife, Clemson Univ., Clemson, S.C. 29631.

[2]Professor of Entomology and Station Director, Kansas Experiment Station, Garden City, Kans. 66506.

alternatives must precede a decision regarding the number of required samples.

Some optimum sample sizes were approximated by Southwood (*1966*) for continuous data from an ecologically homogeneous habitat by the formula:

$$N = \left(\frac{ts}{D\overline{X}}\right)$$

where s = standard deviation, D = required level of accuracy expressed as a decimal, t = obtained from tables but about 2 for more than 10 samples at the 95 percent confidence level. Southwood (*1966*) also presented procedures for testing for clumping the spatial homogeneity of populations. When *T. ni* populations exist as a negative binomial distribution, as reported by Harcourt (*1965*), the following formula proposed by Rojas (*1964*) has been successfully used by Shepard (*1973*) for sampling larvae on cabbage:

$$N = \frac{1/\overline{X} + 1/K}{D^2}$$

where K = dispersion parameter of the negative binomial and D = same as above. Obviously, effort expended to gather data for determination of optimum sample size must be considered with the overall sampling time and cost.

Definition of reliability of samples was presented by Karandinos (*1976*). He suggested that sampling reliability may be defined as (1) the coefficienct of variability or (2) a formal probabilistic statement where the confidence interval is equal to a percent of a parameter or a fixed positive number.

Harcourt (*1962*) developed a formula from variance components and cost for sampling the imported cabbageworm, *Pieris rapae* L., on cabbage:

$$N = \sqrt{(S_s^2/S_p^2)\,(C_p/C_s)}$$

where S_s^2 and S_p^2 are within and between variance components; C_p is the cost of moving from one plant to another and C_s is the cost of sampling one plant. This same procedure should be applicable to immature stages of *T. ni*. Reports of time-budget studies for sampling insects are scarce, and intensive researches involving the cost function associated with sampling *T. ni* are not known.

Equally important as establishment of a sound statistical basis for sampling is determination of the most efficient and practical sampling method. For loopers on cauliflower, Harcourt (*1966*) found the half-plant to be the most suitable sample unit. Shepard et al. (*1974*) reported that both small (<1.25 cm) and large (>1.25 cm) larvae of *T. ni* and *P. includens* were sampled more effectively from soybeans using the ground cloth method. This method involved the use of a 1- by 1.23-m cloth, which was placed on the ground between two soybean rows. One 1.23-m section of row was then slowly bent over the cloth and beaten vigorously, using hands and forearms for about 10 seconds to dislodge the loopers. Those that fell to the cloth were counted and recorded. This method results in more effective and earlier detection of looper populations than do the sweep-net and vacuum suction net (D-vac) methods of sampling. Looper larvae infected with the entomogenous fungus *Nomuraea rileyi* were also more easily detected when sampled by the ground cloth method. Newman and Carner (*1975*) provided evidence that indicated that significantly higher numbers of loopers infected with *Enthomophthora* spp. were sampled using the sweep-net method in soybeans. The reason for this was that infected larvae usually climbed to the top of the plants thereby allowing easier collections to be made by the sweep-net.

Obviously, the sampling method of choice should not damage the host plants or interfere with indigenous populations by removal of significant numbers of loopers from that population. We avoided these problems in soybeans by sampling from a different quadrant around a sampling station each week (Shepard et al. *1974*). For further information about sampling soybean loopers, *P. includens*, in soybeans, see Herzog (*1980*).

Timing of the sampling may be important because of certain behavioral characteristics exhibited by loopers, which may affect their position on the plant during various times during the day. Greene and Morrill (*1970*) showed that cabbage looper larvae displayed a negative phototaxis in light and a positive geotaxis in the dark. In earlier studies, Greene (*1968*) suggested that behavior of cabbage loopers may ultimately affect sampling this species on cabbage plants. His research revealed that the preponderance of looper eggs and larvae were found on the lower surface of the leaves and eggs were mostly within 1 inch of the leaf margin. This phenomenon could be one reason for aggregation tendencies reported by Harcourt (*1965*) and could be important in designing sampling plans.

Emphasis upon modeling insect populations in the field has increased the necessity for obtaining realistic and reliable population estimates. The problem of sampling sparse numbers of insects is particularly difficult but must be dealt with to provide population estimates for certain computer simulations. Knight (*1969*) has provided some useful points associated with sampling low numbers of insects. Computer simulation models of field populations can be tested, refined, and validated only after development of valid sampling methodology that accurately reflects population size.

Another important consideration in constructing a sampling program for cabbage loopers includes estimation of populations by indirect methods such as the damage caused by a certain number of larvae. Greene et al. (*1969*) used a rating system to classify damage to cabbage heads by loopers, and Wolfenbarger (*1967*) calculated numbers of loopers required to reduce the weight of cabbage by various amounts.

The growth stage of plants to be sampled is important in designing a sampling plan for cabbage loopers. With soybeans, removal of over 30 percent of foliage between bloom and pod set may reduce yields while over 50 percent defoliation did not affect yields before plants began to bloom (Turnipseed *1972*). Therefore, sampling for information about treatment decisions at the critical postbloom periods may have to be more frequent than usual.

Sequential sampling is one of the most promising and useful methods. It allows rapid yet accurate decisions to be made by categorizing population levels into "low," "medium," or "high" by providing information on whether to apply a control measure. In addition, the ease with which sampling is effected allows assessment of the control method. The method was developed by Wald (*1947*). Since that time, several researchers have published information on sequential sampling for various species (Pieters *1978*). Harcourt (*1965*) first used this method for determining treatment decisions on cabbage looper larvae on cauliflower. Shepard (*1973*) developed a sequential plan for loopers on cabbage. Sequential techniques require no fixed sample size, with fewer samples necessary when population levels are low or high. Three essential pieces of information are necessary for construction of the model: (1) the insect's mathematical distribution, (2) the economic threshold, and (3) the level of risk that the grower (or sampler) is willing to accept.

Waters (*1955*) has provided the most extensive treatment of the use and development of sequential models of pest insect populations that conform to the negative binomial, binomial, Poisson, and normal distribution. Computer programs developed by Gates and Ethridge (*1972*) have greatly facilitated determination of spatial distributions of insects by fitting field counts of the species in question to several generalized frequency distributions. A computer program for sequential analysis has been published (Talerico and Chapman *1970*).

Operating characteristic and average sample number curves can be calculated to provide insight into the sequential sampling scheme, but these are not necessary for implementation of the model. The most easily utilizable plan is the sequential sampling table.

Using the entire cabbage plant as the sample unit, sequential sampling has resulted in a savings of four insecticide applications on cabbage in the central Florida area without loss of marketable heads (Shepard *1973*). The 2.43-ha commercial fields used for the study had high populations of loopers. Greater savings using the sequential plan would have probably resulted during cooler times of the year when the numbers of loopers were low and samples required to achieve a satisfactory "treat" or "no treat" decision would have been greatly reduced.

Decisions to treat or not to treat are generally based on levels of insect damage. Economic threshold, injury level, and damage threshold are terms used to describe insect damage, which sometimes confuse the user. Stern et al. (*1959*) gave a good description of these terms. Our discussion of this subject will deal with the so-called action threshold, which is described as the insect population level at which action is initiated to prevent further damage or economic crop loss.

The economic threshold levels for cabbage looper damage varies considerably from crop to crop (Harcourt *1966*; Wolfenbarger *1967*; Greene *1972*). This variation results primarily from a quality rating rather than purely quantity or volume of production. The quality of cabbage heads is adversely affected by cabbage looper larval feeding, and the results of damage to heads vary with market conditions. When supplies are below demand, the price or evaluated quality is less reduced than when supplies exceed demand. Changing market acceptance automatically alters the economic threshold levels; therefore, the threshold will fluctuate as long as a standard grading system is lacking. This confusion has led to considerable differences in threshold levels of damage inflicted and numbers of insects per plant tolerances. The stage of plant development when insect population samples are taken also alters the damage levels because vegetative plants can withstand more feeding than can fruiting plants that would receive a quality reduction.

A relatively good summary of the current state of our knowledge of damage levels caused by the cabbage looper is provided by Harcourt (*1966*), Wolfenbarger (*1967*), Greene (*1972*), and Shepard (*1973*). Harcourt (*1966*) considered 0.6 or less larvae per plant as not needing treatment and 0.6 to 1 as the treatment level for cabbage looper larvae on cauliflower. He indicated that this threshold is widely used in New York State as well as in Ottawa, Canada. These damage levels are somewhat higher than those reported on cabbage by Wolfenbarger (*1967*) who showed that 168 small plus 27 large larvae per 100 plants resulted in only 66 percent marketable heads. In another test, however, he showed that 53 small larvae per 100 plants resulted in a 60 percent loss of marketable

heads. Greene (*1972*) reported less than 100 percent marketable cabbage heads when weekly counts of looper larvae surpassed 0.1 per head. Obviously, many factors—including the crop, stage of insect growth, and market demand—influence damage thresholds and make it very difficult to establish broad base action thresholds for the cabbage looper.

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Chapter 7. Computer Simulations of Development

By George D. Butler, Jr.[1]

Abstract

The construction of an input into a computer model to simulate the development of the cabbage looper, *Trichoplusia ni* (Hübner), under fluctuating temperatures is discussed. The uses of the model include estimating the duration of the stages in the life cycle, determining age structure, estimating the numbers of each stage present, and evaluating control actions. The needs for refinement of the model and its application as a research and control tool are discussed.

Considerable work is being done on computer simulation of insect development for modeling and predicting population fluctuations, and models are being prepared for a number of insect species (Stinner et al. *1974*; Gutierrez et al. *1975*).

A team of agricultural and electrical engineers at the University of Arizona has been modeling the cotton agrosystem and has prepared dynamic models of the cotton plant, insect development, and harvesting systems. The insect model, which I have called WATBUG, was written by F. L. Watson (*1973*) and is a generalized model of the life history of an insect. WATBUG is written in FORTRAN IV and is currently being run on a CDC-6400 computer using 70K. An early version was translated for an IBM-650 by K. W. Briggs (unpublished). A logic diagram for the program is shown in figure 1. I have prepared several versions of the program that differ only in relatively minor changes made in the format of the output. One version (P), documented in Watson's University of Arizona dissertation (*1973*), differs from the others in that it uses daily egg laying and egg hatching data at each temperature and includes the death rate of the insect.

Components of the Model

Development Rates

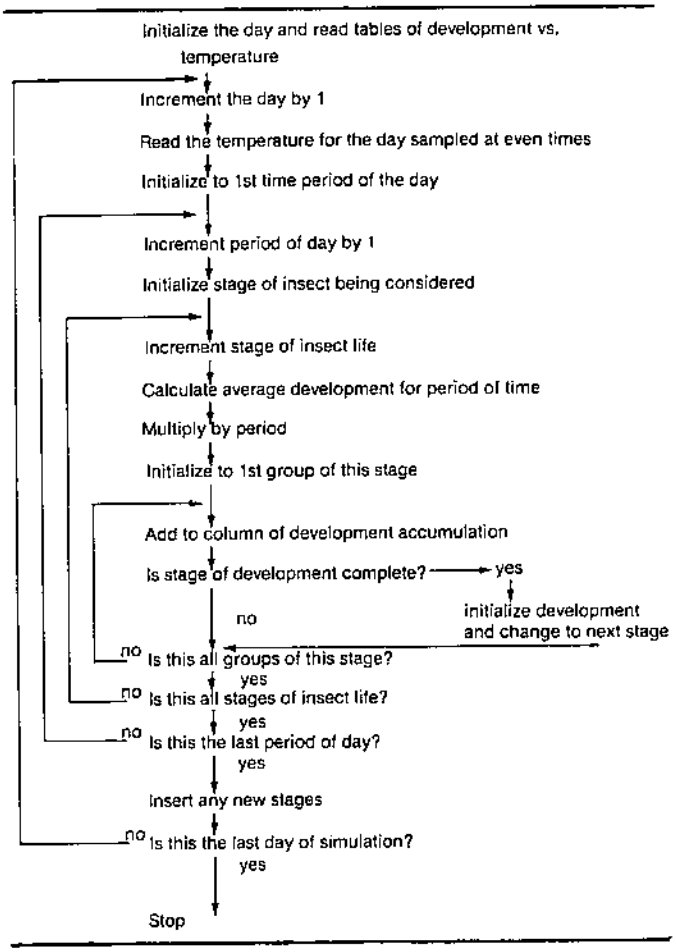
Development of the cabbage looper, *Trichoplusia ni* (Hübner), is based on studies of the different stages conducted at constant temperatures. The computer takes development rates and calculates the proportion of development for any given hourly fluctuating temperature for each day of the simulation. Our program assumes that delay in development is negligible when temperatures change. Biological information from Jackson et al. (*1969*), Fye and McAda (*1972*), Toba et al. (*1973*), and Butler and Hamilton (*1973*) was used to develop the regression equations in table 1. Table 2 presents a more detailed description of the information concerning the biology of the cabbage looper. For example, the duration of the instars was estimated by determining the average percentage duration of each instar from Fye and McAda (*1972*) and Toba et al. (*1973*) and partitioning the proper amounts from the total larval period as shown in table 1.

Mortality Rates

Mortality rates determined at constant temperatures, unlike development rates, cannot be used with fluctuating temperatures; however, some useful information on mortality at fluctuating temperatures is given by Toba et al. (*1973*). New techniques are being developed to provide better estimates of thermal mortality rates.

In addition to the intrinsic mortality effect of temperature, numerous other factors such as parasites, predators, and diseases contribute to mortality. Life tables such as those

Figure 1.—Logic diagram of computer program for WATBUG model.



[1]Research entomologist, Western Cotton Research Laboratory, Agric. Res. Serv., USDA, 4135 E. Broadway Rd., Phoenix, Ariz. 85040.

Table 1.—*Regression equations for the duration (days) of the life stages of the cabbage looper in relation to temperature (° F)*

Stage	Regression equation[1]
Egg	−0.5388 + 0.0111X
Larval	−0.1434 + 0.0027X
Pupal	−0.2499 + 0.0049X
Preoviposition	−1.0498 + 0.0180X
Total egg through preoviposition	−0.0778 + 0.0015X

[1] $\hat{y} = a + bX$, where $\hat{y}$ is the reciprocal of the time in days and X is the temperature in degrees Farenheit.

of Sutherland (*1965*) and Elsey (*1969*) are useful for estimating the magnitude of these mortality factors. The first approximations for WATBUG of survival rates (table 2) from the life tables of Sutherland (*1965*) and Elsey (*1969*) were made for this report and should be considered tentative because considerable subjective judgment was used. Even if these values are reasonable estimates for much of the year, the work with the life table has shown that mortality due to certain factors varies during the year. For example, there is increased mortality in August due to disease and during the fall due to *Voria ruralis* (Fallen).

Temperature

Although every ecology text discusses dozens of environmental factors that affect the mortality and development of organisms, I have found that temperature is by far the most dominant factor. Thus, I think we should see how far we can go with temperature-based models, always being watchful that we consider adding other factors if unexplained deviations occur. Maximum and minimum temperatures (° F) can be used to estimate 3-hr temperatures, or the actual 1-, 2-, or 3-hr temperature records from daily thermograph charts can be used as input for the model.

Potential Uses of the Model

Timing of Events

Timing refers to the duration of time (in days) between stages in the life cycle at a given temperature. The model gives good estimates of the duration of the larval stage of the cabbage looper. Butler et al. (*1976*) using estimates for fluctuating temperatures in the laboratory—from data of Fye and McAda (*1972*), Toba et al. (*1973*), and G. L. Greene (personal communication)—found a good fit of deviations with those obtained for the values given in table 1. They also compared the duration of the larval stage in the field near Charleston, S.C. (C. S. Creighton, personal communication) and at Orlando, Fla. (G. L. Greene, personal communication) with those obtained with the model; the estimates were very close to the observed values.

The time between the peaks of light trap populations can also be determined. I made a detailed study of the light trap records from College Station, Tex., in 1970 (Hollingsworth and Harstack *1970*). The WATBUG model was loaded as for March 1, 1970, with 2 adults and 545 pupae of different ages so that they would develop into moths at the rate demonstrated in the light trap catches during March and April. Since these pupae were sorted into groups according to age, the input of each group could be used separately, and the progeny could be determined through the season. Certain identifiable population peaks were formed by one age group or by the summation of two or more groups. Such information might be useful in evaluating the effect of sterile moth releases or other treatments during specific time periods, or it could be used to indicate when during the season the effects might be expected or when the releases should be made.

Age Structure

Detailed daily life tables can be prepared that show the complete age structure of a cabbage looper population. In Arizona, at least 70 different ages of cabbage looper larvae appear to be present in midwinter and 30 ages on April 1. These represent eggs laid over a 70- and 30-day period, respectively. This detailed information may be useful for parasite studies since *Copidosoma truncatellum* (Dalman) and *V. ruralis* can successfully parasitize only portions of certain developmental stages.

Numbers

There is little use in making extensive simulations of numbers of loopers until more biological inputs are put into the model. However, preliminary simulations have been run, and these indicate that valuable outputs might be produced.

A model without any mortality factors was run with Red Rock, Ariz., temperatures for June to September 1967. The results showed that the densities of the eggs and larvae per acre on cotton increased at the same rate that R. E. Fye (personal communication) had observed. Furthermore, the number of adult moths caught per night in 36 survey traps by O. L. Barnes and J. H. Ford (personal communications) was similar to that produced by the model. According to the simulation, one moth collected per trap per night was equivalent to 1,000 moths per acre.

In addition, several years of simulations have been run for Mesa, Ariz., with the values in table 1. The simulated average rate of buildup from February to September was the same as that observed in light traps, a 10,000-fold increase. A simulation was made for Tifton, Ga., in 1970, and again the general rate of increase was the same as that observed for June to September. A simple model of the buildup of the cabbage looper (Butler et al. *1974*) shows a similar uniform buildup of the populations.

Table 2.—*The duration (days) of the stages of the cabbage looper and the percentage survival (values used in WATBUG, November 14, 1974)*

Temp. °C	1st Stage		2nd Stage		3rd Stage		4th Stage		5th Stage		Prepupal	
	Days in stage	Percent survival	Days in stage	Percent survival	Days in stage	Percent survival	Days in stage	Percent survival	Days in stage	Percent survival	Days in stage	Percent survival
11	1430.0	45	229.0	40	1000.0	25	1321.0	25	1572.0	50	678.0	5
13	20.0	60	16.0	50	14.0	40	18.5	40	22.0	60	9.5	30
15	10.2	70	8.1	60	7.1	50	9.4	50	11.0	85	4.8	75
30	2.1	70	1.7	60	1.5	50	2.0	50	2.3	85	1.0	75
32	1.9	70	1.5	60	1.3	50	1.8	50	2.1	85	.9	70
34	2.0	50	1.6	40	1.4	40	1.8	40	2.2	65	.9	55
36	2.1	45	1.7	35	1.5	20	1.9	20	2.3	60	1.0	50
40	2.5	30	2.0	25	1.8	20	2.3	20	2.8	40	1.2	30
50	2.5	5	2.0	5	1.8	5	2.3	5	2.8	5	1.2	5

Additional information used: Sex ratio is 0.50; adults stop laying eggs after 0.65 of their lives.

Temp. °C	Pupal		Adult		Egg Stage		Egg Laying		
	Days in stage	Percent survival	Days in stage	Percent survival	Days in stage	Percent survival	Days in stage	Percent survival	Preoviposition (days)
5					200.0	5			
10	100.0	50	200.0	50	63.0	20	4.0	99	
15	25.5	95	22.2	50	8.6	40	15.0		100.0
20	12.0	95	9.5	50	54.0	99	5.7		
25	7.9	95					42.0	99	3.0
30	5.8	95			2.4	40	10.0	99	2.0
32			9.5	50	2.2	35	9.0	99	
33	5.1	85							
34					2.3	30			
36			5.7	50	2.4	25			
40	5.0	45			2.9	15			
50	5.0	5			2.9	5			

Control Actions

The most valuable and useful capability of WATBUG is its ability to simulate control actions. A control can be applied on any day, the percentage of each stage that survives can be provided, and the numbers in the model can be reduced accordingly. Recent examples of the usefulness of this capability of WATBUG are found in studies of the control of the corn earworm, *Heliothis zea* (Boddie), on sweet corn in Idaho and of the beet armyworm, *Spodoptera exigua* (Hübner), on chrysanthemums in Florida (Butler and Scott *1976*; Butler et al. *1976*), or a control can be applied automatically when the weighed sum (or the "count") reaches some predetermined threshold value. Another section will predict the accumulated damage to the host plant by the insect by summing the consumption of each stage multiplied by the predicted number of insects in that stage each day. If the amount of damage or consumption is approximated, the accumulated consumption is translated to dollars and can be added to the cost of control. Thus, the cost of control or of no control can be predicted. Finally, this program can be used in connection with a general optimization program to determine when treatments should start.

Needs for Refinement and for Application as a Research and Control Tool

A considerable amount of information is now available concerning the development of the stages of the cabbage looper at constant temperatures. This information can be utilized in the WATBUG model to produce useful predictions relating to the time between events at temperatures below 90° F. Additional biological data are needed for both development rates and mortality rates at temperatures above 90° and below 60°. Likewise, additional information is needed concerning fecundity and egg

hatchability in relation to temperature; however, additional experience is needed to establish how mortality functions can be handled in the model. Information and insight into the dynamics of cabbage looper populations can best be gained by simulating numerous sets of field observations. The information thus gained should give a clearer understanding of the dynamics of the cabbage looper population, which is fundamental to the successes of any area-wide suppression program.

Little is known about how to relate the daily consumption (damage) of each instar of the host plant in terms of the daily cost of damage. Moreover, cabbage looper damage to cotton is indirect, unlike the direct damage to fruiting parts caused by bollworms, *Heliothis* spp., and boll weevils, *Anthonomus grandis* Boheman, because it affects the photosynthetic producing parts of the plants. The damage thus must be evaluated through both the dynamic photosynthetic and fruiting plant systems now modeled by the dynamic computer simulation models of COTTON (Stapleton et al. *1973*) and SIMCOT II (McKinion et al. *1974*). The combination of one of these models with WATBUG would afford a unique technique for evaluating the costs of cabbage looper damage and the relative costs of different treatments and would permit optimization of the timing of control efforts and the setting up of threshold numbers for treatments. This type of model has recently been developed by Gutierrez et al. (*1975*) for cabbage loopers on cotton.

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Chapter 8. Diseases

By C. M. Ignoffo and D. L. Hostetter[1]

Abstract

Pathogenic micro-organisms normally associated with cabbage looper, *Trichoplusia ni* (Hübner), larvae are described as well as the symptoms they produce. About 20 species of micro-organisms, representing viruses, bacteria, protozoans and fungi, have been isolated from cabbage looper larvae. Eight of the 20 species are fungi.

About 20 species of pathogens have been reported from larvae of the cabbage looper, *Trichoplusia ni* (Hübner) (fig. 1). Most of these are from natural infections, although a few were isolated from laboratory-reared *T. ni*. Of these 20 species, 8 are fungi; 6, protozoans; 4, viruses; and 2, bacteria. No rickettsial infection of *T. ni* has ever been recorded. All pathogens were initially isolated from the immature larval stage, although at least one species of each major group has also been isolated from pupae, adults, and even eggs.

[1]Invertebrate pathologist and research entomologist, respectively, Biological Control of Insects Research Unit, Agric. Res. Serv., USDA, P.O. Box A, Research Park, Columbia, Mo. 65205.

Figure 1.—Mature healthy cabbage looper larva feeding on cotton leaves (about 5X).

The causative agent of the reported diseases and the symptoms will be discussed for each group of pathogens.

Causative Agents and Disease Symptoms

Viral Pathogens

The four viruses representing three major viral groups isolated from the cabbage looper include two nuclear polyhedrosis viruses, one cytoplasmic polyhedrosis virus, and one granulosis virus (table 1). An entomopox virus or a noninclusion virus has never been isolated from *T. ni*. The first virus described from *T. ni* was a nuclear polyhedrosis virus (NPV) isolated from larvae feeding on field cabbage (Chapman and Glaser *1915*); however, it was not until later that the causative agent, a singly embedded virion (SEV) (Scott et al. *1971*), and the pathology of the disease (Drake and McEwen *1959*) were described. Another type of NPV that produced symptoms similar to those produced by the SEV was detected in *T. ni* larvae (Heimpel and Adams *1966*). The virus of this new NPV, which contained multiple-embedded virions (MEV) groups in packets, was first found in laboratory cultures and subsequently isolated from larvae collected from cole crops and lettuce. The cytoplasmic polyhedrosis virus (CPV) was both isolated and described by Vail et al. (*1967*) from laboratory cultures of larvae feeding on a semisynthetic diet. The granulosis virus, first detected in field collected larva, was described by Hamm and Paschke (*1963*) and Summers and Paschke (*1970*).

Single-Embedded Nuclear Polyhedrosis Virus (SEV)

Causative Agent

Inclusion bodies of SEV were first observed by Chapman and Glaser (*1915*) although the disease was observed much earlier (Osborn *1893*). The causative agent is a rod-shaped, DNA-enveloped virion belong to the genus *Baculovirus* (Vago et al. *1974*). Virions with an evelope (nucleocapsid) measure 72 by 300nm; those without are 33 by 300 nm (Scott et al. *1971*). Virions are singly embedded within irregular, polyhedral-shaped, proteinaceous inclusion bodies. The inclusion bodies average 1.12±0.24 μ in diameter (Tomkins et al. *1969*). Ultrathin sections of the inclusion bodies reveal a characteristic internal crystalline lattice structure with no apparent disruption of the lattice due to the embedded virions.

Symptoms

The description of external symptoms of this NPV is from Drake and McEwen (*1959*) and Vail and Hall (*1969*). A faint white mottling in the region of the third to sixth abdominal segment is the first external sign of disease in *T. ni* larvae. These symptoms are observed 2 to 3 days after the larvae are fed a high dose of inclusion bodies.

About 3 to 4 days postexposure, about 50 percent of exposed larvae show symptoms, and almost all larvae show symptoms 4 to 5 days postexposure. The faint mottling gradually increases until the entire larva is opaque white or creamy white in color. At this stage, the larvae are swollen, have stopped feeding, and are lethargic compared with the voraciously feeding, aggressive, normal larvae. As the disease progresses, small dark areas appear on the integument, which eventually takes on a shiny luster. Diseased caterpillars crawl to a high place as the disease progresses and die within several hours. Dead larvae are often seen hanging by their prolegs. The first death in a population of young larvae may occur within 2 days of exposure. Shortly after death, the entire body turns brown-black. The integument at death is extremely fragile, and when ruptured releases a dark liquid containing billions of inclusion bodies and lysed tissue.

The description of the internal symptoms induced by the SEV is from Drake and McEwen (*1959*), Heimpel and Adams (*1966*), Mathad et al. (*1968*), Vail and Hall (*1969*), and Vail and Gough (*1970a*). About 2 days after larvae are exposed to a large dose of inclusion bodies, the nuclei of fat body cells and hyperdermal cells are noticeably enlarged, and a chromatin network extends throughout the nucleus. As the infection progresses, the nucleus appears granular because of the formation and accumulation of inclusion bodies. Most nuclei of the fat body cells, tracheal matrix cells, and hypodermal cells contain inclusion bodies by 3 days postexposure. Shortly thereafter, inclusion bodies are observed in the hemocoel, and the blood loses its green color. Inclusion bodies now can be found in the nuclei of nerve and muscle cells. All cells of infected tissue contain inclusion bodies 4 to 5 days postexposure. The following tissues are invaded: fat body, hypodermis, tracheal matrix, blood, connective tissue, wingbuds, Malpighian tubules, testicular sheath, nerve, and muscle (Mathad et al. *1968*). Infection of the midgut epithelium rarely if ever occurs. All tissues infected in larvae were also infected in pupae (Vail and Gough *1970a*).

Multiple-Embedded Nuclear Polyhedrosis (MEV)

Causative Agent

The causative agent of MEV was described by Heimpel and Adams (*1966*). This disease, like the SEV, is caused by a rod-shaped enveloped DNA virion belonging to the genus *Baculovirus* (Vago et al. *1974*); however, several virions are contained within a double developmental membrane that in turn is occluded in angular, more regularly shaped polyhedral inclusion bodies (Tompkins et al. *1969*). There is an average of 4.5±0.1 virions per developmental membrane (Benton et al. *1973*). From published photomicrographs, the size of the isolated virions of the MEV is similar to that of the SEV, that is, 70 by 310 nm. Inclusion bodies average 1.54±0.27 μ in diameter (Tompkins et al. *1969*).

Symptoms

The external symptoms of the MEV in *T. ni* larvae (Tompkins et al. *1969*) are similar to those described for the SEV (Drake and McEwen *1959*). Infected larvae lose their characteristic light green color and change to a creamy-white color 2 to 5 days postinfection. Shortly thereafter, the integument may wrinkle; the anterior and posterior ends of the body shrivel. Symptoms preceding death are similar to those reported for the SEV.

Internally, MEV development is initially in the midgut epithelial cells and shortly thereafter the hemocytes and other tissues are infected. The extent of tissue susceptibility has not been described. Nuclei of infected cells are greatly hypertrophied and may completely displace the cytoplasm. As the nuclei enlarge, adjacent cells become difficult to distinguish. A stromatic network forms in the nuclei of epithelial cells, and discrete inclusion bodies are observed 3 to 4 days postinfection. Connective tissue surrounding the midgut may also be invaded.

Granulosis Virus (GV)

Causative Agent

A granulosis was first detected in *T. ni* larvae by Hamm and Paschke (*1963*). The virion is a rod-shaped particle containing DNA surrounded by a unit-membrane envelope. Virions measure 32 by 317 nm without the envelope and 53 by 360 nm with the envelope (Summers and Paschke *1970*). The virus is placed in the genus *Baculovirus* (Vago et al. *1974*). No detailed description of the inclusion bodies is available; however, they appear morphologically similar to other granuloses (Smith *1967*). The inclusion bodies, also called capsules, are oval shaped and contain one or rarely two virions. A molecular crystalline lattice is visible when an ultrathin section of a capsule is examined under electron microscopy. Subunits of this lattice are cubically arranged with no visible disruption of the lattice due to the presence of virions. Inclusion bodies measure 190 by 530 nm (Summers and Paschke *1970*).

Symptoms

The first obvious external symptom is a pale-yellow body color contrasted with the pale green of normal larvae (Hamm and Paschke *1963*). Later, generally 7 to 9 days after exposure, inclusion bodies within fat bodies show through the integument as white patches. Still later, mature diseased larvae turn pale yellow to white and are slightly swollen compared to normal larvae. Larvae at this stage stop feeding and are noticeably lethargic. This condition may last for 7 to 10 days before death; normal larvae have already pupated. After death, the body color gradually darkens to brown-black. The integument rarely breaks and mostly remains tough and leathery.

Table 1.—*Some major pathogens of the cabbage looper, Trichoplusia ni (Hübner)*

Causative agent	Reference
	Viruses
Single-embedded nucleopolyhedrosis virus	Chapman and Glaser *1915*; Drake and McEwen *1959*.
Multiple-embedded nucleopolyhedrosis virus	Heimpel and Adams *1966*; Tompkins et al. *1969*.
Granulosis virus	Hamm and Paschke *1963*; Summers and Paschke *1970*.
Cytoplasmic polyhedrosis virus	Vail et al. *1967*; Vail and Gough *1970*.
	Bacteria
Bacillus thuringiensis Berliner	Tanada *1956*.
Serratia marcescens Bizio	Tanada *1956*; Steinhaus *1959*; Bell *1969*.
	Protozoans
Nosema trichoplusiae Tanabe and Tamashiro	Laigo and Paschke *1966*; Tanabe and Tamashiro *1967*.
Thelohania sp. prob. *diazoma* Kramer	Splittstoesser and McEwen *1968*.
	Fungi
Nomuraea (=Spicaria) rileyi (Farlow) Samson	Getzin *1961*.
Entomophthora gammae Wieser	Harper and Carner *1973*.
Entomophthora sphaerosperma Fresenius	Yendol and Paschke *1967*.
Beauveria bassiana (Balsamo) Vuillemin	Behnke and Paschke *1966*.
Metarrhizium anisopliae (Metch)	Getzin *1961*.
Metarrhizium brunneum Petch	Getzin *1961*.
Aspergillus flavus Link	Behnke and Paschke *1966*.

Internally, infection of *T. ni* larvae is generally restricted to the fat bodies and possibly hemocytes (Hamm and Paschke *1963*). Tissues of hypodermal origin are largely unaffected. Fat cells, generally small and with few vacuoles, begin to proliferate 3 to 4 days after infection, and the nuclei enlarge. Within the next 2 days, a Fuelgen-positive virogenic network has extended throughout the cell, and the nucleus cannot be differentiated from the cytoplasm. Concurrently, or soon after, inclusion bodies form within or closely associated with the nuclei of infected fat cells. Inclusion bodies can also be found in the hemolymph and in the cytoplasm of hemocytes.

Cytoplasmic Polyhedrosis Virus (CPV)

Causative Agent

The causative agent of the CPV, a subspherical, icosahedron-shaped virion containing RNA, was first reported in larvae from laboratory cultures of *T. ni* by Vail et al. (*1967*). The diameter of the virion is 60 to 70 nm. Virions are randomly distributed and occluded in proteinaceous inclusion bodies. Inclusion bodies, generally regular polyhedrons, measure 1.5 μ in diameter (range 1 to 3 μ). Ultrathin sections of inclusion bodies reveal a crystalline molecular lattice. The molecular lattice is not disrupted by the occluded virion.

Symptoms

The disease is largely confined to the larval stage although the virus is found in adults and may be transmitted to progeny via external contamination of eggs. The following description of the external symptoms of CPV in cabbage loopers is from Smith (*1967*), Vail et al. (*1967*), and Vail and Gough (*1970b*). One of the first obvious symptoms is the appearance of smaller-than-normal larvae, pupae, and adults and a lengthening of the time to pupation. Moths emerging from diseased larvae may be deformed, and female fecundity may be significantly reduced. Several larval molts may occur without a corresponding increase in body size with the result that the larvae have seemingly large heads and prominent setae. As the disease progresses, the midgut region of the body becomes white; this color may later extend to both the anterior and posterior ends of the body. Dissection reveals a white-opaque midgut packed with inclusion bodies. Fecal pellets change upon their normal green to a yellow-green and then eventually to opaque-yellow-white. The larval integument is seldom ruptured even after death. The disease may exist for long periods in a chronic subacute form in laboratory cultures of cabbage loopers. Inclusion bodies can be found in the feces of moths that are infected.

No complete description of the internal histopathology of the CPV in *T. ni* is available; however, Vail et al. (*1967*) indicated that the symptoms they observed were similar to those reported for other CPV. They published photomicrographs showing inclusion bodies in the cytoplasm of midgut epithelial cells. The following description of the probable histopathology of a CPV in *T. ni* is abstracted from Xeros (*1956*) and Smith (*1967*) from studies of other caterpillar species. Within 5 days of exposure, inclusion bodies are observed in the cytoplasm of epithelial cells of the midgut, and there is a noticeable hypertrophy of the entire midgut. As the disease progresses, inclusion bodies are observed throughout the fore and midgut cells.

Development and formation of inclusion bodies are confined to columnar epithelial cells, never goblet or regenerative cells. Virogenic stroma appear in the cytoplasm before the development of inclusion bodies. Initially, inclusion bodies are small and confined to the cytoplasm near the walls of epithelial cell bordering the lumen of the midgut. As the virogenic stroma increases, the number and size of inclusion bodies noticeably increase. Large clear areas may later develop in the stroma with inclusion bodies eventually occupying the open areas. Still later, the cytoplasm is completely filled with inclusion bodies; the nucleus eventually disintegrates; and the cell enlarges into a triangular-shaped cell that eventually ruptures and releases inclusion bodies into the lumen of the gut.

Bacterial Pathogens

Two bacteria are often reported from *T. ni*, that is, *Bacillus thuringiensis* Berliner and *Serratia marcescens* Bizio (table 1); however, neither has ever been isolated from a field-collected *T. ni* larva. The spore-forming, endotoxin-producing *B. thuringiensis* was first isolated in 1915 (Berliner *1915*) from larvae of the flour moth, *Ephestia* (=*Anagasta*) *kuehniella* (Zeller). Much later, it was developed into a bacterial insecticide for use primarily against pest caterpillars (Steinhaus *1956*). Although *B. thuringiensis* has not been isolated from *T. ni* in nature, it was isolated from larvae exposed to an artificial application of spores and endotoxin (Tanada *1956*) and is effective against larvae feeding on many vegetable crops. The nonsporulating *S. marcescens* was used by Bell (*1969*) in laboratory tests to induce mortality of *T. ni* larvae.

Bacillus thuringiensis

Causative Agent

The causative agent, *B. thuringiensis*, is a spore-forming bacterium belonging to the genus *Bacillus*. Currently, more than 200 isolates of *B. thuringiensis* are grouped into about 12 serotypes. The following description of *B. thuringiensis* is from Breed et al. (*1957*). The vegetative cells are rod-shaped with square ends measuring 1.0 to 1.2 by 3.0 to 5.0 μ. The rods usually occur in short to long tangled chains. Spores are thin walled, ellipsoidal, and measure 0.5 to 1.2 by 1.3 to 2.5 μ. The spores generally lie obliquely in a sporangium. Crystalline, bipyramidal, parasporal bodies, as large as or sometimes larger than the spore, are contained in the sporangium. A detailed description of this crystal is provided by Hannay and Fitz-James (*1955*) and Labwa (*1961*). The crystal is toxic for many species of lepidopteran and mosquito larvae (Reeves and Garcia *1970*).

Symptoms

The description of symptoms is abstracted from Heimpel and Angus' (*1960*) description of the disease in the silkworm, *Bombyx mori* (L.), and Broersma and Buxton's (*1967*) description of the disease in *T. ni*. The first obvious external symptom, the cessation of larval feeding, may occur within 4 hours of exposure. Feeding inhibition, due to a small dose of endocrystal, can often wear off if affected larvae are transferred to clean food. Early instar larvae exposed to a sublethal dose do not develop normally and remain small. As the toxicity progresses, the midgut region becomes noticeably discolored. This discoloration gradually progresses to both the fore and hind regions. Larvae shortly before death are a pallid yellow. Shortly after death, the body color changes to a pale-yellow brown and eventually turns brown-black. The integument at this stage is easily ruptured, and vegetative cells can be isolated from the body contents.

A detailed description of internal effects of *B. thuringiensis* has not been published. The following is based upon studies on *B. mori* (Heimpel and Angus *1960*). After feeding on endocrystals and before gut paralysis, extensive internal changes occur, especially in the gut epithelium. The permeability of the gut epithelium is altered, and the alkalinity of the blood changes progressively. The lumen of the midgut region is reduced in size because of many folds in the epithelial lining. As the disease progresses, the size of fat bodies decreases and an obvious dehydration and erosion of gut epithelial cells occurs. Epithelial cells are distorted and eventually separate from each other and from the basement membrane. The midgut epithelium is completely disrupted just before death, and vegetative cells of *B. thuringiensis* can be observed in the hemocoel.

Serratia marcescens

Causative Agent

Although *S. marcescens* is often isolated from laboratory or insectary-reared cultures of insects, it is rarely encountered in nature (Steinhaus *1949*, *1959*; Bucher *1963*; Bell and Hamalle *1971*), and it has never been isolated from *T. ni* larvae in nature. The following description is from Breed et al. (*1957*). Vegetative cells are gram-negative, short rods, sometimes spherical, and measure 0.5 by 0.5 to 1.0 μ. Rods usually occur singly but occasionally may form chains of five or six cells. The cells, which are motile, are moved by three to five peritrichous flagella. Eight to ten flagella may be formed in cells grown at 20° to 25° C. Depending on the medium, the colonies grown on agar are circular, thin, and generally change from white to red. Isolates cultured from insects may produce the characteristic red pigment.

Symptoms

The symptoms induced by *S. marcescens* were not described in *T. ni* larvae; however, those produced in other insect larvae develop within 1 to 2 days postexposure

(Bucher *1963*). Larvae infected with the red strain develop a red or rosy body color at death. As postmortem changes develop, the larvae darken and eventually turn completely black (Steinhaus *1959*; Faust *1974*).

Detailed internal changes of the histopathology of *S. marcescens* in *T. ni* also were never described; however, following ingestion and after a short incubation period of 1 to 2 days, larvae die of a typical septicemia (Bell *1969*). Some indirect evidence suggests that *S. marcescens* may multiply in the gut (Bucher *1963*; Steinhaus *1959*); however, there are no real symptoms of disease until *S. marcescens* is detected in the hemocoel. Blood and all other tissues are invaded, and growth of *S. marcescens* continues after death. The result is the complete disintegration of larval tissue. The bacterium is easily isolated from the insect shortly before and after death.

Protozoan Pathogens

Six protozoan species are reported from *T. ni*. Two of these were isolated from field-collected larvae; the others were obtained from experimentally induced laboratory infections. All but one, *Mattesia grandis*, belong to the order Microsporida, family Nosematidae. Spores of the Nosematidae are oval, pyriform, ellipsoid, or subcylindrical with the length generally less than four times the width. The two species recovered from nature are *Nosema trichoplusiae* Tanabe and Tamashiro (Tanabe and Tamashiro *1967*) and a *Thelohania* species (Splittstoesser and McEwen *1968*). Species reported from experimentally induced infections are *N. sphingidis* Braades, *N. heliothidis* Lutz and Splendor (Brooks *1970*), *N. necatrix* Kramer, *T. diazoma* Kramer (Kramer *1965*), and *Mattesia grandis* McLaughlin (Ignoffo and Garcia *1965*).

An evaluation of a study by Fowler and Reeves (*1974*), by J. Maddox (Ill. Nat. History Survey, Urbana, Ill., 1975, personal communication), suggested that the species *N. necatrix* and *T. diazoma* may be the same species. In addition, Maddox suggested that the *Thelohania* described by Splittstoesser and McEwin (*1968*) may not be a new species but rather *N. necatrix*.

Nosema trichoplusiae

Causative Agent

The protozoan, *Nosema trichoplusiae*, was isolated from larvae by Laigo and Paschke (*1966*) and described by Tanabe and Tamashiro (*1967*). Nordin and Maddox (*1974*) believe that *N. trichoplusiae* is indistinguishable, using published descriptions, from at least seven other species of *Nosema*.

All developmental stages could be found simultaneously shortly after infection of the host. The spore is typically ovoid but elongated; slightly curved spores are also formed. Fresh spores average 3.63±0.20 μ long by 1.99±0.06 μ in diameter. The polar filament, easily extruded by physical pressure but not by drying, averages 54.4±4.5 μ long. The spherical schizont is binucleated and averages 2.0 μ; schizonts before division are tetranucleated and average 3.2 to 3.8 μ. Sporonts are elongated binucleated bodies, sometimes tetranucleated, averaging 5.5 to 6.4 μ long. The nucleus is often indistinct. Sporoblasts, initially fusiform, change into an oval shape as the spores mature. Each sporont develops into a single spore. The disease is transovarially transmitted (Maddox, 1975, personal communication).

Symptoms

The most obvious external symptom of the disease is the smaller than normal body size of infected larvae (Tanabe and Tamashiro *1967*). After infection, the normal green body color becomes mottled with white blotches. Dark brown-to-black pigmented spots may form on the surface of the integument, and the terminal abdominal segment may enlarge and fill with a clear, watery liquid (fig. 2). Infected larvae are sluggish, eat little, and frequently die just before pupation; pupae may be deformed. At death, the integument is flaccid and intact. The dying process can be prolonged for many days.

Internally, schizonts and fully developed spores can be observed in midgut epithelial cells 3 days after the spores are ingested (Tanabe and Tamashiro *1967*). Cellular lesions are not present although the cytoplasmic contents appear to thin as the infection progresses. The nucleus is not penetrated and remains intact even in late stages of infection. Infected cells, particularly hypodermal cells, are generally larger than normal. Schizonts are detected in Malpighian tubules 2 to 3 days postexposure. The Malpighian tubules and the midgut epithelium apparently are the primary sites of infection. Schizonts also can be detected in the hemocoel after 3 days of infection, and hemocytes are infected by the fourth day. The schizonts

Figure 2.—Mature cabbage looper larva infected by the protozoan *Mattesia grandis* McLaughlin (about 5X).

thereafter spread rapidly throughout the body. At 4 to 5 days postexposure, schizonts or spores are detectable in all tissues; nerve tissue is infected later. Heavily infected tissue is chalky-white because of the accumulation of spores. Infected adults laid fewer eggs and were able to transmit the pathogen transovarially (Tanabe and Tamashiro *1967*).

Thelohania sp., probably *diazoma*

Causative Agent

The description of *Tehlohania diazoma* is from Splittstoesser and McEwen (*1968*), Kudo (*1971*), and Weiser (*1961*). In personal communications, Maddox (*1975*) believes that *Thelohania diazoma* and *Nosema necatrix* are the same species and that the *Thelohania* species described by Splittstoesser and McEwen (*1968*) is identical to *N. necatrix* and *T. diazoma*.

Fresh spores from living larvae average 4.94±0.45 μ long by 2.06±0.29 μ in diameter. Fixed and stained spores average 4.24±0.49 μ (length) by 2.14±0.23 μ (width). Polar filaments, as long as 155 μ, readily extrude after treatment with hydrogen peroxide. The binucleated, ovoid schizonts are 2 by 3 μ; after staining they are 3 by 4 μ. Tetranucleated and octonucleated sporonts are formed. The eight sporonts develop into eight sporoblasts that ultimately develop into eight spores. Octosporoblasts are ovoidal and measure 5 by 7 μ. The sporont membrane often degenerates during spore formation.

Symptoms

The first visible sign of infection is a change in body color from green to pale yellow observed 5 days after the spores are fed (Splittstoesser and McEwen *1968*). Dark mottled areas may also develop on the dorsal integument. The anal segments of the abdomen frequently enlarge and fill with liquid. Heavily diseased larvae are noticeably listless and feed less than normal larvae. Thereafter, larvae may develop diarrhea and regurgitate a watery vomitus shortly before death. In acute infections, young larvae may be killed before spore formation. In chronic subacute infections, the larval stage may be prolonged for 1 to 2 weeks beyond normal pupation during which time extra molts may occur. Larvae infected during the last two instars generally do not develop symptoms and frequently survive to pupae. All stages of *T. diazoma* are found in tissue of pupae and adults. Transovarial transmission has not been reported, and there is little or no effect on adults (Maddox *1975*, personal communications).

No detailed description of the internal symptoms or histopathology of this disease in *T. ni* is available. The following description was abstracted from Splittstoesser and McEwen (*1968*) and Kramer (*1965*). The most obvious evidence of infection is cell hypertrophy. The fat body is probably the primary site of infection, and the cytoplasm of these cells is eventually completely destroyed. Tissues other than fat cells and hemocytes (Kramer *1965*; Laigo and Paschke *1966*) apparently are not invaded by *T. diazoma*.

Fungal Pathogens

Eight species of fungi were reported associated with *T. ni* (table 1): two species of *Entomophthora*, that is, *E. shpaerosperma* Fresenius (Yendol and Paschke *1967*) and *E. (Tarichium) gammae* Weiser (Harper and Carner *1973*); two species of *Metarrhizium*, that is, *M. anisopliae* (Metchnikoff) Sorok. and *M. brunneum* Petch (Getzin *1961*); and one each of *Nomuraea rileyi* (Farlow) Samson (Getzin *1961*), *Aspergillus flavus* Link ex Fr. (Behnke and Paschke *1966*), *Beauveria bassiana* (Balsamo) Vuillemin (Behnke and Paschke *1966*), and *Spicaria prasina* (Maublanc) Sawada (Yen *1960*). Recently, *Spicaria prasina* has been described as a synonym of *S. rileyi*, both of which are now in the genus Nomuraea (Kish et al. *1974*). The designation *E. (Tarichium) gammae* (MacLeod and Muller-Kogler *1970*) is a provisional name. Currently, the only valid name for this species is *Tarichium gammae* Weiser. All species of fungi listed, except species of *Aspergillus* and *Metarrhizium*, are frequently isolated from field-collected cabbage looper larvae.

Nomuraea rileyi

Causative Agent

The description of *N. rileyi* is from Kish et al. (*1974*). On malt agar at 25° C, colonies grow slowly and within a month attain a diameter of 0.7 to 1.2 cm. Sporulation initially occurs in localized areas and then spreads throughout the medium. The color of the colony progresses from a pale green to malachite green. No odor or exudate is produced. The vegetative hyphae, which average 2 to 3 μ in diameter, are smooth, septate, and hyaline to slightly pigmented in color. Conidiophores, which grow from submerged hyphae, are erect, septate, and measure up to 160 μ in length with a diameter of 2 to 5 μ. Branches, formed at the apical portion of a septum, develop whorls of 2 to 4 phialides. The branches, which measure 5 to 8 by 2 to 4 μ, are usually cylindrical but occasionally have a swollen base. Conidia that occur in dry divergent chains are smooth, ellipsoidal, and pale green. Conidia measure 3.4 to 4.5 μ by 2 to 3.1 μ.

Symptoms

The first overt sign of an infection of larvae is the development of yellow to brown, small, discrete spots on the integument. These spots are the site of cuticular penetration by the conidia. Spots can be observed 1 to 2 days postexposure. No other visible external symptoms are

obvious for the next few days other than a slight change in body color from the normal green to a pale yellow-green. Retardation of feeding and lethargy also may be encountered. Mycelium growth in heavily infected larvae can be observed 6 to 9 days after exposure with nocidiophore and conidia formation occurring within the next 1 to 2 days. Larval death occurs as early as 4 to 6 days postexposure depending on the dose, temperature, and stage of larvae when infected. During the latter stages of mycelial development, the larval body is still and mummified. *Nomuraea rileyi* forms a dense white feltlike mass of hyphae on the body of dead larvae. Conidiophores arise close together from the mycelial mass and produce a pile of pale-green conidia over the mummified body.

There are no published descriptions of internal symptoms of *N. rileyi* infecting *T. ni*.

Entomophthora sphaerosperma

Causative Agent

The following description of *E. sphaerosperma* is from Sawyer (*1931*, *1933*), Thaxter (*1888*), Steinhaus (*1949*), Yendol and Paschke (*1967*), and MacLeod and Muller-Kogler (*1970*). Conidia are narrowly eliptical, nearly cylindrical with a tapering base and a rounded apex. The base of the conidia is encircled by a collar that connects to the conidiophore. Vacuoles, absent at maturity, develop shortly after the conidia are forcibly discharged from the conidiophore. Conidia are 19.7±2.4 μ long by 8.1±0.1 μ in diameter. A single membrane encloses the conidia, and the apex is covered by a detachable gelatinous cap. Conidia after germination may produce a secondary conidium from the tip of the germ tube. Resting spores may also be formed; however, the simultaneous occurrence of both conidia and resting spores is rare. Resting spores are globular in shape, hyaline to yellow, and smooth walled; they appear laterally or terminally on hyphal threads. Spores average 25 μ in diameter (range 20 to 27) but may vary from 18 to 35 μ.

Symptoms

The external symptoms induced by *E. sphaerosperma* (Yendol and Paschke *1967*) are similar to those described for *E. gammae* (Harper and Carner *1973*). Small, discrete, dark-colored spots, caused by cuticular penetration of the conidia, are the first external symptom of an infection. Infected larvae change in color from green to yellow-green. Feeding slows shortly before death. After death, larvae are flaccid and compressed. The larval body at this stage breaks easily, but there is little or no escape of body fluids.

The mycelial stage develops internally. After infection, the mycelium grows rapidly and spreads via the hemocoel to fat and muscle tissue (Sawyer *1931*, *1933*; Yendol and Paschke *1967*). As the disease progresses, elements of the mycelium develop irregular shapes and produce tubes that grow outward toward the integument. When the apex of these mycelial tubes reaches the inner wall of the cuticle, they form bulbous structures. Shortly thereafter, the cuticle wall is ruptured, and fascicles form at the external site of the rupture. Conidia develop at the apical portions of the fascicles. In some instances, the ends of the hyphae expand and fasten the host body to the substrate.

Entomophthora gammae

Causative Agent

Two types of spores are produced by *E. gammae*, that is, resting spores and conidia (Weiser *1965*; MacLeod and Muller-Kogler *1970*; Harper and Carner *1973*). Resting spores, formed internally in dead larvae, are released in the body fluids when the integument is ruptured. Resting spores are pill-like in shape; seen from the side, they are round. They are dark brown and average 47.9±3.8 μ by 45.7±4.1 μ. The exosporium is covered by fine, minute projections (height, 1 to 1.5 μ; diameter, 2.5 to 3 μ) that are evenly distributed over the surface. Conidia are oval to ellipsoidal, have a rounded apex, and are covered by a clear adhesive substance. Conidia measure 18.2±2 μ by 8.8±1.6 μ.

Symptoms

Larvae of *T. ni* infected by *E. gammae* exhibit two distinct external symptoms, depending on whether conidia or resting sproes are formed (Harper and Carner *1973*). After infection (as evidenced by dark spots caused by the penetrating germ tube), diseased larvae gradually change from normal green to a yellow-green (Yendol and Paschke *1967*). When conidia are to be formed, the body is turgid immediately after infection, but as the mycoses develops, water is lost, and the body becomes flaccid and laterally compressed. The integument at this stage is not easily ruptured. Conidiophores formed within the body penetrate the integument and produce conidia that are mechanically ejected. The appearance of larvae is completely different when resting spores are formed. These larvae turn a glossy black after death, do not lose water, and maintain their turgidity. The integument is easily ruptured at the segments to release body fluids consisting of nearly pure resting spores.

The internal symptoms of *E. gammae* in *T. ni* are not described. It is assumed that they are similar to those described for *E. sphaerosperma* in *Plutella* (Steinhaus *1949*) or in *T. ni* (Yendol and Paschke *1967*).

Beauveria bassiana

Causative Agent
On culture media, *B. bassiana* produces a flat, mealy, chalky mycelial growth (Lefebvre *1934*; Steinhaus *1949*; MacLeod *1954*). Sporulation occurs after 4 to 7 days at 28° C. Large numbers of conidia are produced in compact globuse heads on the main hyphal branches or on short lateral branches. Conidia develop on slender zigzag sterigmata borne at the apex of the conidiophores. The conidiophores are flask shaped. Secondary cymose sterigmata also arise from the conidiophores, which, in turn, bear additional conidia. Conidia are subglobular and average 2.1 to 2.5 μ long (range 1.0 to 4.5 μ) by 2.1 to 2.5 μ wide (range 1.0 to 3.5 μ). They generally germinate within 2 days of exposure in water and produce germ tubes up to 80 μ long. Short lateral branches may extend from the developing germ tube.

Symptoms
No reports of symptoms of *B. bassiana* in *T. ni* larvae have been published. The following is described from infections reported in the silkworm, *B. mori* (Paillot *1930*), and European corn borer, *Ostrinia nubialis* (Hübner) (Lefebvre *1934*). Small discrete spots, due to conidia penetration of the cuticle, are observed within 2 to 3 days of exposure. The normal green body color lightens to a pale green and may turn slightly pink. Shortly thereafter, infected larvae are sluggish, but the body remains turgid. During this period, hyphal filaments spread throughout the body, and the larva loses its turgidity. Shortly at or following death, the body becomes rigid and mummified. The integument at this stage is easily ruptured, and diseased larvae can be ground into a dry, fine chalky powder.

During penetration of the integument, the chitin is apparently dissolved by the germ tube. Destruction of hypodermal cells is observed in the region immediately surrounding the site of penetration. Mycelial development is initiated when the germ tube reaches the hemocoel. Short filaments of hyphae form shortly therafter, and the blood volume decreases. As mycoses progresses, fat tissue is invaded, blood circulation stops, and the blood develops a pasty consistency. General paralysis then occurs followed shortly thereafter by death. Most of the larval tissue is not invaded until after the insect has died. At this stage, the body is hardened and mummified. The internal tissue may liquify (probably due to a bacteremia); when this occurs, spores are not formed.

Metarrhizium anisopliae

Causative Agent
On artificial media, spores of *M. anisopliae* germinate within 1 to 2 days of seeding. Germ tubes may develop at both ends of a spore. A heavy mycelial growth develops within 5 to 6 days at 26° to 28° C. Hyphae above the substrate develop into sporophores that are usually short and closely packed together. Hyphae are septate and vary in diameter from 1 to 3 μ. Transverse septa are continuous with the inner layer of the cell wall. Hyphal bodies may produce ovoidal to cylindrical cells by budding or septation. Sporulation develops 7 to 9 days postseeding. Conidia, which are formed in chains, are initially white but change to an olive green as they mature. The conidia measure 5 to 7.5 μ (length) by 2.3 to 3.7 μ (diameter). Chlamydospores may also form in large numbers, either singly or in chains, within the body cavity of dead larvae. Chlamydospores develop from the hyphae by globular enlargement and septation. The chlamydospores are subglobular to elliptical, have a thick cell wall, and measure 4 to 5 μ by 5 to 6 μ.

Symptoms
Neither external or internal symptoms of *M. anisopliae* infections of *T. ni* larvae have been described. The following symptoms were observed in European corn borer larvae infected with *M. anisopliae* (Wallengren and Johansson *1929*): The first symptoms are small yellow or brown spots on the cuticle that usually spread to other parts of the body. Four to 5 days after exposure, infected larvae lose their appetite. Death generally follows at 5 to 6 days postexposure. The body then becomes stiff and mummified, and the mycelium develops rapidly internally. With proper environmental conditions, a white-fluffy growth develops on the surface of the integument 7 to 9 days postexposure. Within the next 2 days, the colony turns green to olive green as conidia are formed. Conidia may stick together to produce large flakes.

Internal symptoms of *M. anisopliae* have not been described for *T. ni*. The following is a composite description of symptoms in silkworm larvae and European corn borer larvae (Glaser *1926*; Wallengren and Johansson *1929*). Infections are acquired via penetration of the larval integument by germinating spores. Initially, hyphal development occurs in the hemocoel, but it soon spreads to fat and other tissues. After death, rapid internal mycelium growth occurs that invades all the tissues and produces a mummified larvae. In studies on laterids, most of the internal tissue or organs are invaded by hyphae, which results in major degenerative changes before the larvae die (Zacharuk *1971ab*). Hyphal invasion is most extensive near the site of penetration. The pathogen may secrete substances that induce cellular changes (cytoplasmic vesiculation, lysome formation, degeneration of mitochondria) before actual hyphal invasion. Hypodermal tissue is apparently invaded first and then shortly thereafter the fat bodies.

Metarrhizium brunneum

Causative Agent

Metarrhizium brunneum was originally described from a colony isolated from a cicadellid nymph collected in the Philippines (Petch *1935*). It differs from *M. anisopliae* in its color and in the shape of the phialides. No native infection in *T. ni* has ever been recorded, but Getzin (*1961*), in laboratory tests, was able to infect *T. ni* larvae. The colony in culture is first white and then turns brown. At maturity, the colony takes on a powdery appearance. Hyphae are short and tangled together in compact masses. The phialides are club shaped, up to 9 μ long, and 2 to 3 μ in diameter. Conidia are yellow to yellow-brown, oval to cylindrical with rounded ends, and measure 4 to 6 by 1.5 to 2 μ. Chains of conidia are first laterally compressed then split into plates of spores.

Symptoms

No descriptions exist of symptoms of *M. brunneum* infecting *T. ni* larvae.

Aspergillus flavus

Causative Agent

The following description for *A. flavus* is from Raper and Fennell (*1973*). Colonies on Czapek's medium reach diameters of 4 to 7 cm in 10 days at 24° to 26° C. The colony develops a thin but close-textured basal mycelium. Conidiophores arise directly from the substrate mycelium. Young conidia heads change in color from white to yellow to yellow-green and then to dark green. Sclerotia are produced by many strains, especially in fresh isolates. These are subglobular in shape (400 to 700 μ) and are dark red-brown to black. The conidial heads are radiate and are 300 to 400 μ in diameter. The conidiophores are heavily walled and uncolored and measure 1 to 2 mm in height with a stalk diameter of about 20 μ. Conidia are globose to subglobose, conspicuously echinulate, and average 3.5 to 4.5 μ (range 3.5 to 5.5 μ).

Symptoms

Small discrete spots on the integument, due to penetration of the cuticle of germinating conidia, are the first visible signs of infection (Behnke and Paschke *1966*). As the mycosis progresses, larvae exhibit spasmodic movements, void liquid feces, and develop black spots under the integument. Shortly thereafter, they stop feeding, become flaccid, and soon die. The body changes from a normal green to pale green. External mycelium develop quickly shortly after death. At sporulation, the body color is olive to golden brown due to the development of conidia.

Summary

The symptoms and causative agents of disease of the cabbage looper, *Trichoplusia ni*, are reported. About 20 species of pathogens are associated with *T. ni*. Four viruses of three viral groups, that is, two nuclear polyhedrosis, one cytoplasmic polyhedrosis, one granulosis, were isolated. Two bacteria (*Bacillus thuringiensis* Berliner, *Serratia marscens* Bizio), neither isolated from nature, are often isolated from laboratory-reared larvae. Six protozoan species are reported from *T. ni*, two from naturally infected larvae (*Nosema trichoplusiae*, *Thelohania* sp.). More fungi than any other group of pathogens have been isolated from *T. ni*. These were: two species of *Entomophthora*; two species of *Metarrhizium*; and one each of *Nomuraea*, *Aspergillus*, *Beauveria*, and *Spicaria*.

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Part II. Control Technologies

Chapter 9. Chemical Insecticides and Resistance

By C. S. Creighton[1]

Abstract

Prior to 1944, botanical and arsenical insecticides were used in cabbage looper, *Trichoplusia ni* (Hübner), control; these were replaced by DDT and other related chlorinated hydrocarbons. During the early 1950's, workers reported resistance of the cabbage looper to DDT, and they also obtained a decrease in effectiveness with parathion, toxaphene, and endrin that indicated resistance of the looper to these compounds. Other compounds that can no longer be relied on to give satisfactory control are carbaryl, naled, mevinphos, endosulfan, malathion, rotenone, pyrethrum, diazinon, dimethoate, and azinphosmethyl. Compounds that are now giving the most effective cabbage looper control are chlordimeform, Ortho 9006 (methamidophos), acephate, leptophos, and several synthetic pyrethroid compounds. It is generally recognized by vegetable insect workers that registered compounds (even the most potent ones) do not perform as well in some areas as they do in others. Even the most potent of the available chemicals are less effective if loopers are allowed to become too large before treatments are initiated. Cabbage loopers seem to be more easily controlled on some vegetables than others, perhaps because of differences in egg deposition, plant growth habit, and deposition of the toxicant.

Chemical insecticides have played the principal role in protecting cruciferous and other crops from destructive feeding by the cabbage looper. Prior to 1944, flourine, arsenical, and botanical insecticides were used in cabbage looper control. Because of residue restrictions associated with the use of arsenical and flourine insecticides, tests were conducted in 1934 to find suitable substitutes for these compounds (Huckett *1934*; Walker and Anderson *1934*). In 1944, DDT was found to be highly toxic to cabbage loopers (Smith and Harrison *1944*; Swingle and Mayer *1944*), and the botanical and arsenical insecticides formerly used in control programs were soon replaced with this material and with other chlorinated hydrocarbons. Within 8 years, however, workers from various parts of the country were reporting resistance of the cabbage looper to DDT (table 1). As early as 1951, workers noted a general decline in the effectiveness of parathion and toxaphene that indicated resistance in the looper to these compounds (Genung *1957*; Reid and Cuthbert *1957*). In 1963, McEwen and Splittstoesser (*1970*) found that field-collected larvae (Long Island strain) were 4 times more resistant to parathion and 3 times more resistant to endosulfan than the laboratory strain; they also found that in 1968, field cultures increased to 16 times more resistant to parathion than the laboratory strain while remaining 3 times more resistant to endosulfan. Resistance to parathion was even more pronounced than that to endosulfan, and by 1963, Long Island growers found both materials inadequate in the field. In 1968, the growers in western New York also were unable to obtain adequate control with either parathion or endosulfan (McEwen and Splittstoesser *1970*).

Other instances of an increased tolerance of loopers to chemicals have been reported. Chalfant and Brett (*1965*) found endrin to be ineffective in 1963 and naled and mevinphos unreliable when used from transplant to harvest. Creighton et al. (*1970*) obtained erratic control with mevinphos and naled in spring and fall tests conducted in 1966–68. Poor or erratic control with the commonly used insecticides was reported by Greene (*1967*) and Greene et al. (*1969*). Hofmaster (*1973*) found that naled, mevinphos, toxaphene, endosulfan, ethyl parathion, and methyl parathion no longer produced satisfactory results in Virginia. Recently, Davis and Kuhr (*1974*) reported increased tolerance of loopers to methomyl.

Some of the better known recently developed compounds that have been tested against the cabbage looper on cole crops are listed in table 2. Compounds that were found effective within the last 8 years and that are now in use are chlordimeform, methomyl, and methamidophos. Compounds that showed promise but are not registered for use are aminocarb, mexacarbate, chloropyrifos, acephate, monocrotophos, and leptophos. Less effective registered compounds are naled, mevinphos, endosulfan, and parathion.

The cabbage looper was reported as being a serious pest of cotton in central Texas in 1956, and the severe damage to foilage due to this pest resulted in reduction of staple length (Parencia et al. *1957*). Some of the insecticides used in controlling the boll weevil, *Anthonomus grandis* Boheman, and the bollworm, *Heliothis* spp., have generally given satisfactory control of the cabbage looper. These treatments have usually consisted of a mixture containing two or three chemical compounds (table 3). In laboratory tests conducted on cotton terminals, Kerr and Brazzel (*1960*) found that endrin and endosulfan produced extremely high mortality of first-instar cabbage loopers and were the most effective compounds used against the larvae through the third instar; they also found that none of the insecticides they tested was effective against fourth- and fifth-instar loopers.

The cabbage looper was not considered a pest of flue cured tobacco until recent years when scattered infestations caused some damage in eastern North Carolina (Elsey and Rabb *1967*). Methomyl is now used to control

[1] Research entomologist, U.S. Vegetable Laboratory, Agric. Res. Serv., USDA, Charleston, SC 29407.

loopers on tobacco, but the data reporting results of trials with this compound (and some others) are not available.

Chemicals that have been tested against the cabbage looper on tomatoes are shown in table 3. None of these compounds gave highly effective control. No data are available concerning trials on tomatoes with any of the recently developed chemical compounds.

Comments and Recommendations

The cabbage looper remains among the most difficult of the caterpillar species to control. Chemical compounds that workers feel are not reliable to give satisfactory control are carbaryl, naled, mevinphos, parathion, endosulfan, taxaphene, malathion, rotenone, pyrethrum, diazinon, dimethoate, and azinphosmethyl. Some workers also feel that methomyl might be "slipping" and not providing the degree of control that it has in the past. Research indicates compounds that are now giving the most effective cabbage looper control are chlordimeform, methamidophos, acephate, and leptophos.

In some areas, a complex of looper species may be present, and since they are hard to distinguish from one another, insecticidal performance data may be affected. In certain areas, the high degree of looper control required by the processors (especially on greens) is not being achieved and may result in growers shifting to other crops. Vegetable insects workers find that registered compounds (even the most potent ones) do not perform as well in some areas as they do in others. Even the most potent of the chemical compounds that are available for use are less effective if the loopers are allowed to become too large before treatments are initiated. Cabbage loopers seem to be more easily controlled on some vegetables than others, perhaps because of differences in egg deposition, plant growth habit, and deposition of the toxicant.

Areas of study that the author and some other workers feel should be given the most consideration include:

1. Registration of more promising experimental materials and extension of present registration of the more potent materials to minor crops.

2. Studies of the development of resistance in loopers to insecticides.

3. Studies to define predator and parasite effectiveness against looper populations and to determine the effects of chemical treatments on predator and parasite populations.

4. Development of new pesticides, juvenile hormones, ovicides, and feeding deterrents.

5. Continued evaluation of chemical insecticides.

6. Increased market tolerance of insect-damaged produce.

7. Continued work on controlling loopers on collards.

8. Work directed towards controlling adult loopers.

9. Combination usage of pathogens such as *Bacillus thuringiensis* Berliner and chemical insecticides.

10. Studies of the relation of chemical control to varietal resistance.

11. Shortening of the residue preharvest limitation (14 days) for methamidophos and expediting the labeling of acephate.

12. Development of more effective application eulpment that would result in better plant coverage.

13. Development of sampling and survey techniques to enable growers to spray at the proper time and to evaluate the results more effeciently; concepts of "pest management" are also important, and some are applicable to vegetable crops against the looper.

14. Additional studies to determine looper movement from south to north and sources of infestations in northern areas; it is thought that one of the reasons loopers are harder to kill in such areas as Virginia and New York is that many of the moths in these areas may be survivors from pesticide treatments in areas to the south.

Table 1.—*Reports on resistance of cabbage looper to chemical insecticides*

Compound	Location	Investigators
DDT	Western New York	Hervey and Swenson (*1954*).
	---------do---------	McEwen and Hervey (*1956*).
	Rio Grande Valley	Wene (*1954*).
	Wisconsin	Chapman (*1956*).
	---------do---------	Chalfant and Chapman (*1958*).
	Arizona	Bibby (*1957*).
	South Carolina	Reid and Cuthbert (*1957*).
	South Florida	Genung (*1957*).
Parathion	Wisconsin	Chalfant and Chapman (*1958*).
	South Carolina	Reid and Cuthbert (*1957*).
	Florida (south)	Genung (*1957*).
	New York	McEwen and Splittstoesser (*1970*).
Toxaphene	South Carolina	Reid and Cuthbert (*1957*).
	Florida (south)	Genung (*1357*).
	North Carolina	Chalfant and Brett (*1965*).
Endosulfan	New York	McEwen and Splittstoesser (*1970*).

Table 2.—*Chemical insecticides and their relative performance in controlling cabbage loopers on cole crops*

Compound	Evaluated (years)	Crop	Performance	Investigators
Acephate	1970-72	Cole crops	Promising	Hofmaster (*1973*).
	1971	Cabbage	--do--	Chalfant et al. (*1973*).
	1971	Collards	Good plant protection	Kouskolekas and Harper (*1973*).
	1971	Cabbage	Outstanding control	Creighton et al. (*1973*).
Aminocarb	1959-63	--do--	Good	Chalfant and Brett (*1965*).
	1961-62	Cabbage-cauliflower	Effective control	Shorey (*1963*).
	1961-62	Cabbage	Most effective	Prochaska et al. (*1964*).
	1963-68	--do--	Outstanding	Creighton and Reid (*1966*); Creighton et al. (*1970b*).
Azinphosmethyl	1958-59	Lettuce	Fair	Hall et al. (*1961*).
	1959-60	--do--	Fair to good	Shorey and Hall (*1962*).
Carbaryl	1958-59	Cabbage	Fair	Hall et al. (*1961*).
	1960	Cauliflower	--do--	Shorey et al. (*1962*).
	1961	Lettuce	Gave best control in test	Schuster (*1966*).
	1962	--do--	Effective	Do
Carbofuran	1969	Collards	Satisfactory protection	Kouskolekas and Harper (*1973*).
Carbophenothion	1957	Cabbage	Significant increase in cabbage yield	Young and Ditman (*1959*).
Chlordimeform as:				
Fundal	1966-71	Cabbage	Very effective	Creighton et al. (*1970b, 1973, 1974*).
	1966-68	Broccoli	Very promising	Judge and McEwen (*1970*).
	1970-72	Cole crops	Promising	Hofmaster (*1973*).
	1971	Cabbage	Gave effective damage control	Chalfant et al. (*1973*).
	1971	--do--	Highly effective	Jaques (*1973*).
Galecron	1966-71	--do--	Very effective	Creighton et al. (*1970b, 1973, 1974*).
	1966-68	Cabbage-collards	Highly promising	Chalfant (*1969*); Chalfant et al. (*1973*).
	1969-71	Collards	Effective plant protection	Kouskolekas and Harper (*1973*).
	1970-72	Cale crops	Promising	Hofmaster (*1973*).
	1971	Cabbage	Best control	Boling (*1972*).
Chloropyrifos	1963-68	--do--	Outstanding	Creighton and Reid (*1966*); Creighton et al. (*1970b*).

Table 2.—Continued

Compound	Evaluated (years)	Crop	Performance	Investigators
American Cyanamid CL 47041[1]	1970	Collards	Ineffective	Kouskolekas and Harper (*1973*).
DDT + toxaphene	1959-60	Lettuce	Fair to good	Shorey and Hall (*1962*).
	1968	Cabbage	Best control in test	Greene et al (*1969*).
Endosulfan	1957	--do--	Significant increase in cabbage yield	Young and Ditman (*1959*).
	1958-59	--do--	Fair	Hall et al. (*1961*).
	1959	--do--	Better protection than methyl trithion	Ratcliffe et al. (*1961*).
	1961-62	Cabbage-cauliflower	Effective control	Shorey (*1963*).
	1963-67	Cabbage	Generally poor to fair	Creighton and Reid (*1966*); Creighton et al. (*1970a*).
	1969	Collards	Satisfactory protection	Kouskolekas and Harper (*1973*).
	1971	Cabbage	Provided high yields	Jaques (*1973*).
Endosulfan + parathion	1963-71	--do--	Generally fair to good	Creighton et al. (*1970a, 1973*).
	1966-68	Brocolli	Satisfactory	Judge and McEwen (*1970*).
Endosulfan + pyrenone	1970	Collards	Poor in reducing population but gave good protection	Kouskolekas and Harper (*1973*).
	1971	--do--	Ineffective control	--do--
Ethion	1957	Cabbage	Significant increase of cabbage yield	Young and Ditman (*1959*).
	1958-59	Lettuce	Fair	Hall et al. (*1961*).
Leptophos	1966-68	Brocolli	Very promising	Judge and McEwen (*1970*).
	1967-68-71	Cabbage-collards	Highly promising	Chalfant (*1969*); Chalfant et al. (*1973*).
	1969	Collards	Satisfactory protection	Kouskolekas and Harper (*1973*).
	1969-71	Cabbage	Very effective	Creighton et al. (*1973, 1974*).
Malathion	1957	--do--	Significant increase of cabbage yield	Young and Ditman (*1959*).
	1958-59	Cabbage-cauliflower	Fair	Hall et al. (*1961*).
Methomyl	1966-71	Cabbage	Good and outstanding	Creighton et al. (*1970b, 1973, 1974*).
	1968	--do--	Best control in test	Greene et al. (*1969*).
	1971	Cabbage	Gave effective control	Chalfant et al. (*1973*).
	1966-68	Broccoli	Good	Judge and McEwen (*1970*).
	1967-68	Cabbage-collards	Highly promising	Chalfant (*1969*).
	1969-70	Collards	Satisfactory protection	Kouskolekas and Harper (*1973*).
	1970	Cabbage	Intermediate control	Boling (*1972*).
	1970-72	Cole Crops	Promising	Hofmaster (*1973*).
	1971	Collards	Ineffective control	Kouskolekas and Harper (*1973*).
	1971	Cabbage	Provided high yields	Jaques (*1973*).
Methamidophos	1966-71	--do--	Highly effective	Creighton et al. (*1970b, 1973, 1974*).
	1966-68	Broccoli	Very promising	Judge and McEwen (*1970*).
	1967-68	Cabbage-collards	Highly promising	Chalfant (*1969*); Chalfant et al. (*1973*).
	1969-70	Collards	Effective control	Kouskolekas and Harper (*1973*).
	1970-72	Cole crops	Promising	Hofmaster (*1973*).
	1971	Collards	Ineffective control	Kouskolekas and Harper (*1973*).
	1971	Cabbage	Best control	Boling (*1972*).
Methidathion	1970	Collards	Ineffective control	Kouskolekas and Harper (*1973*).
Mevinphos	1959-63	Cabbage	Unreliable when used from transplant to harvest	Chalfant and Brett (*1965*).
	1963-68	--do--	Variable-usually inadequate	Creighton et al. (*1970b*).

Table 2.—Continued

Compound	Evaluated (years)	Crop	Performance	Investigators
	1967–68	Cabbage-collards	Good but less effective in cold weather	Chalfant (*1969*).
	1970	Cabbage	Intermediate control	Boling (*1972*).
Mexacarbate	1959–60	Lettuce	Fair to good	Shorey and Hall (*1962*).
	1959–63	Cabbage	Effective control	Schuster (*1966*).
	1960	Cauliflower	Excellent	Shorey et al. (*1962*).
	1961–62	Cabbage-cauliflower	Effective control	Shorey (*1963*).
	1961–62	Cabbage	Most effective	Prochaska et al. (*1964*).
Monocrotophos	1963–68	--do--	Outstanding	Creighton and Reid (*1966*); Creighton et al. (*1970b*).
	1967–68	Cabbage-collards	Highly promising	Chalfant (*1969*).
	1968	Cabbage	Best control in test	Greene et al. (*1969*).
	1970	Collards	Effective control	Koukolekas and Harper (*1973*).
	1970	Cabbage	Poor	Boling (*1972*).
Naled	1957	--do--	Significant increase of cabbage yield	Young and Ditman (*1959*).
	1958–59	Cabbage-lettuce	Fair	Hall et al. (*1961*).
	1959	Cabbage	Better protection than methyl trithion	Ratcliffe et al. (*1961*).
	1959–60	Lettuce	Fair to good	Shorey and Hall (*1962*).
	1959–63	Cabbage	Unreliable used from transplant to harvest	Chalfant and Brett (*1965*).
	1961	Lettuce	Gave best control in test	Schuster (*1966*).
	1962	--do--	Effective control	Do
	1963–68	Cabbage	Variable and usually inadequate	Creighton and Reid (*1966*); Creighton et al. (*1970b*).
	1967–68	Cabbage-collards	Good control—less effective in cold weather	Chalfant (*1969*).
	1970–72	Cole crops	Not satisfactory	Hofmaster (*1973*).
Parathion	1963–67	Cabbage	Fair	Creighton et al. (*1970b*).
	1966–68	Broccoli	Not so effective	Judge and McEwen (*1970*).
Rohm & Haas Q-137[2]	1958–59	Cabbage-lettuce Cauliflower	Fair	Hall et al. (*1961*).
Stirofos	1970	Cabbage	Poor	Boling (*1972*).
Trichlorfon	1970	Collards	Ineffective control	Kouskolekas and Harper (*1973*).

[1]2-Diethoxyphosphinylimino)-1, 3-dithiolane.
[2]2,2 Dichloro-2, 2 bis (4-ethylphenyl) ethane.

Table 3.—*Chemical insecticides and their relative performance in controlling cabbage loopers on cotton and tomatoes*

Treatment	Performance	Investigators
	COTTON	
Dust		
Toxaphene	Satisfactory	Wene (*1968*).
Toxaphene + DDT	--do--	Do.
Toxaphene + methyl parathion	--do--	Do.
Heptachlor + methyl parathion + DDT	--do--	Do.
Endosulfan + DDT	--do--	Do.
Endrin	Good	Parencia et al. (*1957*).
Methyl parathion + DDT	Highly effective	Wene (*1968*).
Azinphosmethyl + DDT	More effective than spray	Parencia et al. (*1957*).
Sprays		
DDT	Ineffective	Do.
Toxaphene + DDT	Most effective	Falcon et al. (*1968*).
Methyl parathion + DDT	Good	Parencia et al. (*1957*).
EPN + DDT	--do--	Do.
Azinphosmethyl + DDT	--do--	Do.
Dieldrin + DDT	Poor	Do.
Endrin	Good	Do.
Trichlorfon	Poor	Do.
Heptachlor + DDT	Ineffective	Wene (*1968*).
Malation + DDT	Effective	Do.
Carbaryl (laboratory)	--do--	Bottger et al. (*1958*).
Deutero—DDT (laboratory, low-vol)	Most effective of several	Wolfenbarger and Lowry
low-vol)	diphenyl aliphatics	(*1969*).
Soil (Sidedress)		
Aldicarb	Ineffective	Hopkins and Taft (*1965*).
	TOMATOES	
Carbaryl	Good	Shorey and Hall (*1963*).
Carbaryl + methylparathion	Moderately effective	Creighton et al. (*1971*).
Diazinon	Good	Shorey and Hall (*1963*).
DDT	--do--	Do.
	Moderately effective	Creighton et al. (*1971*).
Stirofos	--do--	Do.
	Good	Shorey and Hall (*1963*).
Naled	--do--	Do.
Mexcarbate	--do--	Do.

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J. D. Rodriquez—Dept. of Entomology, Univ. of Kentucky, Lexington, KY 40506.

J. A. Harding—Agr. Res. and Ext. Ctr., Texas A&M Univ., Weslaco, TX 78596.

W. D. Wylie—Dept. of Entomology, Univ. of Arkansas, Fayetteville, AR 72701.

J. D. Harper—Dept. of Zool.-Entomology, Auburn Univ., Auburn, AL 36830.

C. A. Kouskolekas—Dept. of Zool.-Entomology, Auburn Univ., Auburn, AL 36830.

H. B. Green—Dept. of Entomology, Mississippi State Univ., State College, MS 29762.

C. H. Brett—Dept. of Entomology, North Carolina State Univ., Raleigh, NC 27607.

T. E. Skelton—Dept. of Entomology, Clemson Univ., Clemson, SC 29631.

C. A. Thomas—Dept. Ext. Entomology, Clemson Univ., Clemson, SC 29631.

R. N. Hofmaster—Virginia Truck and Ornamentals Research Station, Painter, VA 23420.

R. B. Chalfant—Dept. of Entomology and Fisheries, Georgia Coastal Plain Expt. Station, Tifton, GA 31794.

R. B. Workman—Ag. Research Center, Univ. of Florida, Hastings, FL 32045.

G. L. Greene—Kansas Agric. Exp. Station, Kansas State University, Garden City, KS 67846.

L. D. Newsom—Dept. of Entomology, Louisiana State Univ., Baton Rouge, LA 70803.

R. P. Mullett—Ag. Extension Service, Knoxville, TN 37901.

S. L. Poe—Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061.

D. O. Wolfenbarger—Ag. Research and Education Center, Univ. of Florida, Homestead, FL 33030.

J. O. Strandberg—Ag. Research and Education Center, Univ. of Florida, Sanford, FL 32771.

W. G. Genung—Ag. Research and Education Center, Univ. of Florida, Belle Glade, FL 33430.

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Addendum

During the last several years, the newly developed synthetic pyrethroid compounds have received considerable attention by researchers in their insecticidal trials. Unlike the earlier synthetic pyrethroids, the more recently developed ones are highly stable on inert surfaces; they are very active contact insecticides, involatile, and readily degraded by metabolizing systems, notably of mammals and soil micro-organisms (Elliott et al. *1978*). In numerous field tests, the synthetic pyrethroids have proved to be effective in controlling cabbage looper on cabbage (Ganthier *1978*; Gerhardt *1977*; Gerhardt *1978*; Gerhardt and Bennet *1976*; Halfhill and Treat *1976*; Libby and Longridge *1978*; McFadden and Creighton *1978*; Schuster and Clark *1977*; Schuster et al. *1977*; Schuster et al. *1978*; Sorensen *1978*; Waites et al. *1978*), brussels sprouts (Waites et al. *1978*), cauliflower (Gerhardt and Short *1978*), celery (Harris et al. *1978*), collards (Hofmaster and Francis *1978*), and tomatoes (Henne *1978*).

The high degree of control obtained with the synthetic pyrethroid may also be due to their ovicidal capability as in the laboratory fenvalerate was shown to be one of the materials with the most ovicidal activity (Chalfant et al. *1979*).

Other treatments showing promising control of loopers have been granular applications of acephate; on broccoli they gave results comparable to weekly foliar sprays of acephate (Hofmaster *1978*) and also gave the highest percentage of marketable heads when it was applied on cabbage (Bowman *1978*). For the last several years, acephate sprays have been reported as giving excellent control of loopers on cabbage in Georgia and Florida (Schuster et al. *1977*, *1978*) and it was highly effective in preventing damage to lettuce in Arizona (Vail et al. *1980*). Sprays of both acephate and methamidophos gave effective control of loopers on tomatoes (Henne *1978*).

Bowman (*1978*) reported that the higher rates of methamidophos and methomyl are now needed to give satisfactory control of the cabbage loopers on cabbage, which indicates the presence of resistant forms.

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Chapter 10. Utilization of Entomopathogens as Control Agents Against Larvae in Various Agroecosystems

By D. L. Hostetter and C. M. Ignoffo[1]

Abstract

A chronological evaluation of the efficacy of viral, bacterial, and fungal entomopathogens used to reduce damaging populations of cabbage loopers, *Trichoplusia ni* (Hübner), is presented. Efforts of major investigators are reviewed and their results summarized from the first tests to the current usage in an attempt to document successes and failures of microbial control of the cabbage looper.

Diseases of insects were first noted by early observers of honey bees, *Apis mellifera*, and silkworms, *Bombyx mori* (Steinhaus *1975*). Subsequent studies formed the foundation of fundamental queries pertaining to the nature of insect disease and its role in the ecology of the host. Eventually, these studies were extended to insect pest species, and the idea of using entomopathogens to regulate insects was born. This interest in entomopathogens and their potential as control agents was greatly enhanced by the development and eventual commercialization of *Bacillus thuringiensis* (Berliner). The commercial production of the bacterium and the testing of other microbial preparations that have now produced the recent registration and commercialization of a nuclear polyhedrosis virus (*Baculovirus heliothis* for suppression of *Heliothis* sp. on cotton) mean that entomopathogens are now considered practical control agents (Ignoffo, *1967*).

In this section on the utilization of entomopathogens as potential control agents against cabbage loopers, we will examine chronologically the use of viruses, bacteria, and fungi in attempts to suppress or control looper populations in various agroecosystems. The discussion is limited to those entomopathogens that have been applied as control agents in field situations (table 1). The greatest number of investigations have been conducted with the nuclear polyhedrosis virus (NPV) and the bacterium *Bacillus thuringiensis.*

Viruses

The first field tests of the nuclear polyhedrosis virus of *Trichoplusia ni* (Hübner) were conducted in California in 1953-54 by Hall (*1957*). He used infected larvae triturated in water as a source of virus inoculum for application to lettuce to control loopers. His results dispelled an earlier view of Semel (*1956*) that young larvae were not as susceptible to the NPV but corroborated Semel's observation that increased temperature decreased the time required for infection. Hall (*1957*) used various concentrations of the NPV ranging from 10^5 to 10^7 polyhedral inclusion bodies (PIB)/ml in total volumes ranging from 12 to 150 gal/acre. Foliar applications were made directly over the row with a single-nozzle hand sprayer. Excellent control was achieved, and the importance of attaining complete coverage with the spray formulations was noted. He also observed that the higher concentrations were most effective and that two applications were better than one.

McEwen and Hervey (*1958*) also demonstrated through field experiments in New York that the NPV was a highly virulent and effective pathogen of *T. ni.* In a series of field experiments on cabbage, cauliflower, and broccoli, they were able to initiate epidemics that greatly reduced looper populations in all field plots. A source of inoculum similar to that of Hall (*1957*) was used at concentrations ranging from about 1 to 120 larvae/acre in a low volume sprayer delivering 30 gal/acre. The relationship between concentration of NPV and prevailing temperatures at the time of applications was also observed. They noted no difference in virulence between freshly formulated inoculum or that which had been stored at 0° C for 6 months and stated that the addition of a spreader-sticker or the insecticide TEPP (tetraethyl pyrophosphate) had no adverse effect upon the NPV. They concluded that in New York a spray containing one to two diseased larvae per acre would be adequate for practical control of looper populations on cabbage and broccoli providing adequate coverage was attained.

Genung (*1959*) surmised the importance of heavy dews and rainwater in dispersing the virus over leaf surfaces in Florida and demonstrated the effectiveness of the NPV against loopers. He postulated that growers' interest in the NPV would develop slowly because of: (1) the time involved between application and visible results, and (2) the production and maintenance of a source of inoculum. He suggested the use of NPV when insecticides failed to suppress populations or the inclusion of NPV in insecticide formulations as a supplementary control agent.

Hofmaster and Ditman (*1961*) reported on large-scale field experiments conducted during 1960 on the eastern shore of Virginia. They indicated that the NPV could be disseminated either alone or with insecticides to control cabbage loopers on commercial cole crops. Weekly applications were made to about 150 acres of broccoli, kale, and collards via high pressure boom-type sprayers delivering 75 to 100 gal/acre at 300 psi. They used an equivalent of 5 to 10 diseased fifth-instar larvae per acre. More than 98 percent reduction of loopers on broccoli was obtained, which demonstrated that regular applications of the virus were more effective than natural infections. They concluded that due to insecticide resistance, alternate methods of looper control must be developed

[1] Research entomologist and invertebrate pathologist, respectively; Biological Control of Insects Research Unit, Agric. Res. Serv., USDA, P.O. Box A, Research Park, Columbia, Mo. 65205.

Table 1.—*A synopsis of field use of microbial pathogens against* Trichoplusia ni *larvae on various crops*

Crop	Concentration[1]	Application	Results	Reference
		Single-Embedded Nucleopolyhedrosis Virus		
Lettuce	10^5 to 10^7 PIB[2]/ml	12–150 GPA Foliar	Excellent	Hall *1957*
Cauliflower, broccoli	10^9 to 10^{11}/acre	30 GPA Foliar	--do--	McEwen and Hervey *1958*
Broccoli, kale, collards	3 to 6 × 10^{10}/acre	75–100 GPA Foliar	--do--	Hofmaster and Ditman *1961*
Cauliflower	5 to 55 × 10^9 PIB/ml	50–85 GPA Foliar	--do--	Elmore *1961*
Cabbage	10^{11} to 10^{12} PIB/acre	Foliar	Effective	Getzin *1962*
Cotton	5 × 10^{12} PIB/acre	--do--	Excellent	Ignoffo *1964*
Broccoli	18 to 72 × 10^9 PIB/acre	--do--	Effective	Woodhall and Ditman *1967*
Cabbage	10^8 to 10^9 PIB/M^2	Soil	--do--	Jaques *1970a*
Do.	6 × 10^{10} PIB/acre	50 GPA Foliar	Excellent	Hostetter *1971*
Lettuce	Unknown	Foliar	Adequate	Vail et al. *1972*
Collards	5 × 10^{10} PIB/acre	--do--		Kouskolekas and Harper *1973*
		Multiple-Embedded Nucleopolyhedrosis Virus		
Broccoli, cabbage	10^8 to 10^9 PIB/acre	30 GPA Foliar	Less than SEV	Splittstoesser and McEwen *1971*
		Multiple-Embedded Virus Autographa californica		
Cabbage	30 × 10^9 PIB/acre	325 GPA Foliar	Effective	Ignoffo et al. *1974*
		Cytoplasmic Polyhedrosis Virus		
Cabbage, lettuce	3.6 × 10^{11} PIB/acre	Foliar	Ineffective	Vail et al. *1971*
		Bacillus thuringiensis		
Broccoli	2.0 g/gal	Foliar	Adequate	Tanada *1956*
Do.	10^{10} viable spores/g	Wettable powder Foliar	-------	McEwen and Hevery *1958*
Celery	Unknown	Foliar Dust	Favorable	Grigarick and Tanada, *1959*
Poled tomatoes	25 to 30 lb/acre-ft	--do--	Good	Shorey and Hall *1963*
Cabbage	10^{10} spores/g	Foliar Aqueus	--do--	Creighton et al. *1964*
Do.	Unknown	Foliar Dust	--do--	Creighton et al. *1970*
Tomatoes	Unknown	Foliar	--do--	Creighton et al. *1971*
Cabbage	12 to 16 × 10^{10} IU/mg	--do--	--do--	Libby and Chapman *1971*
Do.	1.7 × 10^9 IU/acre	Foliar Flowable Wettable powder	--do--	Dulmage et al. *1971*
		Spicaria rileyi		
Do	10^5, 10^6, 10^7 conidia/ml	Foliar Flowable	Fair	Getzin *1961*

[1] Approximate.
[2] Polyhedral inclusion bodies.

and that the NPV could be utilized in large-scale commercial plantings. Hoffmaster (*1961*) further pursued the relationships between looper populations, precipitation, temperature, and the incidence of NPV concluding that: (1) high populations of loopers developed during or following relatively dry periods, never during periods of excessive rainfall; (2) rainfall and heavy dews help to disperse the virus but are not essential to disease development; (3) the peak virus infection occurs about 1 week after the peak looper infestation; (4) the rate of infection and development of NPV is directly influenced by temperature; and (5) three or more looper outbreaks and subsequent elimination by NPV may occur in a single season.

Elmore (*1961*), using an inoculum containing 5.5×10^9 PIB/ml at rates of 1, 5, and 10 ml/50 to 85 gal/acre, achieved effective control of loopers on cauliflower in California. Two applications of the NPV at 5 and 10 ml reduced looper populations more than 95 percent. He also noted the relationship between temperature and disease progression and concluded that the NPV was quite virulent under a wide variety of weather conditions. He attained the most effective control with higher concentrations but thought that 27.5×10^9 PIB/acre was sufficient to obtain adequate control.

Getzin (*1962*) significantly reduced looper populations on cabbage in the lower Rio Grande Valley of Texas with concentrations of NPV (9.5×10^9 to 9.5×10^{11} PIB/acre). He found that the highest concentrations were most effective and that weekly applications were more effective than applications made every 2 weeks. He also obtained increased control of each succeeding larval instar after spraying, which eventually culminated in an 85 percent reduction at the fifth larval instar. He stressed the need for adequate foliar coverage, particularly on the undersides of the leaves where the early instar larvae occur. Getzin (*1962*) considered the NPV to be a feasible alternative for the control of loopers resistant to chemical pesticides and the resultant toxic residues.

Elmore and Howland (*1964*) conducted field studies to determine whether cabbage looper moths could transmit the disease to their offspring. They concluded that this was not a feasible method of dissemination and that foliar sprays were far more efficient.

Ignoffo (*1964*) demonstrated that the looper NPV could be mass-produced by rearing and infecting larvae on semisynthetic diet. He utilized raw suspensions at a concentration of 5.3×10^{12} PIB/acre at 50 gal/acre in cage tests on cotton. Over 97 percent reduction in looper populations was achieved in two generations.

Wolfenbarger (*1965*) evaluated the addition of surfactants to NPV formulations used against looper populations on cabbage in Texas and determined that when they were added to the virus sprays, control increased significantly. Increased control was attributed to better spreading and sticking of the materials to the foliage.

Heimpel and Adams (*1966*) described two morphologically distinct types of NPV in *T. ni*. One was characterized by large PIB's that contained multiple virus rods (MEV) enclosed within double membranes, the second by smaller PIB's with singled embedded rods (SEV). It was probably the SEV (although this cannot be stated with certainty) that was the type used by the various researchers prior to this discovery. Splittstoesser and McEwen (*1971*) conducted field studies with these NPV in 1968–69 on broccoli and cabbage in New York and Ontario. They used suspensions containing 65 percent MEV: 35 percent SEV, 65 percent SEV: 35 percent MEV, and 94 percent SEV; 6 percent MEV at concentrations of 10^9 and 10^{10} PIB/acre in 1968. In 1969, 75 percent MEV: 25 percent SEV, 90 percent SEV: 10 percent MEV, and a 50 percent MEV-SEV mixture were applied at 30 gal/acre and 60 psi with a tractor-mounted row-crop sprayer. The analysis of their field tests confirmed that sprays containing 50 percent or more SEV caused significantly higher mortalities than those containing predominantly MEV. The SEV was the dominant type in the majority of diseased specimens that were collected from field plots. They also reported on the nonspecificity of the looper MEV and noted that it was transmittable to at least two other noctuids.

Woodhall and Ditman (*1967*) reported on small-scale field tests in Maryland in which they used the looper NPV against populations on broccoli. They tested a series of concentrations ranging from 3 to 12 larval equivalents (LE), or about $18–72 \times 10^9$ PIB/acre, and noted that significantly better control was achieved as concentrations were increased. They also reported that fresh preparations of the looper NPV were more effective at lower concentrations than euivalent concentrations of commercial preparations. Control of loopers was observed to decrease as the intervals between applications increased from 7 to 21 days; compatibility of the virus with two insecticides was also reported.

Interest in the looper NPV and other associated pathogens increased as additional investigators became increasingly aware of the potentials of microbial control. In-depth investigations became more frequent, and information was compiled dealing with pathogen-host and environmental relationships (Canerday and Arant *1968*); the influence of NPV on adult loopers and their progeny (Vail and Hall, *1969*); and the construction of life tables. Elsey and Rabb (*1970*) reported that the principal cause

of mortality of large looper larvae in North Carolina was the NPV. Hostetter and Biever (*1970*) demonstrated the presence and virulence of looper NPV isolated from the feces of English sparrow (*Passer domesticus*) and suggested this as another method of dissemination of the virus in the environment. Jaques (*1967b*) demonstrated that soil splashed on cabbage foliage during rains could be a source of inoculum. Loss of insecticidal activity in 3 to 5 days with NPV suspensions applied to cabbage as foliar sprays was also observed (Jaques *1967a*). Jaques (*1970a*) reported on the natural occurrence of three looper viruses (a typical NPV, a typical NPV forming abnormally large polyhedra, and a granulosis) in field plots in Canada. Jaques (*1970b*) further investigated these viruses and the effects of soil and foliar treatments on looper populations. He found that four applications gave better results than two and that the highest concentrations were most effective. He demonstrated that: two applications of NPV to the soil early in the season substantially reduced looper populations late in the season; applications of 75×10^9 PIB/m^2 were only slightly more effective than applications of 7.5×10^9 PIB/m^2; and a single soil application was nearly as effective as two applications. Jaques concluded that looper viruses can have a long-term effect on looper populations particularly if the virus is applied to the soil.

Vail et al. (*1971*) reported on field and cage tests with three viruses against cabbage looper populations. The viruses were: the SEV of *T. ni*; NPV-MEV isolated from the alfalfa looper, *Autographa californica* (Speyer); and a cytoplasmic polyhedrosis virus (CPV) isolated from *T. ni* (Vail et al. *1967*). This was the first time the CPV of *T. ni* was used in the field. Vail conducted tests in southern California during 1967–68 against the looper on cabbage and lettuce to determine the effectiveness of these viruses. He demonstrated that they were effective in reducing looper populations, particularly at the higher concentrations (3.6×10^{11} PIB/acre), and that the NPV's were more effective than the CPV. He also recognized the potential of the NPV as a microbial control agent for *T. ni* on fall lettuce in Arizona (Vail et al. *1972*).

Loss of activity of the NPV in 3 to 5 days after application to cabbage as foliar sprays was noted by Jaques (*1968*). He also reported on a series of field tests in which he used microbial and chemical control methods in reducing cabbage insects in Canada (Jaques *1972*). The NPV significantly reduced cabbage looper populations in all field tests. These data from tests in growers' fields were particularly interesting, because they demonstrated that the virus can be used effectively by growers with conventional application equipment.

Kouskolekas and Harper (*1973*) reported attempts to control insects on collards in Alabama with chemical and microbial insecticides. They used a NPV suspension derived from infected larvae at a concentration of 5×10^{10} PIB/ acre or about 8 LE. This formulation was tested against a complex of insects occurring on collards at the time. The predominant defoliators were *T. ni*; the imported cabbageworm, *Pieris rapae* (L.); the diamondback moth, *Plutella xylostella* (L.) and the crossstriped cabbageworm *Evergestis rimosalis* (Guenee). They concluded that 10 LE of the NPV was ineffective against the insect complex. This is not at all surprising because of the specificity of the looper NPV; however, no mention was made regarding the reduction of loopers after treatment.

Hostetter (*1971*) reported significant reduction of loopers on cabbage in Missouri after a single application of 10 LE/acre using the *T. ni* NPV-SEV. Populations were high (15 larvae/plant), and within 7 days the population in the 1-acre plot had been reduced over 98 percent.

Further observations of the effectiveness of the NPV in naturally occurring field populations of *T. ni* larvae were made at three commercial truck farms in St. Louis County, Mo., during an epizootic in 1968. Monitoring of larval populations, rates and stages of infection, and sampling of foliage indicated that in a 30-day period (July 17–August 17, 1968) an estimated 170,000 LE of NPV were produced in 7 acres of cabbage (Hostetter, unpublished). Bioassays of soil samples taken from these endemic areas over a 19-month period indicated the continuous presence of virulent polyhedra in the soil (Hostetter, unpublished).

Jaques (*1974*) reported on the occurrence and accumulation of *T. ni* NPV virus in the soil and on cabbage foliage after a 4-yr monitoring study in Canada. He found that a single application of *T. ni* NPV to the soil or five foliar applications at 10-day intervals in August and early September maintained substantial concentrations of the NPV on foliage and resulted in heavy accumulation of the NPV in the soil.

Ignoffo et al. (*1974*) conducted the first field tests of an NPV virus produced in an established insect cell line. Field tests were conducted against looper populations on spring and fall cabbage crops in Missouri in 1973. Foliar sprays significantly reduced looper populations and demonstrated for the first time that insect viruses produced in vitro could be used to control field populations and that viruses propagated in vitro were as efficacious as those propagated in vivo.

Thus, the field efficacy and the potential of the looper NPV have been established, whether the material is used alone or in conjunction with conventional insecticides. Timely applications, environmental conditions, and the coverage will, to a large extent, determine the successful use of this biocontrol agent.

Cytoplasmic Polyhedrosis Virus (CPV) of T. NI

Vail et al (*1967*) first isolated a CPV from *T. ni* larvae in California during routine bioassays with the NPV. The CPV was tested in the field and in small field cages on cabbage and lettuce in California (Vail et al. *1971*). The CPV did not provide adequate crop protection in these tests, and further investigations were terminated.

Bacteria *Bacillus Thuringiensis*

Some of the early field trials with microbial control agents, including those with *Bacillus thuringiensis* (Bt), were conducted in Hawaii in 1953 and 1954 by Tanada (*1956*) against pests of cruciferous crops. The BT formulation he used was dry spores (1 to 2 yr old) suspended in water and sprayed on broccoli for control of loopers. In his analysis, he concluded that loopers were partially resistant to BT and that adequate control may be obtained with a spray containing 2 g spores/gal when moderate infestations occur, but that higher concentrations would be necessary to control very high infestations. These tests, and later those of Hall and Dunn (*1958*), indicated the susceptibility of various crucifer-feeding lepidopteran larvae to BT.

Hall and Andres (*1959*) explored the possibility of using BT for control of field populations of *T. ni* and other pests of cruciferous crops and delineated possible advantages and disadvantages. Their initial tests were made with products developed by Bioferm Corp., Wasco, Calif.; Merck & Co., Rahway, N.J.; and Nutrilite Products, Inc., Buena Park, Calif. Determination of potency of standardization was based on the number of viable spores per gram dry weight of preparation. Investigators of this era were cognizant of the relationship between the crystalline endotoxin and viable spores but assumed the relationship to be constant and based pathogenicity primarily on spore counts. Hall and Andres (*1959*) also observed that the best control was achieved with dust formulations and pursued this method of application. They noted that standardization of preparations was very important and that adequate control of pests could be achieved with lower concentrations of BT provided better formulations and adequate coverage were attained.

Formulations of BT and several chemical pesticides were tested against cabbage loopers on celery in California (Grigarick and Tanada *1959*). Dust formulations compared favorably with some of the chemical pesticides, and control was directed related to coverage. Grigarick and Tanada (*1959*) emphasized the absence of toxicity of BT to plants and mammals and strongly recommended its use for controlling loopers on celery in California.

Possible problems in formulation and standardization of some early commercial preparations were also noted by McEwen and Hervey (*1959*). They used wettable powder (WP) preparations and arbitrarily assumed a concentration of 10×10^{10} viable spores/g. These workers concluded that successful control of the looper on broccoli with BT would require two to four times the amount required to control the imported cabbageworm, *Pieris rapae*.

McEwen et al. (*1960*) conducted another series of tests against four lepidopteran pests of crucifers and apples in New York with five commercial WP formulations. Their studies on broccoli indicated that a concentration eight times greater would be needed to control *T. ni* than to control *P. rapae* larvae. Differences in insecticidal activity between the products were observed, which further attested to the need for standardization. They also investigated the compatability of BT suspensions with five insecticides and four fungicides and determined that the insecticidal activity of BT was not adversely affected; however, prolonged standing of spray mixtures (about 3 hr) reduced effectiveness, which was most pronounced with the fungicide chloranil (2,3,5,6-tetrachloro-1,4-benzoquinone).

Hall et al. (*1961*) reviewed the research that led to the development of commercial formulations of BT for insect control. They reported that the looper was only moderately susceptible to the early formulations of BT but that better control was being achieved with the newer formulations. Dust preparations of Rohm & Haas Co. and Nutrilite Products, Inc., were as effective (quickness of kill and residual activity) as chemical insecticides. These workers also noted variations in preparations of viable spores per gram and of insecticidal activity and suggested the need for industrial standardization of these commercial products.

Shorey and Hall (*1962*) reported effective control of the cabbage looper (including large larvae) with most BT dust preparations they tested. (The ability to control large larvae is one of the most important criteria for the evaluation of a candidate insecticide for loopers.) These authors again noted the variation in commercial preparations of BT and the need for standardization before these products could be properly evaluated. Shorey and Hall (*1963*) reported that high concentrations of BT showed promise for the control of loopers on poled tomatoes. Dust formulations at rates of 25 and 30 lb/acre-ft appeared to give control comparable to that obtained with DDT (1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane at a rate of 2/3 lb/acre-ft. They also reported that a BT spray formulation gave larval control equal to or better than that provided by DDT, toxaphene (chlorinated camphene containing 67 to 69 percent chlorine), DDT and toxaphene, or malathion (*0,0*-dimethyl*S*-(1,2-dicarbethoxyethyl) phosphorodithioate).

Creighton et al. (*1964*) evaluated BT for control of loopers on cabbage in South Carolina. Their tests indicated that formulations containing 7.5×10^{10} spores/g were comparable to naled (1,2-dibromo-2,2-dichloroethyl dimethyl phosphate) and parathion (*0,0*-diethyl *0-p*-nitrophenyl phosphorothioate) in protecting cabbage from loopers. Addition of corn oil to this formulation was of value in reducing looper populations and preventing feeding. The BT formulations exerted a repellent effect upon looper feeding and were usually more effective in preventing looper damage than in reducing the looper population. Creighton et al. (*1970*), in a later paper, reported on a 5-yr study in South Carolina (*1963–68*) in which they tested pathogens and chemicals against caterpillars on cabbage. They found that sprays containing only BT failed to provide adequate control of the looper. However, a new dust formulation of BT tested for the first time in 1967 was as effective as a conventional spray containing endosulfan (6,7,8,9,10,10-hexachloro-1,*5a*6,9,*9a*-hexahydro-6,9-methano-2,4,3-benzo (*e*)-dioxathiepin-3-oxide) and parathion, and in 1968 the dust formulation was significantly better than the spray. Creighton et al. (*1971*) also obtained highly effective control of loopers with BT on tomatoes in South Carolina.

Dulmage (*1970*) reported the isolation of the *δ*-endotoxin of a strain of BT var. *alesti,* later redescribed as *kurstaki* (DeBarjac and LeMille *1970*), which was designated HD-1. It had insecticidal activity 15 to 30 times greater than that of the commercial BT formulations then available. Libby and Chapman (*1971*) and Dulmage et al. (*1971*) reported on the field testing of HD-1 against loopers. Libby and Chapman used Dipel, a WP formulation of HD-1 produced by Abbott Laboratories, which contained $12–16 \times 10^3$ International Units[2] (IU)/mg of insecticidal potency. They also used products formulated by Nutrilite Products, Inc. (Biotrol BTB-183) and International Minerals and Chemicals Corp. (Thuricide HP); both were WP. Biotrol BTB-183 contained var. *thuringiensis* and 600–800 IU/mg; the Thuricide HP was HD-1, $12–16 \times 10^3$ IU/mg. These authors concluded that commercial formulations containing the HD-1 isolate could be successfully utilized in the field as part of an integrated control program against loopers in Wisconsin. During the same growing season, Dulmage et al. (*1971*) conducted similar tests with the HD-1 strain against loopers in the Rio Grande Valley of Texas. The formulations used in these trials contained HD-1 with a potency of 9.9×10^3 IU/mg. Their results demonstrated that good protection of cabbage was obtained with weekly applications of as little as 1.1×10^9 IU/acre or with 2.2 and 4.5×10^9 IU/acre applied at 10-day intervals. They also indicated that foliage damage was a more valid indicator of protection than worm counts.

The isolation of HD-1 and its subsequent commercialization were significant steps in improving the efficacy of BT formulations. Since then, numerous investigators (for example, Greene and Workman, *1971*; Creighton et al. *1972*; Boling *1972*; Chalfant et al. *1973*; and Creighton and McFadden *1974*) have tested these formulations on various crucifers in diverse ecosystems and over a wide range of climatic regions. Differences in success, quite naturally, have been reported; however, progress in formulation and application technology has been made, and the use of BT as a control agent for loopers has been firmly established.

Fungi *Nomuraea Rileyi*

The fungus *Spicaria rileyi*, recently redescribed as *Normuraea rileyi* (Kish et al. *1974*) has been considered a potential microbial control agent for many years. Its pathogenicity and its efficacy in reducing damaging populations of lepidopteran larvae have been reported by several authors (Hill *1925*; Getzin *1961*; Behnke and Paschke *1966*; Allen et al. *1971*). Although the fungus has potential as a control agent of cabbage loopers, its efficacy is probably much more dependent on environmental conditions than is the efficacy of other microbial agents (that is, viruses and bacteria).

Commercialization of fungal control agents has not been achieved in the United States. Instead work with bacterial and viral control agents has been emphasized, and little work has been conducted with fungi such as *N. rileyi* as applied control agents.

Getzin (*1961*) reported on field tests conducted with *S. rileyi* against loopers in the lower Rio Grande Valley of Texas in 1959. He attempted the artificial dissemination of spores to determine whether infection could be induced in a looper population at a time when natural infection was not evident. He used three treatments consisting of 10^5, 10^6, and 10^7 spores/ml of spray. Environmental conditions were monitored, and applications were made when the relative humidity was 98 to 100 percent during the initial 24-hr posttreatment period. During the 7 days after application, temperatures averaged 60° F; thereafter they ranged between 65° and 84° F. The RH averaged 95 percent on the third day after application and ranged between 60 and 80 percent for the duration of the test.

[2] A method of establishing potency standards for BT materials was devised in 1966 at Wageningen, the Netherlands, by a working party. The party proposed that potencies be determined through bioassays in which LD_{50}'s of unknown BT samples are compared with those of a standard (Burges *1967*). The party recommended as a primary reference standard, E-61, a BT material prepared at the Institute Pasteur, Paris, France, and assigned it a potency of 1000 International Units (IU/mg). Potencies of BT materials are compared with the potency of the E-61 standard and expressed in IU's/mg relative to it.

Between 0.08 and 0.26 inch of rain was recorded each day for 5 days after the treatment. He first noted mummified looper cadavers 11 days after treatment; he also determined that the two highest treatments were superior to the lowest and that the fungus failed to sporulate in the field on the cadavers due to insufficient moisture at the time the larvae died. He concluded that the limited distribution of spores would be efficient only if a secondary spread from infected larvae could occur. Because of this dependence on specific environmental conditions after treatments and the impossibility of predicting them, he did not think spore distribution could be a practical control measure.

Small field tests were conducted on spring and fall cabbage crops at Charleston, S.C., in 1971 (J. V. Bell,[3] personal communication). A dust formulation was used at a rate of 1.0 lb actual spore powder/acre (diluted in 20 lb of pyrophyllite). Seven weekly applications were made during the growing season; efficacy was based on larval mortality and damage at harvest. Considerable protection was afforded to the heads; however, the damage done the wrapper leaves precluded grading to USDA No. 1 classification. These results were less than anticipated and generally unsatisfactory when compared with conventional control methods.

Ignoffo et al (*1976*) demonstrated that one heavy application of *N. rileyi* conidia could be used to alter the epizootic pattern normally associated with soybean caterpillars. In addition, fungicides and some insecticides and herbicides registered for use on soybeans inhibited growth and development of *N. rileyi* (Ignoffo et al. *1975*). In laboratory tests, *T. ni* was as susceptible as larvae of *Heliothis zea* (Boddie), *H. viescens* (Hübner), and *Plathypena scabra* (F.) but not as susceptible as *Spodoptera exigua* (Hübner) (Puttler et al. *1976*).

Considerable work remains to be done with potential fungal control agents before they can be realized as commercialized agents for looper control. In certain situations, they are very effective as natural regulators of populations and should be considered in control programs.

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Chapter 11. Role of Parasitoids and Predators in Regulating Populations[1]

By P. B. Martin, P. D. Lingren and G. L. Greene

Abstract

Regulations and suppression of populations of cabbage looper, *Trichoplusia ni* (Hübner), by parasitoids and predaceous arthropods have been studied directly and indirectly in numerous domestic crops (including crucifers, lettuce, and cotton) and wild host plants in California, Florida, New York, Minnesota, and North Carolina. *Trichogramma* spp., *Litomastix truncatella* (Dalman), and *Voria* spp., parasitize substantial numbers of cabbage loopers in many areas of the United States. Predators such as *Orius* spp., *Geocoris* spp., *Coleomegilla maculata* (DeGeer), *Hippodamia convergens* Guerin-Meneville, *Labidura riparia* Pallas, and *Polistes* spp. are sometimes abundant and can cause substantial mortality to the cabbage looper under some conditions.

About 70 different parasitoids have been recovered from the cabbage looper, but only a few are abundant in each of various localities. *Trichogramma* spp. are the major egg parasitoids. Natural parasitism by this parasitoid complex has often been estimated at more than 40 percent in tomatoes in various areas of the United States, and supplemental releases of *Trichogramma pretiosum* (Riley) have shown potential for suppressing cabbage loopers on various crops in several experiments in California, Missouri, and Florida. The larval parasitoid, *Voria ruralis* (Fallen), has shown similar potential.

Generally, it appears likely (1) that the majority of intrageneration mortality for cabbage looper occurs in the egg-small larva interval, (2) that *Orius* spp., coccinellids and *Geocoris* spp. may be the major entomophages inflicting this mortality, (3) that *L. truncatella*, *V. ruralis*, *Brachymera ovata* (Say), and *Patrocloides montanus* (Cresson) may sometimes be important in regulating cabbage looper populations through intergeneration mortality, and (4) that augmentative-releases of *Reduviolus alternatus* (Parshley), *Geocoris punctipes* (Say), *T. pretiosum*, and *V. ruralis* have potential for use in suppressive actions against cabbage loopers.

Additional research is needed to provide information (behavioral, chemical ecology, functional response, movement, population dynamics) for the development of simulation models explaining the effects of numerical relationships between beneficial arthropods and the host under various conditions. This should result in a greater utilization of beneficial arthropods in pest management schemes for control of cabbage looper.

Ecological and biological studies designed to ascertain the importance of natural populations of parasitic and predaceous arthropod species in regulating populations of the cabbage looper, *Trichoplusia ni* (Hübner), have been conducted at several locations and on various domestic crops and wild host plants in the United States. In general, parasitoids (Oatman *1966*; Sutherland *1966*; Clancy *1969*; Oatman and Platner *1969*; Elsey and Rabb *1970*; Oatman and Platner *1972*; Ehler et al. *1973*) have received more attention than predators (Falcon et al. *1968*; Oatman and Platner *1969*; Ehler et al. *1973*; Weires and Chiang *1973*; Ehler *1977a*). A few studies have been conducted in an attempt to determine the potential of conservation and manipulation of beneficial species for control of populations of the cabbage looper. Although somewhat confusing, the complex of studies has revealed that parasitoids and predators play an important role in the regulation of cabbage looper populations and that conservation and manipulation of some species have good potential for control of the cabbage looper on certain crops. Consequently, the purpose of this paper is to review the research information on the subject that has been compiled to date and try to identify some of the more important species. In addition to previously published data, this review contains unpublished information obtained by the authors from studies conducted in northwest Florida during 1971–73 and personal communications with several researchers currently working on the subject.

Natural Control of the Cabbage Looper by Parasitoids

At least 68 parasitoid species have been recovered from field-collected cabbage loopers (table 1). As many as six additional species may be represented in collected material that has been questionably identified. Eight species complete development in eggs of cabbage looper and about 60 utilize various larval instars. A major parasitoid, *Litomastix truncatella* (Dalman), in many cabbage looper studies in many crops, is an egg-larval parasitoid. Two parasitoids are frequently recovered from pupae of cabbage looper. Some parasitoids (especially tachinids) may be carried over from host larvae to host pupae.

Parasitoids such as *Trichogramma* spp., some *Apanteles* spp., and *Meteorus autographae* Muesebeck kill their host

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[1]Research conducted by authors at former Tobacco Insects Res. Lab., Quincy, Fla., location, Agr. Res. Serv., USDA, in cooperation with Agr. Res. and Educ. Center, Institute of Food and Agricultural Sciences, University of Florida, Quincy (Cooperative Agreement No. 12-14-100-10, 914(33)).

Current addresses of authors: Dep. Entomol.-Fisheries, Coastal Plain Sta., University of Georgia, Tifton; Western Cotton Res. Laboratory, 4135 E. Broadway Rd., Phoenix, Ariz.; and Box L, Garden City, Kans., respectively.

Table 1.—*Parasitoids of cabbage looper found in field studies in the United States*[1] [2]

Stage attacked	Parasitoid species	References
	Scelionidae	
	Telenonus sp.	Martin et al. (*1981b*)
Egg	Trichogrammatidae	
	Trichogramma australicum Girault	Manjunath (*1972*)
	T. chilotracae Nagarkatti and Nagaraja	Do.
	T. exigumm Pinto and Platner	Martin et al. (*1981b*)
	T. evanescens Westwood	Oatman et al. (*1968*)
	T. japonicum Ashmead	Manjanath (*1972*)
	T. minutum Riley	McKinney (*1944*)
	T. pretiosum (Riley)	Oatman (*1966*)
Larval and/ or pupal	Braconidae	
	Apanteles autographae Muesebeck	Muesebeck and Krombein (*1951*)
	A. congregatus (Say)	Riley (*1883*)
	A. glomeratus (L.)	Chittenden (*1902*)
	A. laeviceps Ashmead	Muesebeck and Krombein (*1951*)
	A. marginiventris (Cresson)	Boling and Pitre (*1973*)
	A. plutellae Kurdji	Manjunath (*1972*)
	A. rufricrus Hal.	Do.
	Apanteles sp.	Butler (*1958a*), Manjunath (*1972*)
	Chelonus blackburni Cameron[3]	Fye and Jackson (*1973*)
	C. insularis Cresson[3]	Ehler et al. (*1973*)
	Meteorus autographae Muesebeck	Muesebeck and Krombein (*1951*)
	Microplitis alaskensis Ashmead	Butler (*1958a*)
	M. brassicae Muesebeck	McKinney (*1944*)
	M. plutellae Muesebeck	Oatman and Platner (*1969*)
	Rogas granulatus DeGant	DeGant (*1930*)
	R. molestus Cresson	Butler (*1958a*)
	R. perplexus Gahan	Do.
	R. rufocoxalis Gahan	McKinney (*1944*)
	Rogas sp.	Wall and Berberet (*1975*)
	Chalcididae	
	Brachymeria ovata (Say)	Elsey and Rabb (*1970*)
	Encyrtidae	
	Litomastix truncatella (Dalman)[3]	Riley (*1883*)
	Eulophidae	
	Euplectrus comstockii Howard	McKinney (*1944*)
	E. plathypenae Howard	Wall and Berberet (*1975*)
	Pediobius sexdentatus (Girault)	Oatman and Platner (*1969*)
	Tetrastichus galactopus (Ratzeburg)[4]	Peck (*1963*)
	Ichneumonidae	
	Campoletis flavicinta (Ashmead)	Krombein et al. (*1979*)
	Coccygomimus aequalis (Provancher)	Sutherland (*1966*)
	Cryptus rutovinctus Pratt	Krombein et al. (*1979*)
	Diadegma insulare (Cresson)	Hayslip et al. (*1953*)
	Diadegma spp.	Sutherland (*1966*)
	Enicospilus sp.	Manjunath (*1972*)
	Echthromorpha punctum Brutte	Do.
	Gambrus ultimus (Cresson)	Sutherland (*1966*)
	Gelis tenellus (Say)[5]	Do.
	Hyposoter exiguae (Viereck)	Oatman (*1966*)
	Iseropus stercorator orgyiae (Ashmead)	Sutherland (*1966*)
	Itoplectis conquisitor (Say)	Muesebeck and Krombein (*1951*)
	Nepiera fuscifemora Graf	Krombein et al. (*1979*)
	Netelia sp.	Watson et al. (*1966*)

Table 1.—Continued

Patrocloides montanus (Cresson)	Clancy (*1969*)
Pristomerus spinator (F.)	Krombein et al. (*1979*)
Pterocormus gestuosus (Cresson)	Mitchell (*1961*)
Stenichneumon culpator cinctincornis (Cresson)	Schaffner and Griswold (*1934*)
Vulgichneumon brevicinctor (Say)	Muesebeck and Krombein (*1951*)
Sacrophagidae	
Sacrodexia sternodontis Townsend	Aldrich (*1927*)
Senotainia sp.	Manjunath (*1972*)
Tachinidae	
Archytas californiae (Walker)	van den Bosch and Hagen (*1966*)
Carcelia sp.	Manjunath (*1972*)
Compsilura concinnata (Meigen)	Schaffner and Griswold (*1934*)
Eucelatoria armigera (Coquillett)	Butler (*1958b*)
E. rubentis (Coquillett)	Watson et al. (*1966*)
Eusisyropa blanda blanda (Osten Sacken)	West (*1925*)
Lespesia archippivora (Riley)	Watson et al. (*1966*)
Lespesia sp.	Clancy (*1969*)
Madremyia saundersii (Williston)	Oatman (*1966*)
Periscepsia helymus Walker)	Clancy (*1969*)
Phorocera sp.	Sutherland (*1966*)
Phryxe vulgaris (Fallen)	Do.
Siphona plusiae Coquillett	Clancy (*1966*)
Siphona sp.	Oatman (*1966*)
Voria aurifrons (Townsend)[6]	Wall and Berberet (*1975*)
V. edentata Bar.	Manjunath (*1972*)
V. ruralis (Fallen)	Schaffner and Griswold (*1934*)
Winthemia quadripustulata (F.)	Allen (*1925*)
W. rufopicta (Bigot)	Schaffner and Griswold (*1934*)
Winthemia spp.	Elsey and Rabb (*1970*)

[1]*Brachymeria intermedia* (Nees) (Peck *1963*) and *Campoletis sonorensis* (Cameron) (Lingren et al. *1970*) were recovered from cabbage loopers exposed to these parasitoids in the laboratory.

[2]Harding (*1976*) reported an additional 14 parasitoids; however, it is impossible to distinguish between cabbage looper and soybean looper parasitoids in his report. Several hyperparasitoids are also included in his list along with primary parasitoids.

[3]Parasitoid oviposition is in the host eggs.

[4]Named *Tetrastichus rapo* (Walker) by Peck (*1963*).

[5]Probably a hyperparasitoid of cabbage looper rather than a primary parasitoid.

[6]According to C. W. Sabrosky, Systematic Entomology Laboratory, Beltsville, Md. (personal communication), *V. aurifrons* probably is a synonym for *V. ruralis*.

early in its life cycle, hence, generally preventing major crop damage by an individual host. Others, such as *Voria* spp., *Eucelatoria armigera* (Coquillett), and *Lespesia archippivora* (Riley) may do little to prevent feeding by the host, but could help reduce numbers of subsequent generations of the host.

Response to host-density also varies among cabbage looper parasitoids. Ehler and van den Bosch (*1974*) classed *L. truncatella* and *Patrocloides montanus* (Cresson) to have density-related parasitization. That of *Hyposoter exiguae* (Viereck) and *Microplitis brassicae* Muesebeck seemed to be inversely related to density. *Chelonus insularis* Cresson, *Apanteles marginiventris* (Cresson), *Trichogramma pretiosum* (Riley), and *Voria ruralis* (Fallen) had erratic parasitization rates.

Several of the parasitoid species listed in table 1 are not widespread in distribution and appear to be incidental records. Others generally attack other hosts and are not of major importance in the population dynamics of the cabbage looper. Ten to 13 parasitoid species were the largest numbers reported from various studies of their abundance in populations of the cabbage looper (Oatman *1966*; Sutherland *1966*; Oatman and Platner *1969*; Clancy *1969*; and Martin et al. *1981b*); in most other publications, 5 or fewer parasitoids are mentioned.

T. pretiosum, *L. truncatella*, and *V. ruralis* appear to be the major and most widespread arthropod mortality agents of the cabbage looper; they are frequently mentioned in the literature as being very important population suppression

agents on many crops and in numerous areas of the United States. Other species, however, are sometimes important because in studies in northwest Florida, *M. autographae*, *A. marginiventris*, and *Apanteles autographae* Muesebeck also caused high cabbage looper mortality during the spring and early summer in a cropping system free of insecticide usage and consisting of collards, cabbage, tobacco, soybeans, tomatoes, and several other crops (Martin et al. *1981b*). Several other parasitoids are sometimes numerous in certain areas and may be important in suppressing populations of the cabbage looper. For instance, Hayslip et al. (*1953*) reported that *Diadegma insulare* (Cresson) was important in reducing numbers of cabbage looper in south Florida crucifers. Sutherland's (*1966*) research indicated that *Stenichneumon culpator cincticornis* (Cresson) and *Vulgichneumon brevicinctor* (Say) might be important regulators of cabbage looper on occasion in New York. In the western United States, *M. brassicae*, *E. armigera*, *L. archippivora*, and *H. exiquae* are apparently important parasitoids of the cabbage looper (Butler *1958a, b*; Oatman *1966*; Clancy *1969*; Oatman and Platner *1969*; Ehler et al. *1973*).

Some natural parasitoid species may not be widespread in the United States nor often cause high mortalities in cabbage looper populations, but could occasionally cause population numbers of cabbage looper to collapse because they destroy the residue of a population already seriously depleted by other mortality factors. In their studies in North Carolina, Elsey and Rabb (*1970*) concluded that *Brachymeria ovata* (Say) might act as such a mortality factor on the cabbage looper in some seasons. Parasitoids with this capability might have excellent potential for integration into a pest management system for the cabbage looper.

Parasitism of Eggs

Parasitism of cabbage looper eggs is very important in crop protection, since the cabbage looper is destroyed before it can feed. Parasitism of cabbage looper eggs is almost exclusively by *Trichogramma* spp.,[2] and *T. pretiosum* appears to be the species most commonly recovered from cabbage looper eggs. McKinney (*1944*) found *Trichogramma* spp. had parasitized up to 47 percent of the cabbage looper eggs he collected from lettuce in Arizona one year, and *Trichogramma* spp. frequently have been recovered from cabbage looper eggs in studies in California (Oatman *1966*; Oatman et al. *1968*; Oatman and Platner *1969, 1972*).

In crucifers, parasitism of cabbage looper eggs by *Trichogramma* spp. was generally lower than 20 percent during studies by Oatman et al. (*1968*) and Martin et al. (*1976, 1981b*) (table 2). In far northeastern Florida, Ru and Workman (*1978*) collected only 3 parasitized eggs in cabbage out of 2,087 eggs collected. In tomatoes, however, *Trichogramma* spp. were frequently observed to destroy at least 40 percent of the cabbage looper eggs collected in our studies (Martin et al. *1976, 1981b*) and others (Graham *1970*; Oatman and Platner *1971*) (table 2). Such differences of parasitism were noted by us in various other crops in a supplemental release test in northwest Florida (Martin et al. *1976*) and in subsequent monitoring of natural parasitism by *Trichogramma* spp. in a 8-acre cropping system near Quincy, Fla. (Martin et al. *1981b*). In these studies, no looper eggs collected from tobacco were parasitized and parasitism was highest in tomatoes in the system; however, egg samples were often small in tomatoes. Parasitism of cabbage looper eggs was first noted in early April, about the time of the first occurrence of substantial numbers of cabbage looper eggs in the spring. Densities of cabbage looper were very low during the winter in Quincy and no *Trichogramma* spp. were recovered from eggs taken during that season; however, heavily parasitized velvetbean caterpillar (*Anticarsia gemmatalis* Hübner) eggs were taken in clover between September and November and green cloverworm, *Plathypena scabra* (F.), was present in this crop during the winter and early spring (Martin et al. *1981a*). *T. pretiosum* was probably overwintering in these host eggs and others at a reduced rate of development similar to what was described by Lopez and Morrison (*1980*).

Parasitism of Larvae

In many crops, estimates of parasitism of cabbage looper larvae have often been higher than those for egg parasitism (table 2), probably because of longer exposure of the larvae to a variety of parasitoid species. McKinney (*1944*) stated that "larval parasites seem to be more uniformly distributed from field to field than do the egg parasites and exercise a more effective control against the looper." In our studies in northwest Florida (Martin et al *1981b*), larval parasitism seemed more erratic than egg parasitism probably because of interaction with polyhedrosis virus effects. Larval parasitism was frequenly high in the spring and fall and low in the summer.

In 1963 and 1964, Oatman (*1966*) collected 1,737 cabbage looper larvae from untreated California crucifers; an average of 26 percent was parasitized, mostly by tachinids. On two dates, over 90 percent of the larvae collected were parasitized. *V. ruralis* and *L. truncatella* were the primary parasitoids recovered, but seven others were also considered to be of importance. In contrast, Ru and Workman (*1978*) collected 3,131 cabbage looper larvae from untreated cabbage in central Florida and only 0.1 percent were parasitized. They were all parasitized by *L. truncatella*.

[2]With the exception of the very important egg-larval parasitoid, *L. truncatella*.

Table 2.—*Percent parasitism of cabbage looper eggs and larvae that were collected during studies in several areas of the United States during the years indicated* [1]

	Crucifers										
	Cabbage			Collards		Tomatoes				Wild hosts	
	S CA[2]	NW FL[3]		NW FL[4]		S CA[5]	S TX[6]	NW FL[7]		S CA[8]	
Month	1963-65	1972	1973	1972	1973	1966-67	1964-65	1972	1973	1966	1967
					Eggs[9]						
Jan.	6	—	—	0	—	—	—	—	—	—	—
Feb.	0	—	—	—	—	—	—	—	—	—	—
Mar.	0	—	0	0	0	—	—	—	—	—	—
Apr.	0	0	0	8	7	—	12[10]	—	—	—	—
May	0	8	16	13	23	—	—	49	14	—	—
June	0	—	48	15	40	—	—	62	58	—	—
July	10	—	—	12	26	8	—	0	—	—	—
Aug.	2	—	—	16	—	57	—	28	—	—	—
Sept.	2	—	—	21	—	56-43[10]	—	0	—	—	—
Oct.	13	—	—	7	—	30	65[11]	—	—	—	—
Nov.	16	—	—	—	—	13	—	—	—	—	—
Dec.	10	—	—	—	—	—	—	—	—	—	—
					Larvae						
Jan.	—	—	—	56	—	—	—	—	—	51	—
Feb.	—	—	—	0	—	—	—	—	—	27	—
Mar.	—	—	—	0	—	—	—	—	—	57	—
Apr.	—	0	25	19	30	—	—	—	—	25	—
May	—	11	28	17	41	—	—	—	62	24	34
June	—	—	32	10	23	—	—	100	84	—	30
July	—	—	—	0	16	—	—	28	—	—	24
Aug.	—	—	—	13	—	—	—	0	—	—	49
Sept.	—	—	—	21	—	—	—	100	—	—	49
Oct.	—	—	—	12	—	—	—	—	—	—	20
Nov.	—	—	—	50	—	—	—	—	—	—	26
Dec.	—	—	—	—	—	—	—	—	—	—	50

[1]Dashes indicate no samples were taken, primarily due to lack of suitable host plants.
[2]S CA = Southern California: Oatman et al. (*1968*); 1,231 eggs were collected.
[3]NW FL = Northwestern Florida: Martin et al. (*1981b*); 365 eggs and 249 larvae were collected in 1972, and 390 eggs and 331 larvae were collected in 1973.
[4]Martin et al. (*1981b*); 2,771 eggs and 906 larvae were collected in 1972, and 1,933 eggs and 1,639 larvae were collected in 1973.
[5]Oatman and Platner (*1971*); 282 eggs were collected.
[6]S TX = South Texas; Graham (*1970*); 1,364 eggs were collected.
[7]Martin et al. (*1981b*); 92 eggs and 14 larvae were collected in 1972, and 53 eggs and 17 larvae were collected in 1973. Some soybean loopers, *Pseudoplusia includens* (Walker), are included in these data.
[8]Clancy (*1969*); 1,760 and 340 larvae were collected in 1966 and 1967, respectively.
[9]All egg parasitoids were *Trichogramma* spp.
[10]Numbers in column represent averages from April 1963 through March 1965.
[11]Means from samples over 3-month period (March-May 1965 and September-November 1964).

In a later study, Oatman and Platner (*1969*) found larval parasitism to be an important mortality factor of cabbage looper on cabbage in southern California, but mortality was often low during the summer months. *V. ruralis*, the dominant parasitoid of 12 species recovered, was most frequently found in the fall and winter. *H. exiguae* and *L. truncatella* occurred most commonly during the summer and fall.

Clancy (*1969*) found similar trends of parasitism from collections of larvae from wild hosts (table 2), alfalfa, and tree tobacco in California with larval parasitism being highest (41 percent) in tree tobacco. Larval parasitism was greater (over all crops and wild hosts) from August to January than during other periods of the year. McKinney (*1944*), Butler (*1958b*), and Brubaker (*1968*) found *V. ruralis* was themost common parasitoid of cabbage looper collected from weeds and cultivated crops in Arizona and that it was most abundant during late fall and winter.

Ehler and van den Bosch (*1974*) felt that *H. exiguae* and *M. brassicae*, recovered from medium-size cabbage looper larvae, were important parasitoids in cotton, but they did not regulate cabbage looper densities. Parasitism by *L. truncatella* (the major parasitoid emerging from large larvae) was density related. Ehler (*1977a*), who did an excellent analysis of the natural enemy situation in the San Joaquin Valley cotton, stated that the numerical dominance of *L. truncatella* over other cabbage looper parasitoids (and at times over predators) was probably due to its polyembryonic development. He found mortality of large larvae by this parasitoid ranged from 10.3 to 72.5 percent; parasitization by other parasitoids was relatively low.

Parasitism of Pupae

Emergence of parasitoids from pupae is less frequent than that from the larval stages. Ehler and van den Bosch (*1974*) found low percentages (6.3 and 9.6) of pupae destroyed by *P. montanus*. *S. culpator cincticornis*, and *V. brevicinctor* were recovered most frequently from cabbage looper pupae collected in late August and September from New York crucifers (Sutherland *1966*). *B. ovata*, another parasitoid of pupae, may be important in regulating cabbage looper under some conditions (Elsey and Rabb *1970*).

Natural Control of the Cabbage Looper by Predators

Direct visual observations are necessary to determine predaceous species and numbers of the host consumerd. Obviously, this has influenced researchers to approach field studies on predation indirectly. For instance, McKinney (*1944*) observed that large numbers of cabbage looper eggs on lettuce had been consumed by what he assumed to be arthropod predators. Ru (personal communication)[3] observed large losses of cabbage looper eggs in cabbage fields, and we observed similar egg losses in various crops in northwest Florida that were attributable to predation. Studies in cotton by DeLoach and Peters (*1972*) indicated egg losses of 50 to 70 percent within 24 hr after cabbage looper eggs were placed on cotton plants. Extrapolation of these data indicated that 69 to 79 percent of the eggs would have disappeared had they been left on the plant until hatch (about 72 hr). They attributed these losses to predators. The most abundant predators in their study were *Orius insidiosus* (Say), *Hippodamia convergens* Guerin-Meneville, and *Coleomegilla maculata* (DeGeer).

Another study in cottonfields by Falcon et al. (*1968*) showed that the cabbage looper becomes a secondary pest when arthropod predators of their eggs and small larvae were suppressed by certain insecticide spray programs. They indicated that *Orius tristicolor* (White), *Geocoris pallens* Stål, *Collops vittatus* (Say), *Reduviolus americoferus* (Carayon), and *Chrysopa carnea* Stephens were the most important predators. In a similar study, using an insecticide-check method and age-specific life tables, Ehler et al. (*1973*) and Ehler and van den Bosch (*1974*) found that these spcies, with the exception of *C. vittatus*, were the most important arthropod predators inflicting mortality on small larvae of cabbage looper in cotton. They concluded that predation of other life stages of the pest was of less importance. As in the work of Falcon et al. (*1968*), Ehler et al. (*1973*) found that when this predation on small looper larvae was suppressed, a secondary pest outbreak of cabbage looper is possible. In a more recent paper, Ehler (*1977a*), with his age-specific life-tables and insecticide-check tests, found by far the majority of the intrageneration mortality for cabbage looper in his cotton occurred during the egg-small larva interval. Survival of cabbage looper larvae in these studies was directly correlated with predator (*O. tristicolor* and *G. pallens*) abundance.

In cruciferous crops, the coccinellids are among the most abundant of species likely to prey on cabbage looper in several areas of the United States (table 3). In fact, Whitcomb and Bell (*1964*) found that coccinellids were important predators of cabbage looper eggs in Arkansas cotton. Ru and Workman (*1978*) concluded that although natural control appeared to be lower than that reported from studies in other regions of the United States, *Labidura riparia* Pallas and *C. maculata* demonstrated a high potential as beneficial predators that might be used in cabbage looper management. Although less abundant (table 3), chrysopids could affect some cabbage looper population levels. Other predators or predator complexes —such as *Erythemis simplicollis* (Say) (Whitcomb and

[3]Nguyen Ru, University of Florida, Gainesville.

Table 3.—*Estimated number of coccinellids and chrysopids per acre in various studies conducted on crucifers in the United States* [1]

	Coccinellids[2]			Chrysopids[2]			
	SW CA	SE MN	NW FL	SW CA	SE MN	NW FL	
						Collards[6]	
Date[3]	Cabbage[4]	Cabbage[5]	Collards[6]	Cabbage[4]	Cabbage[5]	Adults & larvae	Eggs[7]
May 6	0	—	2,800	0	—	0	0
14	4,700	—	2,300	0	—	0	3,700
21	6,800	—	2,000	0	—	0	200
28	6,500	—	2,200	0	—	0	0
June 4	6,700	—	5,200	0	—	0	200
11	4,700	—	1,600	0	—	0	700
18	1,800	—	1,400	500	—	200	0
25	2,900	—	300	800	—	0	500
Jul. 2 & 2	0	100	200	0	100	0	800
9 & 9	1,600	300	0	300	100	0	4,000
16 & 15	800	500	0	0	300	0	0
23 & 20	0	500	7,400	0	100	0	2,200
30 & 27	0	1,000	—	0	0	—	—
Aug. 6 & 3	500	1,200	—	500	100	—	—
13 & 10	800	5,500	0	800	100	0	0
20 & 17	1,300	20,300	100	0	500	0	0
27 & 24	3,600	17,000	200	800	100	0	0
Sep. 3 & 1	2,900	17,000	100	0	200	0	0
10 & 9	0	10,100	0	0	100	0	0
19	2,100	—	0	0	—	0	0
24	4,200	—	1,000	0	—	0	0
Oct. 1	1,800	—	700	0	—	0	0
8	1,600	—	300	300	—	0	0
15	2,900	—	1,000	0	—	0	0
22	6,800	—	0	0	—	0	1,300
29	3,900	—	100	0	—	0	0
Nov. 5	3,400	—	1,000	300	—	0	0

[1]SW CA = southwestern California; SE MN = southeastern Minnesota; NW FL = northwestern Florida. Dashes indicate that no data were taken, primarily because of lack of host plants.

[2]Adults and larvae.

[3]The first column of dates is for SW CA taken in 1963; second column of dates is for SE MN taken in 1970; data taken in NW FL by Martin et al. (unpublished data) were taken in 1972 on same day of month as indicated for SW CA. D-VAC samples by Martin et al. taken over 0.03 acre of linear row per week.

[4]Reported by Oatman and Platner (*1969*) as number per 50 suction samples (1 ft² each); approximate number per acre = number reported times 260.

[5]Reported by Weires and Chiang (*1973*) for the St. Paul location as number per 10 plants; approximate number per acre = number reported times 650.

[6]Martin et al. (unpublished data) from 1972.

[7]From weekly inspection of whole plants on 0.003 to 0.006 acre (Martin et al., unpublished data).

Bell *1964*), *Polistis* spp. (S. L. Poe, personal communication)[4] *Vespula* spp. (Sutherland *1966*), and Araneae (Pimentel *1961*)—are sometimes relatively abundant and important predators of cabbage looper attacking cabbage, collards, lettuce, cotton, and tomatoes.

Many factors such as varied and complex agroecosystems, lack of host specificity, and difficulty of direct observation have made it difficult for researchers to obtain estimates of the true value of natural control of cabbage looper by predators; however, at least 27 species, or species complexes, of arthropod predators have been reported feeding on various life stages of the cabbage looper in the field (table 4). Some of these species and others have been observed consuming large numbers of the cabbage looper eggs and young larvae in the laboratory (table 5). Hendrick (*1967*) found that *R. americoferus* nymphs consumed more cabbage looper eggs per unit of time as temperature increased from 70° to 90° F; however, adult food consumption in response to increased temperature varied. Various other predaceous species probably prey on the cabbage looper, but additional studies like those conducted on predators of *Heliothis* spp. in cotton (Whitcomb and Bell *1964*; Lingren et al. *1968*) are needed to identify other predators and show their capabilities for consumption of cabbage loopers. Moreover, autoradiography (McCarty et al. *1980*) might be helpful in identifying potential predators of cabbage loopers. Finally, there is currently (1981) an ambitious project in Florida soybean systems to characterize predators and their functional response to prey, that might serve as a model for similar studies of predators of cabbage looper (W. H. Whitcomb, personal communication).

Manipulation and Conservation of Parasitoids and Predators of the Cabbage Looper

Naturally occurring arthropod parasitoids and predators are sometimes abundant in various host crops of the cabbage looper. At times, relatively high rates of parasitism and predation have been observed in some crops. Even so, populations of the host can increase rapidly and cause excessive damage to crops before the natural control agents can suppress the best below levels that would cause economic damage. Consequently, some method of manipulation or conservation of beneficial arthropods would be necessary to insure the immediate availability of adequate numbers that one could rely on for suppression of the pest below economic injury levels.

Several methods of manipulating parasitoids and predators, such as mass rearing and supplementary releases, strip-cropping, and importation and colonization have received limited testing in attempts to control the cabbage looper. Mass rearing and release of *Trichogramma* spp. have received more attention than any of the other methods (Oatman and Platner *1971*; Parker *1971*; Parker and Pinnell *1972*; Ashley et al. *1974*; Martin et al. *1976*).

Releases of a uniparental strain of *Trichogramma* sp. at a rate of about 32,800 per week/acre in tomatoes resulted in a substantial increase in parasitism of eggs of the cabbage looper (Oatman and Platner *1971*). Parasitism averaged 59 percent in the release field, but ranged from 28 to 100 percent as compared with an average of 42 percent in a control field with a range of 0 to 100 percent. Parasitism in the control was due to a native *T. pretiosum*. Releases of this species at a rate of about 40,200 per week/acre gave an average of 39 percent parasitism with a range of 16 to 100 percent as compared with a 10 percent average in a control field with a range of 0 to 67 percent. Releases of greater numbers of *T. pretiosum* could have resulted in good control of the cabbage looper.

In our studies at Quincy, Fla., three releases of *T. pretiosum* made at 3-day intervals at a rate of about 230,000 ♀ ♀/acre per release resulted in immediate and relative high rates of parasitism of eggs of cabbage looper in three different crops (Martin et al. *1976*). Parasitism averaged 51, 58, and 68 percent in collards, cabbage, and tomatoes, respectively, during the 9-day period that parasite releases were made. In contrast, Parker and Prinell (*1972*) found that releases of two strains of *T. pretiosum* were ineffective against the cabbage looper in cabbage fields; however, releases of *Trichogramma evanescens* Westwood resulted in from 68 to 90 percent parasitism of cabbage looper eggs. All three strains parasitized a high percentage of cabbage looper eggs in the laboratory.

Other studies suggest that neither *T. pretiosum* (Fye and Larsen *1969*; Ashley et al. *1974*) nor *T. evanescens* (Schmidt *1970*) is a well-adapted control agent for the cabbage looper. Thus, it seems that major behavioral differences exist in strains of *Trichogramma* sp. or that the taxonomy of the group is not well known. Both conditions exist and much more information will be needed before releases of *Trichogramma* spp. can be fully utilized as control agents of cabbage looper. Ridgway et al. (*1981*) have recently reviewed these areas of (needed) research plus the effects of hosts and host-habitats on the quality and behavior of mass-reared *Trichogramma*. They considered important research needs for better utilization of *Trichogramma* to be: (1) selection for effective strains; (2) control of dispersal after releases; (3) improvement of production and release efficiency; (4) development of a better understanding of relationships of *Trichogramma* release numbers, target pest densities, and yield and quality of the target commodity; (5) improvement of prediction,

[4] Letter dated October 26, 1973, from S. L. Poe, formerly Agr. Res. and Educ. Center, University of Florida, Bradenton, now Department of Entomology, Virginia Polytechnic Institute and State University, Blacksburg.

Table 4.—*Arthropod predators observed feeding on cabbage looper in the field*

Host stage fed on	Predator	Researcher
Egg	Chyrsopidae	
	Chrysopa spp.	Whitcomb and Bell (*1964*)
	Chrysopa carnea Stephens	Ehler (*1977a*)
	Coccinellidae	
	Coleomegilla maculata (DeGeer)	Whitcomb and Bell (*1964*)
	Hippodamia convergens Guerin-Meneville	Do.
	Coccinella novemnotata Herbst	Do.
	Labiduridae	
	Labidura riparia (Pallas)	Ru (personal communication)[1]
Larva	Araneida	Pimentel (*1961*)
	Carabidae	
	Calosoma peregrinator Guerin-Meneville	McKinney (*1944*)
	Coccinellidae	
	Coccinell atransversoguttata richardsoni Brown	Pimentel (*1961*)
	Coleomegilla maculata	Do.
	Hippodamia convergens	Do.
	Chrysopidae	
	Chyrsopa spp.	Do.
	Labiduridae	
	L. riparia	Strandberg and Tucker[2] (personal communication)
	Nabidae	
	Reduviolus americoferus (Carayon)	Sutherland (*1966*)
	Lygaeidae	
	Geocoris pallens Stål	Ehler (*1977a*)
	Pentatomidae	
	Podisus maculiventris (Say)	Hayslip et al. (*1953*)
	Reduviidae	
	Zelus bilobus (Say)	Do.
	Z. exsaguis (Stål)	Whitcomb and Bell (*1964*)
	Sycanus indagator (Stål)	Greene and Shepard (*1974*)
	Syrphidae	
	Sphaerophoria asymmetrica Knutson	Pimental (*1961*)
	S. contigua Macquart	Do.
	S. philanthus (Meigen)	Do.
	Toxomerus marginatus (Say)	Do.
	Vespidae	
	Polistes spp.	Poe (personal communication)[3]
	Vespula spp.	Sutherland (*1966*)
Pupa[4]	Carbidae	
	Calosoma sayi Dejean	Whitcomb (personal communication)[5]
	Formicidae	Elsey (*1969*)
	Labiduridae	
	L. riparia	Strandberg and Tucker (personal communication)[2]
Adult	Asilidae	
	Asilus sp.	Zeiler (*1869*)
	Libellulidae	
	Erythemis simplicicollis (Say)	Whitcomb and Bell (*1964*)
	Lycosidae	
	Lycosa rabida Walck.	Do.
	Oxyopidae	
	Peucetia viridans (Hentz)	Do.

Table 4.—Continued

Salticidae		
Phidippus variegatus (Lucas)	Chittenden (*1902*)	

[1]Nguyen Ru, Univ. of Florida, Gainesville, Fla.
[2]J. O. Strandberg and Linda Tucker, Agricultural Research and Education Center, Univ. of Florida, Sanford, Fla.
[3]S. L. Poe, formerly Agricultural Research and Education Center, Univ. of Florida, Bradenton, Fla., now Department of Entomology, Virginia Polytechnic Instit. and State University, Blacksburg, Va.
[4]Elsey (*1969*) observed a harlequin bug, *Murgantia histrionica* Hahn, puncturing a pupae which subsequently died.
[5]W. H. Whitcomb, Univ. of Florida, Gainesville, Fla.

Table 5.—*Arthropod predators observed feeding on immatures of the cabbage looper in the laboratory*

Host stage fed on	Predator	Stage and period of observation	No. cabbage loopers consumed	Reference
Egg	Chrysopidae			
	Chrysopa carnea Stephens	Complete larval[1]	[2]311–322	Sutherland (*1965*)
	C. oculata Say	--do--	272–323	Do.
	Coccinellidae			
	Coleomegilla maculata (DeGeer)	--do--	260	Do.
Egg + 1st-instar larvae	Chrysopidae			
	C. oculata	Complete larval	[3]221+172	Do.
	Syrphidae			
	Toxomerus marginatus (Say)	Complete larval (13 days)	63+112	Sutherland (*1966*)
1st-instar larvae + 2d- and 3rd-instar larvae	Nabidae			
	Reduviolus americoferus (Carayon)	Adult (34 days)	406+187	Do.

[1]Egg to adult.
[2]Range.
[3]Number of eggs consumed plus number of 1st-instar larvae consumed.

and survey methods for pest and naturally occurring entomophages; and (6) limitation of insecticide interference.

Releases of larval parasitoids of cabbage looper have received very little attention by researchers; however, *A. marginiventris* (Boling and Pitre *1971*), *L. truncatella* (Clancy *1969*), and *V. ruralis* (Brubaker *1966*;[5] Clancy *1969*; Soo Hoo et al. *1974*) have been released against cabbage looper. The releases of *A. marginiventris* and *L. truncatella* gave relatively poor results, but all three studies on *V. ruralis* indicated that releases of the parasite were relatively effective. In the field-cage study conducted by Soo Hoo et al. (*1974*) on collard plants, releases of 5, 10, and 50 parasites/288 ft² resulted in 43, 62, and 85 percent parasitism of cabbage looper larvae at host densities of two per plant.

Supplemental releases of predators of cabbage looper have also received a cursory evaluation in field cages (Barry et al. *1974*; Martin *1976*). The work of Barry et al. (*1974*) in soybeans indicated that *Reduviolus alternatus* (Parshley) and *Geocoris punctipes* (Say) could be effective in reducing defoliation and increasing yields when released against cabbage looper in soybeans; however, *C. carnea* eggs sprinkled onto the soybean foliage did not effectively reduce defoliation or increase yields. Ru and Workman (*1978*) recovered no *Chrysopa rufilabris* (Burmeister) from caged cabbage plants receiving 160 *C. rufilabris* eggs. Martin (*1976*) also recovered few released *C. carnea* larvae, and three releases of 194,000 2- to 5-day old larvae/acre were not effective in suppressing densities of cabbage looper in collards or cabbage.

The importation and colonization of the parasitoids and predators of the cabbage looper have received very little attention although it has been argued this might be a suitable suppression technique for the cabbage looper. Ehler (*1977b*) suggested that thorough analysis of previos success and failures (of single- and multiple-species introductions) in classical biological control efforts are needed to improve the success rate. Moreover, Ehler (*1977a*) has suggested that additional attempts at importation and colonization of natural enemies should yield fruitful information into the bionomics of the cabbage looper and its natural enemies and should aid in perfecting future classical biological control efforts.

Oatman et al. (*1968*) did attempt colonization of *T. evanescens* on cabbage looper in southern California. *T.*

[5]Brubaker, R. W. 1966. Quarterly Informative Memorandum, Jan.-Mar., 1966. U.S. Dep. Agr., Agr. Res. Serv., Entomol. Res. Div., Mesa, Ariz.

evanescens was established on cabbage looper, but a native parasite, *T. pretiosum*, was dominant. Similar studies on *T. evanescens* have been conducted on cabbage looper populations in cabbage at Columbia, Mo. (Parker *1971*; Parker and Pinnell *1972*). In these studies, *T. evanescens* was established and parasitized up to 80 percent of eggs of the cabbage looper.

An imported reduviid predator, *Sycanus indagator* (Stål), was studied by Greene and Shepard (*1974*) for feasibilty of introduction to achieve regulation of cabbage looper populations in Florida. Although predation of cabbage loopers ranged from 29 to 79 percent in field cages over cabbage, they concluded that survival of introduced *S. indagator* eggs (0 to 97 percent) and consumption of cabbage looper larvae (26 to 39 larvae killed during *S. indigator* development) was too low to suggest introduction of this predator would realize benefits in the regulation of cabbage looper populations in cabbage or soybean fields.

Strip-planting of certain crops has shown some promise as a means of creating reservoirs for large numbers of predators. For instance, our studies near Quincy (Martin *1976*) demonstrated that crops such as crucifers and tomatoes supported considerably fewer predators than crops such as white clover, sweet corn, and grain sorghum. Major differences in predator numbers were observed in collards and white clover (table 6). The study also indicated some movement of predators from white clover into cruciferous crops occurred. A similar study by DeLoach and Peters (*1972*) demonstrated that predators would move from strip-plantings of corn into cotton. Predation on eggs of cabbage looper in cotton was increased from 15 to 35 percent by utilizing the strip-planting technique.

Discussion

The limited information available on naturally occurring parasitoids and predators of cabbage looper indicated that several species (complexes) show considerable potential for use in pest management systems; however, a number of other species probably have equal or higher potential and deserve proper testing. Predaceous arthropods, for instance, have not received the research they deserve. Whitcomb (*1973*) illustrated our lack of knowledge of predaceous arthropods and discussed the importance of certain groups of predators. Ehler (*1977a*) presented an excellent case for more thorough and widespread (including importation) studies of (potential) predators of cabbage loopers. Many of the predaceous species from cruciferous crops mentioned in the lists of Root (*1973*) and Wieres and Chiang (*1973*) have not been observed feeding on cabbage loopers in the field but are probably important consumers of this pest.

Thus, the natural enemies of the cabbage looper have not been the target of exhaustive investigations nor have extensive studies been conducted abroad in an attempt to introduce foreign strains of parasitoids and predators of the cabbage looper. Research along these lines would be very useful and productive in providing additional knowledge and techniques for managing cabbage looper populations. Despite the lack of basic background information, certain more specific areas of future research pertinent to manipulating cabbage looper populations that might be more productive than others can be discussed. For instance, augmentation of *Trichogramma* spp. for effective suppression of cabbage loopers seems feasible, at least in certain crops. Specifically, Oatman and Platner (*1971*) concluded that cabbage loopers and some other lepidopteran pests on early plantings of tomatoes could be suppressed sufficiently by using semiweekly releases of *T. pretiosum* for a total of about 465,000/acre during June and July. Our studies in northwest Florida indicate it might take considerably more predators (Martin et al. *1976*) but that this is a feasible approach in cabbage looper management.

With increased knowledge of population dynamics and predictive techniques for target pests, such as are being sought for *Heliothis* spp. in Texas cotton (Hartstack et al. *1975*, *1976*), manipulation of *Trichogramma* spp. might be employed only when necessary. *Trichogramma* spp. reared for supplemental releases could be produced efficiently for properly timed releases, thus eliminating much expense. Expanded knowledge of behavior of *Trichogramma* spp. as it relates to kairomones (Gross *1981*) and of reasons why certain crops such as tomatoes frequently possess high rates of parasitism by *Trichogramma* spp., could help in manipulating this egg parasitoid effectively and economically. Moreover, as the biosystematics of *Trichogramma* spp. (Oatman and Platner *1973*) and the effect of host (Boldt et al. *1973*; Parker and Pinnell *1974*), temperature, and humidity on the behavior and effective parasitization of *Trichogramma* spp. (Biever *1972*; Boldt *1974*) are more clearly understood, we will be better able to use this natural enemy for suppressing and regulating cabbage looper populations.

Voria spp. are another parasitoid group which should probably receive further research for conservation and manipulation. Manipulation of *Voria* spp. in conjunction with polyhedrosis virus for effective suppression of crop-damaging cabbage loopers probably should be tested. From their life table studies, Elsey and Rabb (*1970*) concluded that the greatest influence on population trends of the cabbage looper was elimination by parasitoids of many of the loopers that survive polyhedrosis virus during the fourth generation. This contributed to a drastic population decline of the fifth generation. *V. ruralis* caused a

Table 6.—*Estimated number of selected arthropod predators per acre of collard and white clover foliage in an 8-acre cropping system, northwestern Florida, 1972*[1]

Week of	Collards				White clover			
	Coccinellid larvae[2]	*Geocoris* spp.[3]	*Orius insidiosus* (Say)	Total predators[4]	Coccinellid larvae[2]	*Geocoris* spp.[3]	*Orius insidiosus*	Total predators[4]
Apr. 2	0	0	0	30	0	0	0	170
9	30	0	0	160	170	0	0	270
16	370	0	0	710	1,830	0	900	3,260
23	70	0	0	420	900	50	450	3,200
30	200	30	0	490	1,030	0	2,900	6,980
May 14	80	130	0	2,290	630	220	21,030	27,820
21	130	300	0	2,390	130	100	8,500	15,790
28	300	200	0	2,090	1,760	1,600	8,270	22,060
June 4	400	400	70	2,760	1,900	2,030	2,170	14,870
11	330	270	0	2,140	3,700	7,600	650	28,550
18	—	—	—	—	700	8,050	1,400	18,700
25	300	200	0	2,900	600	15,100	0	23,650
July 2	0	150	0	950	9,600	20,000	1,100	60,200
9	1,130	430	0	3,530	500	2,570	400	5,470
16	700	870	0	3,330	3,670	8,330	670	22,840
23	770	700	0	3,200	7,570	22,000	870	31,940

[1]About 0.03 of an acre was D-vaced weekly. Dashes indicate not data were taken.
[2]Primarily *Coleomegilla maculata* (DeGeer) and *Hippodamia convergens* Guerin-Meneville.
[3]Mostly *Geocoris punctipes* (Say).
[4]Includes adults and immatures of *Geocoris* sp., nabids, *O. insidiosus* (Say), *Podisus maculiventris* (Say), *Jalysus spinosus* (Say), *Chrysopa* spp., coccinellids, carabids (mostly *Calleida decora* (F.)), Dermaptera, *Micromus* spp. and Araneida, and adults of *Notoxus* spp. and formicids.

major portion of the mortality occurring for larvae eluding the virus. Moreover, Thakare (*1973*) found in the laboratory that although yield of *V. ruralis* was substantially reduced in cabbage looper larvae infected with nuclear polyhedrosis virus prior to parasitization parasitoid-yield was comparatively higher when larvae were infected with polyhedrosis virus after parasitization. There appeared to be no detrimental effect by the virus on *V. ruralis* developing to adulthood (that is, on longevity and sexual functions). Thus, further investigations into the possible interrelationships of *V. ruralis* and cabbage looper nuclear polyhedrosis virus, with more detailed data on parasitization and disease, should allow us to more effectively and beneficially manipulate these natural enemies of cabbage loopers.

Although we have dealt primarily with arthropod parasitoids and predators in this review, parasitism by nematodes and predation by other animals may also often influence population levels of cabbage looper. Moore (*1964*) tested *Neoplectana carpocapsae* Weiser, which killed a substantial number of cabbage looper larvae. Whitcomb (*1973*) discussed the importance of birds as predators in certain cropping systems, and birds have been considered important predators of cabbage loopers in Florida tomatoes (S. L. Poe, personal communication) and cabbage (J. O. Strandberg, personal communication).[6]

Research by Hostetter (*1971*) and others indicates sarcophagids, birds, and other animals may also be important in dispersing cabbage looper polyhedrosis virus and should be investigated further. Beegle (*1971*) showed *H. exiguae* could transmit infective doses of polyhedrosis virus to cabbage looper. Through a series of laboratory tests, Staten (*1970*) established *G. punctipes* as potentially important in the transmission of nuclear polyhedrosis virus. According to Staten, "*G. punctipes* nymphs were definitely capable of acting as a vector for this virus disease under restricted bioassay conditions."

In conclusion, we can say that research and general experience have revealed that conservation of our naturally occurring arthropod parasitoids and predators is highly desirable. Supplementary releases of parasitoids, such as *Trichogramma* spp., *Voria* spp., *R. alternatus*, and *G. punctipes*, appear to have good potential for managing

[6]Letter dated November 13, 1973, from J. O. Strandberg, Agr. Res. and Educ. Center, University of Florida, Sanford. This information is presently being reviewed for publication.

populations of cabbage looper in certain crops. Moreover, sound, usable, predictive models, formulated under various conditions for numerical relationships between the host and its enemies, are needed before we will be able to fully utilize the potential of beneficial insects as control agents of the cabbage looper. This will require a considerable amount of behavioral and ecological information pertinent to the population dynamics of the host and its arthropod enemies.

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Chapter 12. Host Plant Resistance

By Frank P. Cuthbert, Jr.,[1] and A. N. Kishaba[2]

Abstract

Appreciable differences in susceptibility to the cabbage looper, *Trichoplusia ni* (Hübner), have been found in cabbage and related cole crops, in cotton, and in lettuce. The development of resistant cultivars appears to have potential for reducing losses, but the mechanisms of resistance remain to be identified, their inheritance studied, and their practical value demonstrated. To date, very little research has been directed towards these goals.

Host plant resistance has not been exploited as a means of preventing crop losses from the cabbage looper, *Trichoplusia ni* (Hübner); however, the possibility has been considered by a number of researchers and enough information developed to indicate that this approach has potential. Next to eradication of the insect, the use of resistant cultivars would probably constitute the most satisfactory control, but because so many crops are involved and many of them are relatively minor, a considerable research investment will probably be required to realize the maximum benefits from this method.

Cole Crops

Host plant resistance to the cabbage looper has been studied most extensively in the cole crops (*Brassica* spp.), undoubtedly because these crops are the favored host of the insect and the ones that most consistently suffer economic loss. Most of this work has been exploratory, consisting of field plot comparisons of looper populations or looper injury to commercial cultivars of one or more of the various crops.

Four studies involved comparisons of the various crops in regards to looper injury. Harrison and Brubaker (*1943*) conducted three experiments in which green cabbage, red cabbage, collards, cauliflower, kale, broccoli, brussels sprouts, and kohlrabi were compared. No outstanding resistance was shown by any of the crops, and they concluded that the numbers of loopers supported by the various crops were probably due largely to the relative amount of foliage produced by the plants, the stage of plant maturity, the height of the plants, and their general physical condition. Pimental (*1961*) failed to find a difference in numbers of looper larvae or parasitism of the larvae on broccoli, brussels sprouts, cabbage, collards, and kale. Radcliffe and Chapman (*1966b*) studied the relative resistance to insect attack of 43 cultivars of *Cruciferae* representing 11 different *Brassica* crops. Chinese cabbage, mustard, rutabaga, and turnip were the most resistant; broccoli, brussels sprouts, and Jersey kale were among the most susceptible. The levels of resistance observed were considered to be primarily a characteristic of the crop species and secondarily one of the cultivar. Resistance to the looper was independent of resistance to other caterpillars. Wolfenbarger (*1967*) screened 85 accessions of *Brassica* for resistance to looper feeding damage. P. I. 236259 (*B. oleraceae* var. *virdis* L.) was the most resistant, and the author believed that it "could be used as a source of resistance to the cabbage looper and that it possibly possesses nutritional factors that prevent normal larval development."

A number of papers (Radcliffe and Chapman *1960, 1962, 1965 a* and *b, 1966a*; Brett and Chalfant *1960*; Brett et al. *1966*; Chalfant and Brett *1967*; Wolfenbarger *1967*; Workman and Shumaker *1971*) reported comparisons of cabbage looper injury to commercial cabbage cultivars. The following were mentioned specifically by the authors as being either resistant or susceptible:

Resistant:

Resistant Detroit (three times)
Racine Market (twice)
Wisconsin Golden Acre
Copenhagen Market
Savoy Perfection Drumhead
Chieftan Savoy
Mammoth Red Rock
Red Acre
Mammoth Red Acre
Golden Acre

Susceptible:

Flat Dutch (three times)
Wisconsin Badger Ballhead (twice)
All Seasons
Red Acre
Red Hollander
Copenhagen Market
Wisconsin Hollander #8
Stein's Flat Dutch
Resistant Golden Acre
Oakview Ball Head

Note that two of the cultivars, Copenhagen Market and Red Acre, appear in both lists.

In no cultivars were the levels of resistance found considered to be adequate to prevent economic loss. Workman

[1]Research entomologist, retired, Vegetable Insects Research Laboratory, Agric. Res. Serv., USDA, 2875 Savannah Highway, Charleston, SC 29407.
[2]Research entomologist, Boyden Entomology Laboratory, Agric. Res. Serv., USDA, Riverside, CA 92521.

and Shumaker (*1971*), however, reported that some of the cultivars in their tests could have been commercially acceptable if lightly trimmed to remove the injury. Only one study considered the possible advantage of using a resistant cultivar in combination with an insecticide. Chalfant and Brett (*1967*) reported that "Resistant varieties responded more favorably to insecticidal treatments than susceptible varieties. However, this difference tended to disappear under heavier infestation pressure.[1]

A number of factors make it difficult to evaluate cabbage for useful mechanisms of resistance to the cabbage looper. There are two obvious criteria for resistance: insect populations (egg or larval) and plant damage. There are problems involved in using either. Looper populations are influenced by plant size (Harrison and Brubaker *1943*; Radcliffe and Chapman *1960*), stage of plant maturity (Harrison and Brubaker *1943*; Radcliffe and Chapman *1965a* and *b*), height of the plants (Harrison and Brubaker *1943*), and prior insect damage (Radcliffe and Chapman *1965 a* and *b*). We have observed at Charleston, S.C., that ovipositing cabbage looper moths avoided plants infested by the imported cabbageworm, *Pieris rapae* (Linnaeus); however, none of these factors are resistance mechanisms that can be used. Plant damage ratings are usually complicated by the presence of several species of caterpillars whose injury cannot be accurately separated. This fact probably explains, at least partially, why several investigators (Brett and Chalfant *1960*; Radcliffe and Chapman *1966ab*; Chalfant and Brett *1967*) showed little or no correlation between looper populations and plant damage ratings.

Another factor that probably enters into the discrepancy between population counts and damage ratings is the number of loose outer leaves around the heads. Observations at Charleston, S.C. also show that damage on the head and four surrounding wrapper leaves was relatively low on cultivars with a large number of loose lower leaves. This is particularly true of the Savoy types. None of the papers reviewed mentioned this characteristic, but Chalfant and Brett (*1967*) categorized a group of resistant cultivars as having the damage confined mostly to the outer leaves.

There are few hard facts in the papers reviewed pertaining to resistance mechanisms that could be used in a breeding program. Boling and Pitre (*1971*) investigated the relative preference of ovipositing looper moths for cauliflower, broccoli, collards, cabbage, or cotton and concluded that collards and cotton were preferred to the other crops. The moths also laid significantly more eggs on 21-week-old broccoli and cauliflower plants than on 15-week-old plants, but differences between the two age groups of the other groups were inconsistent. Radcliffe and Chapman (*1966b*) stated that "larval populations reflect ovipositional preference with sufficient precision that nonpreference must be considered the primary mechamism of resistance to the cabbage looper." Neither of the two investigations, however, established which of the many factors known to influence ovipositional preference are involved. Chalfant and Brett (*1967*) reported apparent antibiosis in Mammoth Red Rock cabbage, but this needs more detailed study for confirmation. Benepal and Hall (*1967*) found the free amino acids pipecolic and tyrosine in resistant but not susceptible cultivars; they also found that the total free amino acid content and total soluble N were higher in susceptible than in resistant plants. The ash, water, and protein content of the leaves appeared to be unrelated to resistance; however, only four cultivars were examined and these were selected for resistance to the combined feeding of the cabbage looper and imported cabbageworm, which leaves some doubt as to their actual resistance to the cabbage looper. Their susceptible line, Golden Acre, was classed as looper resistant by another investigator (Wolfenbarger *1967*). Workman and Shumaker (*1971*) found evidence that low looper injury was associated with increased flaccidity, toughness, and pungency in the cabbage plant.

Cotton

Little research has been done on cabbage looper resistance in cotton, most of it incidental to research of more important cotton pests. Lukefahr (*1960*) and Lukefahr et al. (*1965*) found that in a cage where no other plants were growing higher looper populations developed on cotton varieties with extra-floral nectaries than on nectariless varieties. Populations on glabrous strains did not differ significantly from those on hirsute strains. Bottger and Patana (*1966*) showed that the incorporation of gossypol into an artificial diet of larvae of the cabbage looper, at a level comparable to that found in some cotton lines, caused marked antibiosis. They suggested the possibility of preventing looper damage by breeding cotton lines with high levels of gossypol in the leaves. Scales and Stadelbacher (*1972*) found no differences in looper populations on four cotton cultivars with varying degrees of pilosity of the leaves.

Lettuce

Two fairly recent studies involving cabbage looper resistance in lettuce were found. Pesho et al. (*1969*) evaluated 433 *Lactuca* spp. plant introductions for resistance to feeding by larvae of the cabbage looper. Plant introductions 261653 (*L. saligna* L.), 274372 (*L. serriola* L.), and 279684 (*L. perennis* L.) were rated highly resistant to larval feeding. Kishaba et al. (*1973*) screened 208 entries of *Lactuca* for resistance to oviposition by cabbage looper moths. One introduction each of *L. serriola* (PI 274372) and *L. saligna* L. (PI 261653) were less attractive to looper moths than any entry of *L. sativa* L. Two independent

investigations of two different resistance factors selected the same plant introductions as being resistant to the cabbage looper. One investigation indicated resistance to larval feeding, the other to oviposition.

Later studies (Whitaker et al. *1974*) demonstrated larval antibiosis in *L. saligna* (PIs 261653, 253229, 281876) and in *L. perennis* (PIs 273594, 274415).

Summary and Recommendations

The research published has not been of sufficient depth to allow a good evaluation of the potential of host plant resistance for reducing cabbage looper losses. There have been a number of studies of looper resistance in commercial cultivars of cole crops. Some of the results are conflicting, but it is obvious that appreciable differences do exist. What is lacking is an appraisal of the practical significance of the levels of resistance found. Apparently, insecticidal controls will still be needed on the most resistant cultivars found to date, but more information is needed to determine if control can be achieved on resistant cultivars with lower dosages or less effective chemicals than needed on susceptible ones. Studies should also be conducted to determine the value of varietal resistance in an integrated control program utilizing parasites and predators of the looper.

Before an effective breeding program for looper resistance in the cruciferous crops can be initiated, the various factors contributing to the observed resistance must be isolated and identified and their inheritance studied. One investigation has indicated ovipositional preference as a basis for resistance. This should be studied further in a manner similar to that employed for screening the *Lactuca*. Nonpreference based on responses of the moths to visual, tactile, and olfactory stimuli emanating from the plant would probably be a usable mechanism. Factors such as plant size, stage of maturity, and presence of other insects should be eliminated as much as possible.

In future investigations of nonpreference, the possible existence of geographical biotypes with distinct preferences should be considered. In Arizona and California, the cabbage looper is a serious pest of lettuce, whereas in some areas of the East this crop is seldom attacked. Larval antibiosis has also been suggested by some of the studies. This should be confirmed and the degree determined in greenhouse or cage tests using known age larvae so that their rate of survival and development can be measured. The apparent association of low quality in cabbage with resistance to the looper should receive more study and the various plant characteristics involved measured quantitatively so that their correlation with looper injury can be tested. The possibility that certain plant types result in lower injury to the marketed portion of the plant should be considered in future studies.

The authors believe that the greatest potential for utilizing plant resistance to reduce looper losses will be found in crops to which the insect has adapted (such as cotton, tobacco, soybeans, lettuce, and tomatoes) rather than in the Cruciferous crops, which are apparently the natural host of the insect. In addition to the better possibility of finding higher levels of resistance, some of the crops such as tomato, cotton, and soybeans can sustain more feeding damage without economic loss. Although the looper is a relatively minor pest of most of these crops, it will probably increase in importance as the major pest problems are solved. Very little work has been done in these crops, but it appears that promising sources of resistance have been found in lettuce and possibly cotton.

It is doubtful that the piecemeal, fragmented type of research conducted to date will result in any real progress in using plant resistance against the cabbage looper. What is needed is a long range comprehensive project designed to find, evaluate, and utilize in a breeding program all available sources of resistance. To be effective, such a project must be carried out by a team possessing expertise in biochemistry, entomology, genetics, and horticulture and should be directed towards the development of looper resistant cultivars.

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Addendum

Significant progress in insect resistance in cole crops was reported by Dickson and Eckenrode (*1975, 1980*). By using a thorough analysis of literature coupled with their field and greenhouse studies with five-parent diallel, they demonstrated that looper resistance is quantitatively inherited with narrow sense heritabilities of 22 to 47 percent. Although not immune, this level of resistance bred into a commercial cultivar may be useful in an integrated pest management program utilizing microbial and chemical control (Creighton et al. *1975*).

With emphasis on other major pests of cotton, studies on resistance to cabbage loopers are scant. B. W. George et al. (*1977*), using two pairs of near isogenic varieties of nectaried and necariless cotton in the greenhouse, found looper population reduced in one paired variety but not in the other. Luedders and Dickerson (*1977*) reported looper resistance among selected soybean genotypes resistant to other leaf feeders. They reported heritability estimates for leaf feeding of 6 to 44 percent.

Breeding cabbage looper resistance into commercial lettuce, *Lactuca sativa* from *Lactuca saligna* and *L. serriola* reported as possible sources of resistance by Kishaba et al. (*1980*) and Whitaker et al. (*1974*) has not been successful, even though breeding studies showed that resistance was heritable. Whether this failure was caused by difficulty in breeding, low level of resistance, and/or insufficient knowledge of the host-insect interaction is still to be resolved.

With present interest in quantitative genetics and less demand for immune type resistance, more crops identified as resistant may become available.

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Chapter 13. Population Reduction with Cultural Management

By R. B. Workman[1]

Abstract
Cultural methods have not been developed for control of the cabbage looper, *Trichoplusia ni* (Hübner), in the United States. Little promise for this method of control is foreseen. It appears that the cabbage looper's wide host range of many common species, large reproductive capacity, probably migration northward from southern overwintering areas, high damage potential, and difficulty of control by insecticides make cultural control methods impractical with the present state of knowledge.

There is little in the literature concerning cultural control of the cabbage looper. Research workers on crucifers, lettuce, cotton, and other crops in 19 areas of the United States and Canada were contacted by letter. They reported that there is little knowledge or possibility, at present, of cultural control of the insect. Reid and Cuthbert (*1957*), on the control of caterpillars on cole crops, mention that natural controls, although effective, will not provide sufficient protection and that little reliance should be placed on them.

There are several reasons for the difficulty of cultural control of the cabbage looper. One is its wide host range (see Sutherland and Greene, chapter 1.), which includes a large number of common weeds, ornamentals, vegetables, and field crops. Populations of loopers will often develop and remain in an area for a long time because a continual succession of host plants sustains them. The presence of many hosts plus favorable temperatures allows the cabbage looper to be active year around in the southern United States. Large populations are generally seasonal, appearing successively northward to Canada during the spring and summer. Migration of the adult or moth stage is suspected for this movement. If this is true, then methods of reducing native populations in an area may be defeated by the influx of migrating individuals into that area. The cabbage looper's ability to develop large populations quickly, along with its voracious feeding habit, also makes cultural controls difficult. On leafy crops and others where the cabbage looper feeds on the marketable portion, control must be near perfect due to Federal grading standards or to the buyer's requirements. I have found that one cabbage looper can cause enough feeding damage to three heads of cabbage to reduce their economic value. At Hastings, Fla., cabbage looper damage is minimal during December to March when temperatures are low; however, the market can handle only so much volume, making it impractical to grow crops only during this period. When looper numbers are high, preventative control measures must be used to protect the crop.

Early destruction of crop residues offers a means of eliminating the various life stages of the cabbage looper that are present and removes the crop as a source for further development of the insect. Recommendations for cabbage growers at Hastings include the chopping and disking of cabbage fields followng the final harvest; however, this practice is mainly to reduce green peach aphid migration to potato fields. Hofmaster[2] reported that early destruction of cabbage residues after harvest in Virginia reduced the later effectiveness of the nuclear polyhedrosis virus of the cabbage looper by limiting insect and virus increase. He found that disking or plowing tended to bury the overwintering virus in the soil where it was ineffective.

Light or pheromone traps plus field inspection for cabbage loopers, with insecticide treatment when necessary, could help reduce populations before they become large and widespread. This practice appears to be one of the more promising ways of cultural control of the cabbage looper. Good weed control is undoubtedly necessary for best insecticide coverage and control on vegetable crops. The cabbage looper is difficult to control with insecticides (especially in the larger instars) and has become resistant to a number of them.

Scales[3] reported that some workers in Mississippi consider the cabbage looper to be beneficial to the cotton crop as it appears after midseason. Larval feeding opens up the leaf canopy, allowing greater air circulation and a reduction of boll rot.

Research needed on cultural methods that may be of value in limiting cabbage looper numbers includes additional data on migration as a source of new infestations. If migration is of low importance, crop residue destruction may be of value. The cabbage looper has been reported from many different plant species. It is not known whether they are regular hosts or if they contribute to maintaining or increasing populations. Studies here are needed. Many other factors relate to cultural management, including various trapping methods, resistant plant varieties, parasites, predators, pathogens, and hormones. These factors are discussed in other sections. Ultimate

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[1]Associate professor of entomology, Univ. of Florida Agric. Res. Center, Hastings, Fla. 32045.

[2]Personal communication from R. N. Hofmaster, Virginia Truck Experiment Station, Painter, Va. 23420.

[3]Personal communication from A. L. Scales (retired), USDA Delta States Agric. Res. Center, Stoneville, Miss. 38776.

methods of pest management will need to be developed from the complete knowledge and application of all factors.

Literature Cited

Reid, W. J., Jr., and F. P. Cuthbert. 1957. Control of caterpillars on commercial cabbage and other cole crops in the South. U.S. Dep. of Agric. Farmers' Bulletin No. 2090:24.

Chapter 14. Premating Communication and Exploitation of the Sex Pheromone

By J. R. McLaughlin[1]

Abstract

The published knowledge of premating chemical communication in the cabbage looper, *Trichoplusia ni* (Hübner), is reviewed and areas requiring further research are suggested. Present and future uses of the cabbage looper sex pheromone in population management are discussed.

Pheromones, chemicals used for communication between two or more animals of the same species (Karlson and Butenandt *1959*), are placed in two categories (Bossert and Wilson *1963*): releaser pheromones stimulate the receiving organism to perform a fairly immediate behavioral response; primer pheromones cause relatively long lasting physiological changes in the receiving organism. The frenulate Lepidoptera are highly reliant upon releaser pheromones that cause aggregation prior to mating and often mediate courtship behavior after the sexes have come together. The volatile chemical(s) is produced by one sex, usually females, and released into the air. Because these chemicals trigger a series of responses in the receiving sex that terminate with copulation, they are called sex pheromones.

The second insect sex pheromone to be isolated and chemically defined was that of the cabbage looper *Trichoplusia ni* (Hübner) (Berger *1966*). The premating and chemical communication behavior of this noctuid moth has received very intensive study. Because of the simplicity of its sex pheromone and behavior relative to that of many other moths, this species serves well as a basic model.

Chemistry and Activity of the Pheromone

Typically, moth sex pheromones are unbranched unsaturated acetates, alcohols, or aldehydes of specific steric configuration. For many years, it was thought that the pheromone emitted by the female cabbage loper was (*Z*)-7-dodecen-1-ol acetate (DDA) (Berger *1966*), and that, in contrast to many other Lepidoptera which have multiple-compound sex pheromones, the cabbage looper used only this one chemical. Bjostad (*1978*) and Bjostad et al. (*1980a*) identified a second pheromonal component, dodecyl acetate (DA), from pheromone gland extracts and from volatiles released by females. The female may release another chemical(s) inhibitory to the pheromone response of males of a related species, the soybean looper, *Pseudoplusia includens* (Walker) (Mitchell *1972*).

The pheromone (DDA) is attractive to males of several noctuid species in the subfamily Plusiinae and has been recovered from females of some of these species (Berger and Canerday *1968*; Kaae et al. *1973a, b*; Mitchell et al. *1972a*; Payne et al. *1973*; Roelofs and Comeau *1970*; Shorey et al. *1965*; Tumlinson et al. *1972a*; Wolf et al. *1972*). Mitchell (*1972*) and Kaae et al. (*1973a, b*) have suggested that secondary chemicals, concentration-response differentials, and differing activity rhythms may serve to isolate some of these species. Male cabbage loopers as well as several other noctuids are, at best, only very weakly attracted to compounds closely resembling the pheromone and are apparently little affected by the (*E*) isomer (Green et al. *1967*; Berger and Canerday *1968*; Jacobson et al. *1968*; Toba et al. *1970a*; Payne *1969*; Payne et al. *1970*; Gaston et al. *1971a*; McLaughlin et al. *1975b*).

Mitchell et al. (*1972b*) and Birch (*1977*) present evidence that female cabbage loopers may also respond to the female-produced pheromone. The significance of these reports is yet to be determined.

Methods of synthesizing DDA were presented by Berger (*1966*), Berger and Canerday (*1968*), Green et al. (*1967*), Henderson and Warren (*1970*), Kovalev and Ischenko (*1974*), Hayashi and Midorikawa (*1975*), Leznoff and Fyles (*1976*), Nagarkatti (*1976*), Leznoff et al. (*1977*), Seidel et al. (*1977*), Nagarkatti and Ashley (*1978*), Bestmann et al. (*1979*), Yokoi and Matsubara (*1979*), and Brown (*1980*). Certain synthetic routes should be avoided as Tumlinson et al. (*1972b*) reported that synthesized (*Z*)-7-dodecen-1-ol inhibits the response of male cabbage loopers to the pheromone. As little as 0.1 percent of the alcohol added to synthetic DDA significantly reduces its effectiveness as a trap bait in the field. Ignoffo et al (*1963*), Berger (*1966*), Berger and Canerday (*1968*), Gaston et al. (*1966, 1971b*), Green et al. (*1967*), Jacobson et al. (*1968*), Jacobson (*1970, 1972*), McDonough and George (*1970*), and Bjostad (*1978*) have described DDA chemically and physically.

Pheromone Gland

The saddle-shaped pheromone gland is an area of modified intersegmental membrane situated dorsally between the eighth and ninth abdominal segments (Jefferson et al. *1966*). The gland and the terminal abdominal segments are retracted within the seventh abdominal segment. The mechanics and physiology of their eversion and inversion have not been accurately determined. There are five groups of muscles associated with these segments that probably control the gland and the ovipositor (Jefferson

[1]Research entomologist, Insect Attractants, Behavior, and Basic Biology Research Laboratory, Agricultural Research Service, USDA, Gainesville, Fla. 32604.

et al. *1966*; Percy and George *1979*). The ovipositor can be extended by a female without exposing the pheromone gland. The gland can be everted by gently squeezing the abdomen of a female; thus, hemolymph pressure may be involved in this process.

The gland can be recognized in a pupa 5 days before eclosion. One day before eclosion the cells, presumably responsible for pheromone production, elongate and their nuclei double in height, but few vacuoles are present. Cell elongation continues and the vacuoles increase in number and size until the maximum is reached 1.5 days after emergence (Jefferson et al. *1966*, *1968*; Miller et al. *1967*; Grant *1970a*; Jefferson and Rubin *1973*; Percy and Weatherston *1974*).

A distinctive two-layered basement membrane underlies the sex pheromone gland cells and contains granular hemocytes that may produce the materials required to synthesize the lipid that accumulates in the cell vacuoles (Percy *1978*). Most of these lipid spheres are surrounded by smooth tubular endoplasmic reticulum containing the enzyme catalase, thus constituting microperoxisomes. Percy (*1979*) hypothesized that these microperoxisomes are responsible for the synthesis of the lipid and that this lipid contains the pheromone. The exact mechanism of biosynthesis is not known.

The lipid spheres evert the apical plasma membrane between the microvilli that are periodically formed. The lipid, which is no longer surrounded by the microperoxisomes, moves away from the gland cells and is stored in the endocuticle as discrete deposits. These deposits, in turn, appear to move to the surface of the gland cuticle by tubular structures that differ from endocuticular filaments (Percy *1979*).

Histological studies and bioassays (Jefferson et al. *1966*; Shorey and Gaston *1965b*; Shorey et al. *1968b*; Sower et al. *1972*) indicate that the pheromone is continually synthesized by females and that its extractable titre reaches a maximum the second night after emergence (corresponding to complete cell elongation and lipid accumulation) and remains fairly constant throughout the life of a female. The extractable quantity of DDA in the gland is quite large relative to other Lepidoptera, with reports as great as 1600 nanograms (ng) for individual females and mean recoveries from groups of about 300 to 700 ng/female for mature 4-day-old virgin females (Shorey and Gaston *1965b*; Sower et al. *1971a*, *1972*; Szentesi et al *1977*; Van Vorhis Key et al. *1978*; Bjostad et al *1980b*). Crowding in a laboratory colony did not reduce the quantity of extractable pheromone (Van Vorhis Key et al. *1978*). An exposed gland volatizes DDA at from 5 to 48 ng/min and a female will release about 800 ng/night if she is not mated (Sower et al. *1971a*, *1972*; Bjostad *1978*; Bjostad et al *1980b*). The ratio of DDA to DA is about 9:1 in gland extracts and 93:7 in extracts of air that has passed over naturally exposed glands (Bjostad *1978*; Bjostad et al. *1980a*).

Female Control of Pheromone Release and the Male Response

Premating communication in the cabbage looper is initiated by the female. In the laboratory, the nocturnal cabbage looper female becomes sexually responsive on the first or second night after emergence. She flies for a short time and then clings to the sides or roof of a cage, spreads her wings, and elevates her abdomen slightly above the plane of the substrate (Ignoffo et al. *1963*; Shorey *1964*; Kaae and Shorey *1972a*). She then extrudes the eversible gland to volatize the sex pheromone into the surrounding air.

The pheromone released by the female or synthetic pheromone evaporated into the air triggers a complex sequence of male responses beginning with activation from the resting state, wing vibration, and upwind flight (anemotaxis), culminating in copulatory attempts at the site of evaporation of the pheromone (Ignoffo et al. *1963*; Shorey *1964*; Shorey and Gaston *1970*). An increasing pheromone concentration (DDA) is necessary for initiation of each successive behavioral step in the mating sequence; however, a male may enter the sequence at any step. Therefore, a male already in flight upon perceiving pheromone would begin to fly in an oriented manner upwind toward the source (Shorey *1964*; Mayer *1973b*). Bjostad (*1978*) observed that DA appears to influence the close-range behavior of males by increasing the tendency of males to land at a site of evaporating binary pheromone and by increasing the time spent at the site of evaporation. Further study of the behavioral role of DA is needed.

Apparently, vision is involved only in short-range orientation of a pheromone-stimulated male to a female. Males may orient to a visual model 2 cm removed from the source of pheromone (Shorey and Gaston *1970*). There is no evidence that cabbage looper males copulate with females that have not indicated readiness to mate by releasing the pheromone or that males will attempt to copulate in the absence of a pheromone cue.

Environmental Control of Mating

Mating in the cabbage looper occurs during certain periods of the night. The release of pheromone by sexually mature females and, to a lesser extent, the response of the males follow an endogenous daily rhythm that is entrained at the initiation of the light period each day (Shorey and Gaston *1965a,c*; Shorey et al. *1968c*; Sower

et al. *1970, 1971b*) and modified by other environmental factors.

Female release of pheromone and male responsiveness to the pheromone are inhibited by light intensities above 0.3 lux (moonlight) (Shorey and Gaston *1964*; Sower et al. *1970*). One might expect that mating would not occur in absolute darkness because males will not fly in response to the pheromone (Mayer *1973b*); however, Shorey (*1964*) found that mating did occur among moths confined in a light-tight 3.6-L container in the laboratory.

At warm temperatures (23° to 27° C) in the laboratory, the release of pheromone and male responsiveness peak during the last half of the night (Shorey and Gaston *1965a,c*; Shorey *1964, 1966*; Sower et al. *1970, 1971b*; Bjostad et al. *1980b*). Sower et al. (*1971b*) and Freeman et al. (*1977*), however, have demonstrated that the time of expression of the circadian rhythm of female pheromone release and male responsiveness relative to the end of the dark period is primarily a function of temperature and not the lengths of the light and dark periods. A forward phase shift in the time of mating activity is correlated with reduced constant temperatures in laboratory studies. The time of pheromone release behavior and of peak male responsiveness in the field during the fall or under warm-day-cold-night fluctuating temperatures in the laboratory is earlier in the night (Shorey *1966*; Henneberry and Kishaba *1967*; Saario et al. *1970*; Mitchell *1973*). Mating under this circumstance occurs predominantly from sunset to midnight. Mating, pheromone release, and peak male response occur later in the night (near midnight) during the summer.

The temperature range allowing maximum sex pheromone release is between 18° and 30° C constant temperature (Sower et al. *1971b*). The number of cabbage looper females that mate is proportional to temperature from a minimum of 13° C to an optimum of 26° C, beyond which mating again decreases (Shorey *1966*; Henneberry and Kishaba *1967*). Few matings occur in the field on nights when the midnight temperature is less than 14° C, presumably because the ability of males to respond to pheromone is sharply reduced at temperatures below 15° C (Shorey *1966*).

Cabbage looper females display a classic economy of effort in pheromone release behavior with regard to wind velocity (Sower et al. *1971a*; Kaae and Shorey *1972a*). They exhibit maximum pheromone emission behavior at wind velocities from 0.3 to 1.0 m/sec. At higher wind velocities, male flight would become difficult; at lower velocities, the pheromone would be inefficiently dispersed. Virgin females typically release pheromone for periods of 5 to 20 min duration (Sower et al, *1971b*; Bjostad et al *1980b*) and then fly briefly, settle, and begin to release once more. The duration of the release period decreases with increasing wind velocity (Kaae and Shorey *1972a*). This maximizes the chance of attracting a male since the pheromone would disperse more slowly at low wind speeds.

Female cabbage loopers frequently vibrate their wings while releasing the pheromone, especially at low ambient wind velocities or when approached by another moth (Shorey *1964*; Kaae and Shorey *1972a*). This increased wing vibration at low wind velocities would appear to aid short-range male orientation by providing an airstream of 0.1 to 0.2 m/sec at a distance of 1 m directly behind the tip of the female abdomen (Kaae and Shorey *1972a*).

Pheromone release, male response, and mating have not been adequately measured with respect to other environmental factors such as barometric pressure, electrical potentials, humidity, or influence of host plant.

Influences of Mating History

Female cabbage loopers can mate several times in a lifetime. The pheromone releasing behavior of mated females is not documented. Upon mating, the female cabbage looper ceases to release pheromone, and she does not tend to release the following night (Shorey *1964*). Virgin females spend less time each subsequent night in pheromone release behavior, but release increasing amounts of pheromone (Bjostad et al. *1980b*). The male threshold for response to the pheromone decreases greatly between the first and second nights after emergence, and virgin males tend to have decreasing thresholds (respond to smaller amounts of pheromone) each subsequent night (Shorey et al. *1968c*; Freeman et al. *1977*). Males may respond to the pheromone and mate one time per night for a number of successive nights (Shorey and Gaston *1974*).

Mating Site

Kaae and Shorey (*1972a*) observed one cabbage looper female releasing pheromone from the apex of an alfalfa plant. Observations of caged females tend to support the view that females seek elevated locations from which to release pheromone (Shorey *1966*; Kaae and Shorey *1972a*), but no detailed studies of environmental influences on the selection of a mating site are available for the cabbage looper.

Male cabbage loopers are caught in greatest numbers in pheromone traps placed at the height of the prevailing plant canopy. In contrast to many Lepidoptera, the cabbage looper male will respond well to pheromone traps in areas devoid of host plants (Saario et al. *1970*; Sharma et al. *1971*). The influences of hosts on mating activity are unknown.

Male Perception of the Pheromone

The antennae are the site of pheromone perception (Shorey *1964*; Payne *1969*; Payne et al. *1970*; Grant *1970a*; Mayer *1973a*). About 6,500 trichoid sensilla are associated with pheromone reception on each male antenna (Jefferson et al. *1970*; Lin and Chow *1972*); however, the surface area and number of sensilla vary with the weight of the pupa and adult (Mayer et al. *1981*). Each sensillum contains the dendrites originating from several (at least three) basal neurons, but only one neuron appears to be involved in perception of DDA (Mayer *1973a*; Ferkovich and Mayer *1975*). Females appear to perceive the pheromone (Grant *1970a*; Mayer *1975*; Light and Birch *1979*) but exhibit no overt behavioral response.

The lower threshold for perception of the pheromone (wing vibration response) by cabbage looper males is about 8 molecules/mm^3 of air (Gaston and Shorey *1964*; Shorey et al. *1964, 1967*; Sower et al. *1971a*). Mayer (*1973b*) established a threshold for upwind flight (attraction) at 21 molecules/mm^3, in close agreement with Toba et al. (*1968*). To obtain an upwind flight response in 50 percent of a test population requires an increase of almost 1,000 times as many molecules per unit volume above this threshold.

Electroantennogram (EAG) potentials correlate with the attraction of male cabbage loopers to various concentrations of pheromone, but EAGs are about 10^6 less sensitive than the attraction response in a flight tunnel (Mayer *1973a*). EAGs are not a reliable indicator of the behavorial response of cabbage looper males because both the pheromone, the inhibitor, (*Z*)-7-dodecen-1-ol, and some analogs of the pheromone evoke similar electrical responses (Priesner et al. *1975*). Measurement of the electrical response from the appropriate neural cell associated with a trichoid sensillum reveals close correlation with behavior and behavioral thresholds (Mayer *1973a*). The inhibitor and pheromone apparently affect different neurons (McLaughlin et al. *1974*; Mayer *1975*; Ferkovich and Mayer *1975*).

The transductory mechanism whereby the chemical signal is converted to nerve impulses at the peripheral receptor level on the male antenna is unknown. A membrane-bound enzyme or enzyme complex capable of converting the acetate pheromone to its corresponding alcohol exists in or on the cuticle of males and females (Ferkovich et al. *1973a,b, 1980*; Ferkovich and Mayer *1975*; Mayer *1975*; Mayer et al. *1976*). This enzyme(s) is specific to the pheromone relative to its isomers or analogs. The antennae of males degrade the pheromone twice as fast as female antennae (Mayer *1975*). Enzymic binding and conversion may be events closely related to the process of transduction or may function to remove excess pheromone from the body surface.

Infrared Radiation

Infrared (IR) radiation may be involved in the long distance assembly of male moths to females (see review of Hsiao *1972*). One theory proposes that the pheromone radiates a distinctive IR signal which is detected via the male antennae. Hsiao (*1972*) tested IR signals with some of the transmission characteristics of the cabbage looper sex pheromone and signals radiated by the pheromone through a NaCl cell. No response of cabbage looper males to these IR stimuli could be observed, and Hsiao (*1972*) concluded that IR radiations do not participate in the pheromone-mediated communication of cabbage loopers.

Using a specially modified infrared Fourier transform inferometer spectrophotometer, Callahan and Hamilton (*1977*) and Callahan (*1977a,b,c, 1980*) described narrow band frequencies emitted by a monomolecular layer or gaseous state of the cabbage looper pheromone. The frequencies occur in a spectral window in the 17- and 26-μm regions. The log-periodic occurrence of these frequencies coincides with the reported spacing of the trichoid sensilla on a cabbage looper antenna (Callahan *1975a,b*); however, recent examination and modeling of the antennal morphometry of the cabbage looper did not support this morphological relationship (Mayer et al. *1981*).

Male Orientation to the Pheromone

It is widely proposed (Shorey et al. *1968a*) that flying insects respond to sex pheromone by orienting with respect to the prevailing wind. Anemotactic orientation would keep the insect moving generally toward the chemical course with chemotaxis and visual cues mediating the final approach. In the hypothesized scheme, sinusoidal upwind flight caused by a turning response at the edge of an aerial plume of pheromone brings the male close to a receptive female.

Shorey and Farkas (*1973*) have demonstrated that wingless cabbage looper males can follow a terrestrial pheromone trail. They suggest that a flying male might follow an odor plume trail in a three-dimensional space using the same steering mechanisms (orientation to the chemical alone) as a scout ant following a scent trail back to its nest or a hound on the trail of a fox.

Communication Distance

From an application of the formula of Bossert and Wilson (*1963*) and their own limiting formula, Sower et al. (*1973*) estimated the optimum wind velocity for mating communcation in the cabbage looper to be 25 cm/sec, allowing a mean maximum communication distance of about 200 m. A field experiment by Kishaba et al. (*1970a*) tends to support this.

Pheromone Trapping

The cabbage looper pheromone is used as a lure in traps for survey and detection in experimental projects. The finding that DA facilitates landing behavior may make sticky traps more useful. Bjostad et al. (*1980a*) stated that DA does not increase trap captures, but failed to describe what type of trap was tested. The can or double-cone trap (Sharma et al. *1971*; Kaae and Shorey *1972b*) and the cylindrical electric grid trap (Mitchell et al. *1972a,b, 1974*) are used most commonly. The electric trap captures the most moths and detects moths at lower densities than other traps. The dose-response characteristic of both traps (Gaston et al. *1971a,b*; Sharma et al. *1971*; Beroza et al. *1974*) indicates an optimum rate of volatilization for the pheromone unique to each trap. Exceeding the optimum rate reduces the capture rate. McLaughlin et al. (*1975a*) found that pheromone traps with low spectral reflectance in the 360 and 550 nm regions were most effective in capturing males, presumably because they were less visible to the males. A little-used maze trap was constructed by Killinen and Ost (*1971*). Trap design may be improved through night observation studies such as those by Kaae and Shorey (*1972b*) and Lingren et al. (*1978*).

The sex lure has been used together with a blacklight (350 nm) since the combination will attract more males than either stimulus alone (Henneberry and Howland *1966*; Henneberry et al. *1967a,b*; Howland et al. *1969, 1971*; Gentry and Davis *1973*). Captures of cabbage looper males and/or females in any type of trap has not been related to population densities or damage levels in a crop. Several attempts have been made to annihilate male cabbage loopers with pheromone or pheromone-light traps to prevent their mating with females (Wolf et al. *1967, 1969*; Howland et al. *1969*; Kishaba et al. *1970b*; Gentry et al. *1971*; Ford et al. *1972*). While showing some promise in field cages, the approach has not proven logistically or biologically feasible in major scale (Gentry et al. *1971*; Ford et al. *1972*).

Wolf et al. (*1971*) have deterined the theoretical spacing for pheromone traps in a male annihilation program; however, data of Toba et al. (*1970b*) indicate that traps placed with the required overlapping spheres of influence would volatilize pheronomone at a molecular density per unit area of land approaching that required for disruption of mating communication (see below). Therefore, trapping may not be the most efficient method of behavioral control for this species.

Atmospheric Permeation

Observations have shown that the behavioral response of male Lepidoptera to sex pheromone may last only a few minutes, after which responsiveness may be markedly reduced for a period of hours (habituation) (Gaston et al. *1967*; Shorey et al. *1967*; Traynier *1970*). For the cabbage looper, this observation has been confirmed by measurement (Shorey and Gaston *1964*). The rapidity and magnitude of this decline in response have enabled disruption of sex pheromone communication in the cabbage looper in the laboratory and field experiments by the continuous evaporation of synthetic pheromone into the atmosphere surrounding the test insects (Gaston et al. *1967*; Shorey et al. *1967, 1971, 1972*; Kaae et al. *1972, 1974*; Farkas et al. *1974*). This disruption in female-male communication has been equated to a reduction in mating (Shorey et al. *1967, 1972*); however, the results of a large field test designed to protect vegetable crops were inconclusive (Shorey et al. *1971*).

Shorey et al. (*1972*) discovered that interference with mating communication only occurred when the amount of pheromone released per given surface of land remained above about 0.08 mg/h per acre. The ability of males to find pheromone-releasing females increased rapidly at lesser concentrations. In the cabbage looper, disruption appears to be independent of the number of pheromone sources per unit area but dependent on the amount of pheromone released into the air per given surface of land (Shorey et al. *1972*; Farkas et al. *1974*). Disruption is also more efficient in a cool, relatively calm, coastal area relative to a hot, erratically windy, desert environment (Shorey et al. *1972*).

The above experiments were evaluated by placing a trap baited with virgin cabbage looper females in the center of each of the pheromone-treated areas. The number of cabbage looper males captured in the trap, relative to the number caught in an identical control trap in a nearby untreated area, was used as the indication of the amount by which communication has been disrupted. In one experiment (Shorey et al *1972*), the reduction in mating of virgin females tethered near the center of pheromone-treated plots relative to females in untreated plots agreed closely with the degree of communication disruption indicated by the trapping technique; however, no experiments have determined the minimum-sized plot for accurate evaluation of the permeation techniques as a population suppressant.

The exact mechanism by which sex pheromone communication is disrupted is not yet known, although the evidence points strongly to adaptation of the olfactory sensory neurons and/or habituation in the central nervous system (Shorey et al. *1967, 1972*; Traynier *1970*; McLaughlin *1974*). The rates of habituation and dishabituation to pheromone and the effects of environmental factors on these rates are not known for the cabbage looper. Also, the morphology of the cloud of synthetic pheromone has not been determined. Males in a pheromone-permeated area probably undergo a dynamic cycle of attraction,

adaptation/habituation, and recovery as they fly through areas with greater or lesser (or no) concentration of pheromone.

Formulation

The cabbage looper pheromone has been evaporated from common sorptive dispensers such as filter paper, string, wood chips, and fiber board. Wolf et al. (*1967*) baited light traps with pheromone-coated sand, and Debolt (*1967*) investigated several types of reservoir-fed wick dispensers.

Gaston et al. (*1971b*) were the first to quantify dispensers of the pheromone. They found volatilization of a liquid film of the pheromone with known surface area to be the most suitable method for their studies because of relatively low temperature dependence and a constant volatilization rate independent of reservoir capacity.

Diffusion of the pheromone through the walls of a polyethylene container that is partially filled with the pheromone is a commonly used dispensing technique (Toba et al. *1969*; Glass et al. *1970*). Kuhr et al. (*1972*) presented data on the release of pheromones from such a dispenser. McLaughlin (unpublished) has determined that once the wall of the container reaches and is maintained at saturation, the volatilization rate of these polyethylene wicks remains reasonably constant.

Fitzgerald et al. (*1973*) incorporated the pheromone into a solid formulation with polyvinyl chloride plastisol as the base matrix. This formulation has excellent long-term release properties. Beroza et al. (*1974*) tested a three-layer plastic laminate in which the pheromone is concentrated in the inner layer. This dispenser also has long-term release properties, is easy to handle (can be cut with scissors), and is said to be biodegradable. Wolf et al (*1972*) determined that N,N'-disubstituted *p*-phenylenediamines (antiozonants) are useful in protecting the pheromone from oxidative degradation during prolonged exposure in the field.

The cabbage looper pheromone has also been successfully microencapsulated in capsules 20 to 200 microns in size. Such capsules have been sprayed on field plots and successfully disrupted mating communication (McLaughlin et al. *1975c*). The pheromone has also been successfully formulated in hollow fibers as trap baits and to disrupt mating communication (McLaughlin et al. *1975c*).

Male-Produced Compounds

Male cabbage loopers possess a lateral pair of abdominal brushes (hair pencils) each with an associated gland (Grant *1970a*; Grant and Brady *1973*). On the basis of electrophysiological data, Grant (*1970a,b*, *1971a,b*) suggested that the scent brush secretions are pheromones that influence the behavior of females to facilitate mating. Birch (*1971*) strongly questioned the biological significance of these data in the absence of behavioral correlation.

Jacobson et al (*1976*) identified 2-phenylethanol from the scent brushes of male cabbage loopers and presented evidence that this compound acts as a sexual stimulant to females. Gothilf and Shorey (*1976*) could find no quantitative or qualitative differences in the precopulatory or copulatory behavior of pairs of cabbage loopers, including all combinations of antennaeless females and males with scent organs removed.

Smith et al. (*1943*) and Creighton et al. (*1973*) reported that phenylacetaldehyde is attractive to female and perhaps male cabbage loopers. This attraction seems to occur when population densities of the moth are high and food is scarce. The significance of the attraction is unknown.

Future Needs

In our search for pollution-free ways to control insects, pheromones have great appeal. They are natural products with virtually no toxic properties and are quickly degraded. Three major approaches may be taken to exploit pheromones for pest management. Two of these, utilizing pheromone-baited traps for survey or male annihilation, are based on the normal behavior of the responding insects; the third involves inhibition of normal behavior. I have already pointed our several areas where knowledge of the mating communication system in the cabbage looper is lacking. Discussion here will be confined to the possible application of pheromones to control the cabbage looper.

Pheromone-baited traps may assist in studies to further clarify the patterns of migration and dispersal for the cabbage looper. As further information becomes available, there may emerge certain correlations between the dynamics of cabbage looper populations in cropped areas and the chronology and rate of capture of males in pheromone-baited traps. With such information, growers might apply pesticides more judiciously and with greater effect. One major stumbling block to this approach is the lack of knowledge of how environmental factors affect trap catches. It is doubtful that trapping information would always be valid on a field by field basis. Thus, growers would continue to rely heavily on their own hard-won knowledge of local conditions and pest histories. Trapping may be quite useful in predicting the rate and intensity of the annual northward movement of the cabbage looper.

Over a period of 20 years, numerous attempts have been made to control the cabbage looper by mass trapping with blacklight or pheromone-baited blacklight traps. None of these projects has been successful in protecting a crop from economic damage. The trap density (one trap to 5 to 10 or more acres) used in the Red Rock Ranch experiment (Wolf et al. *1969*) is probably well past the economic limits imposed by electricity and labor costs.

Certainly, one could exceed this trap density only by using nonlighted pheromone traps. Toba et al. (*1970b*) determined that trapping efficiency is greatly reduced even when pheromone traps are as much as 244 m apart. In fact, they were undoubtedly experiencing a communication disruption effect by permeating the trapping area with a constant high level of pheromone. Farkas et al. (*1974*) have placed pheromone evaporators in the field at the rate of one per 10 acres and achieved communication disruption. Thus, this approach to cabbage looper control would seem to be more promising than annihilative trapping.

Experiments testing the atmospheric permeation technique as a crop protectant are lacking. Cabbage looper females may fly long distances between the time of mating and the completion of oviposition. If more were known about this critical parameter, it would be possible to set appropriate limits on an experiment. Presently, commercial formulations are available for such a test.

At present, we are faced with puzzling structure-function relationships. We know that (*Z*)-7-hexadecen-1-ol acetate evaporated over a test plot will disrupt sex pheromone communication in the cabbage looper, while (*Z*)-7-dodecen-1-ol will not (Kaae et al. *1972, 1974*; McLaughlin et al. *1974*). We must enlarge our understanding of the mechanisms by which chemical communication is disrupted in permeation tests with the pheromone. Studies of the basic processes of olfaction will undoubtedly yield several avenues by which male-female communication can be blocked.

The possibility of a male-produced pheromone mediating some final stage of mating in the cabbage looper opens still another possible area of exploitation. Experiments thus far are inconclusive, and this aspect of premating behavior requires much more intensive research.

The physiology and biochemistry of pheromone production, storage, and release are sadly neglected areas of study. This information may provide important points for attack in our search for methods of population control for pest insects.

The cabbage looper has been considered as a candidate for control through the release of sterile insects. The effects of the method of sterilization on premating behavior must be considered in any program (see review and experiments of Szentesi et al. *1977*).

Pheromone-mediated behaviors appear to be common among insects. Certainly, one of the most dramatic of these is the sex pheromone response of a male moth to a female. This appears to be a vital step in the life cycle of most moths, and our full understanding of this process must surely lead to methods whereby pest species can be controlled in an environmentally acceptable fashion.

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Chapter 15. The Current Status of Induced Sterility for Population Suppression

by P. D. Lingren,[1] D. T. North,[2] H. H. Toba,[3] and T. J. Henneberry[1]

Abstract

Since the early 1960's, laboratory scientists have attempted to determine the amount of radiation, chemical sterilant, and genetic mechanisms required to obtain maximum effect against the cabbage looper, *Trichoplusia ni* (Hübner). They have defined some of the debilitating effects of radiation and chemosterilants such as reduced mating and sperm transfer, with the latter phenomenon being correlated with remating and oviposition. Their results indicate that sterility can be a very effective tool for studying and suppressing cabbage looper populations. These results have been substantiated in field cages and, to a limited extent, in field studies. Further pilot field tests utilizing all feasible suppression techniques available, concentrated research on culture maintenance and behavior, and an economic evaluation are needed before an area-wide suppression program is attempted.

The concept of rearing and releasing sterile insects to overcome the reproductive potential of a natural population was first introduced by E. F. Knipling in 1937. After about two decades of concentrated research, the sterile technique was used to eliminate the screwworm fly, *Cochliomyia hominivorax* Coquerel, from the island of Curacao (Baumhover et al. *1955*). A few years later, the pest was eliminated from the southeastern United States (Baumhover *1958*). The technique is now being used in conjunction with a barrier of sterile males to drastically limit screwworm populations throughout the United States (Bushland *1971, 1975*). The validity of the sterility concept has been demonstrated with some success in suppression of various species of Tephritidae (Steiner et al. 1965, Christenson *1966*). When compared with dipteran species, success in the suppression or elimination of lepidopteran species by the sterile concept has been limited. One of the major reasons for this is that relatively large doses of ionizing radiation are required to induce sterility in the Lepidoptera. These large doses of radiation can result in numerous physiological disturbances. To minimize these disturbances, researchers have concentrated on the use of inherited sterility as a population suppression technique since it requires less irradiation and possibly results in a more competitive insect.

[1]Research entomologists, Western Cotton Research Laboratory, Agric. Res. Serv., USDA, 4135 E. Broadway Rd., Phoenix, Ariz. 85040.
[2]Research geneticist, Metabolism and Radiation Research Laboratory, Agric. Res. Serv., USDA, P.O. Box 5674, State University Station, Fargo, N. Dak. 58105
[3]Research entomologist, Yakima Agricultural Research Laboratory, Agric. Res. Serv., USDA, 3706 W. Nob Hill Blvd., Yakima, Wash. 98902.

North (*1975*) reviewed the subject of inherited sterility as it relates to cytogenetics and physiology in the order Lepidoptera. Much of the review relates to the history and development of research on sterility from ionizing radiation as it pertains to the cabbage looper, *Trichoplusia ni* (Hübner). Therefore, this paper will treat that area lightly and deal more extensively with other methods of obtaining sterility and the ecological considerations of the use of sterility to suppress populations of the cabbage looper. Much of the information presented will be drawn from unpublished material from a pilot test conducted on St. George Island, Fla., during 1972–73, in which partially sterile insects irradiated in the late pupal stage (0 to 72 h before eclosion) were released in an attempt to suppress natural populations of the cabbage looper. The pilot test was conducted in a cooperative effort between the Agricultural Research Service (ARS), USDA, and the State Agricultural Experiment Station of the University of Florida and included inputs from the following researchers: P. D. Lingren, T. J. Henneberry, Boyd George, A. H. Baumhover, Harold Toba, D. T. North, Jerry Holt, F. I. Proshold, and D. L. Williamson of ARS, and G. L. Greene and P. B. Martin of the University of Florida's, North Florida Agricultural Research and Education Center, Quincy, Fla.

Why the Need for Population Control of the Cabbage Looper

The cabbage looper is the most destructive insect pest of cole crops in the Southeast and along the eastern seaboard as well as in most U.S. areas where cole crop production is concentrated. It also causes considerable damage to other vegetable crops and ornamentals and sometimes attacks tobacco, cotton, and soybeans. The cabbage looper is very tolerant of most conventional insecticides and has become resistant to others that at one time were partially effective in controlling the pest. Moreover, it generally attacks high cash value crops where quality is of extreme importance to the marketing syndrome. The cabbage looper is a voracious feeder and attacks marketable portions of many crops. These facts make the cabbage looper a feared and expensive pest.

The cabbage looper apparently does not diapause; therefore it can overwinter only in the southernmost areas of the United States and in warm spots along the eastern and western seaboards. Yet, each year it damages several crops in central and northern U.S. areas as well as in certain areas in Canada. If some means could be developed to suppress the looper to very low levels in

its overwintering range in the South, then damage from this pest within and to the north of its overwintering range might be greatly reduced or even eliminated in some areas.

Theoretical calculations by Knipling (*1970*) suggest that the cabbage looper could be controlled along the eastern U.S. seaboard by releases of partially sterilized males in the overwintering areas of the cabbage looper for an estimated annual cost of $2.5 to $5 million. This cost could easily be justified since annual costs from crop loss and conventional control measures for the cabbage looper along the eastern seaboard have been estimated at $25 million. This figure is likely very conservative because of inflation during the last decade.

Effects of Sterilizing Agents

Ionizing Radiation (Adults)

North and Holt (*1968b*) demonstrated in laboratory tests that the dose-response curve for gamma irradiation (Cobalt-60) induced adult male sterility in laboratory-reared cabbage loopers was nonlinear as in most dipteran species. No significant sterility occurred at doses less than 10 krad, and a dose of at least 35 krad was required to obtain complete sterility. Longevity of males that received completely sterilizing doses was unaffected, and initial mating response was not impaired; however, sperm transfer was greatly reduced, and unirradiated females mating with treated males oviposited about 50 percent less eggs.

Further laboratory studies and theoretical calculations by North and Holt (*1968a, 1968b, 1969*) suggested that effective population suppression of the cabbage looper was possible through the introduction of partially sterile adult males into a population. A partially sterilizing dose of 20 krad of Cobalt-60 applied to 2- to 3-day-old adult laboratory-reared males resulted in about 82 percent sterility in normal females mating with the treated males. The F_1 progeny of these males, when outcrossed to normal untreated adults of the opposite sex, were more sterile than the P_1 parents. Male progeny were over 95 percent sterile, and female progeny were about 90 percent sterile. This delayed sterility (F_1 sterility) was attributed to the induction of reciprocal chromosomal translocations observed in cytological studies. These translocations probably occur because Lepidoptera have diffused centromeres (holokinetic chromosomes) (LaChance et al. *1967*). Bauer (*1967*) has presented detailed descriptions of translocations in several species of Lepidoptera.

Partially sterile F_1 males show a reduced capability for sperm transfer, and females oviposit fewer eggs than normal parents. Both factors are dependent upon the radiation dose given to the male parent (North and Holt *1970*). Further studies by Holt and North (*1970a*) show that irradiated males are less capable than unirradiated males in proper placement of sperm into the spermatophore and that the concentration of eupyrene sperm in the spermatheca of normal females mating with irradiated males is reduced. Also, the average length of mating time shows a slight increase. All these factors appear to be dose dependent.

Holt and North (*1970b*) defined the sequential development of spermatogenesis in cabbage looper and showed that eupyrene sperm bundles first appeared as pupation began and that apyrene bundles became noticeable 3 days later. Spermatogenesis was essentially complete at the time of adult eclosion. Therefore, only mature sperm would be subjected to radioactivity when adult males were irradiated. As suggested by Holt and North (*1970b*), however, the term "mature sperm" should be used with some reservation since Rieman (*1970*) demonstrated morphological changes in cabbage looper sperm from the time they leave the testes until they reach the spermatheca of the mate. The studies by Holt and North (*1970a, b*) and Rieman (*1970*) on the mechanisms of sperm transfer, spermatogenesis, and metamorphosis of sperm led to further studies on sperm transfer, irradiation of pupae, effect of other sources of irradiation, female sterility, and laboratory competitiveness of irradiated cabbage loopers.

Three-day-old adult males receiving 5 krad of irradiation were capable of transferring sperm as well as unirradiated males (North and Holt 1970, 1971b). Males receiving 15 krad transferred less than a normal ratio of eupyrene and apyrene sperm but were most effective between the fourth and sixth mating. Males receiving 30 krad were considerably less effective in transferring a normal complement of sperm, but were more effective during the first two matings than in later matings. Irradiation did not appreciably affect their capability for copulation; however, field cage tests have shown that females receiving a normal complement of eupyrene sperm are less likely to remate than those receiving less than a normal amount of sperm (P. D. Lingren, F. Proshold, G. G. Holt, and D. T. North, unpublished data).

Because of cost associated with rearing, handling, and sexing cabbage looper adults, irradiation of both sexes was considered by North and Holt (*1971a*). Consequently, studies relating to the effect of irradiation on the female were begun. Results indicated that females were much more susceptible to irradiation than males. A dose of 20 krad administered to P_1 adult females that subsequently mated with untreated males resulted in a 50 percent reduction of eggs deposited and a 93 percent reduction in hatch. The F_1 progeny from treated females also showed at least a 50 percent reduction in egg depo-

sition. On the basis of egg hatch, the F_1 male progeny demonstrated about 60 percent inherited sterility; whereas, inherited sterility was essentially absent in F_1 female progeny. Further laboratory tests showed that irradiated males and females released together were equally competitive to males alone in the P_1 generation, but releases of male only were superior in the F_2. Other laboratory tests, however, showed that males irradiated with a lesser dose of Cobalt-60 (15 krad) and placed at a 9:1 ratio (treated to untreated) with normal females were capable of reducing the reproductive potential of the population by about 56 percent in the P_1 generation (North and Holt *1970*).

Field cage tests conducted by Toba et al. (*1972*) demonstrated that males given a partially sterilizing dose of 15 krad as adults were superior to males given a completely sterilizing dose of 30 krad in reducing populations. Partially sterile males released at a 9:1 ratio (treated to untreated) against unirradiated laboratory-reared females reduced the population by about 92 percent by the F_2. Completely sterile males released at the same ratios reduced the population by about 82 percent. Further field cage studies by H. H. Toba and A. N. Kishaba (personal communication) showed that partially sterile laboratory males suppressed caged natural populations by about 97 percent. Irradiated adult males and females released together were more effective than males alone in suppressing caged laboratory populations in the P_1 generation. The overall suppression of a population by releases of sterile adult females was more effective than male releases, and both sexes released together were more effective than either sex released alone. In these tests, however, only 10 normal adults of each sex were released per cage. Consequently, results of these tests should be interpreted carefully since the mortality of one female would greatly affect the total population.

Further field tests by Stimmann et al. (*1972*) indicated that laboratory-reared females exposed to 30 krad of gamma irradiation retained their ability to attract natural or laboratory-reared males. Similarly irradiated males retained their capability to respond to synthetic pheromone and to laboratory-reared females. Therefore, irradiation does not affect sex pheromone communication between sexes.

Pupal Irradiation

Gamma radiation applied to male pupae 120 h before eclosion results in a drastic reduction in mating capability (North and Holt *1970*). A dose of 20 krad of Cobalt-60 completely sterilizes the males and sperm transfer, and transfer of normal ratios of eupyrene:apyrene sperm is essentially eliminated at a dose of 10 krad. Further studies conducted in 1-acre cages showed a 50 percent reduction of mating competitiveness of males originating from pupae that had received 25 krad of Cesium 137 at 120 h before eclosion (P. D. Lingren, unpublished data). Therefore, irradiation of male pupae 5 days prior to eclosion with a gamma source does not produce competitive sterile male adults. Further studies by North and Holt (*1971b*) with various doses of 0.43 MeV fast neutrons administered to pupae 5 days prior to eclosion showed rather dramatic differences in the biological effect of the two radiation sources. These differences were as follows: (1) A reduction in the mating capability of irradiated males increased with dosage increases but was much less drastic than when gamma radiation was used. (2) Males given a 15-krad dose of fast neutrons were essentially as sterile as those given a 20-krad dose of gamma radiation. (3) At the sterilizing dose of 15 krad, 60 percent of the males mated and 36 percent of these transferred a normal ratio of euphrene:apyrene sperm. (Only 7.1 percent of the males receiving a sterilizing dose of gamma radiation mated and none passed sperm). (4) At sterilizing dosages, males irradiated as adults with a gamma source, when compared with pupae irradiated with neutrons, were comparable in mating and transferring sperm, but were much less efficient in transferring normal ratios of eupyrene:apyrene sperm.

Further studies showed that 10 krad of 0.43 MeV fast neutrons administered to male pupae 72 h before eclosion resulted in about 57 percent sterility in irradiated P_1 x normal crosses, and outcrosses of the F_1 progeny with normal adults resulted in complete inherited sterility (North and Holt *1971a*). In contrast, 10 krad of 0.43 MeV fast neutrons administered to adult males (0 to 24 h old) resulted in very little P_1 or F_1 sterility. Since neutron sources were limited and immobile, further research in that area was discontinued even though the results were very encouraging; however, subsequent studies on the effect of gamma sources on pupae of different ages demonstrated that pupal irradiation was almost as effective as adult irradiation (Ercelk and Holt *1972;* Toba and Kishaba *1973*).

Male pupae irradiated with 20 krad, and adult males receiving 15 krad, of Cobalt-60 at 24 h prior to eclosion mated (90 percent +) and transferred sperm (80 percent +) equally well. Outcrosses of the F_1 progeny from the irradiated pupae showed that the males were 90 percent sterile and females were 85 percent sterile. These results were comparable to those obtained when males were irradiated as adults with 15 krad; however, the F_1 progeny of males irradiated as adults were slightly more capable of transferring normal amounts of sperm than the F_1 progeny from pupae irradiated 24 h before eclosion. Irradiation of early pupae (5 days before eclosion), prepupae, fifth stage larvae, and eggs proved to be ineffective (Ercelik and Holt *1972).* The effect of gamma irradiation on eggs was substantiated by Toba and Kishaba (*1974*).

Additional laboratory tests on the effects of irradiation of pupae by Toba and Kishaba (*1973*) indicated that cabbage loopers irradiated as pupae will produce males comparable in performance to irradiated adults provided the dose administered does not appreciably exceed 20 krad and the pupae are no more than 4 days from eclosion at the time of irradiation. Female pupae irradiated 24 to 72 h before eclosion with 20 krad Cobalt-60 oviposit few eggs and for all practical purposes are completely sterile. In addition, Toba and Kishaba demonstrated that a fractionated dose of 15 krad applied in 5-krad increments to pupae at 0 to 24, 24 to 48, and 48 to 72 h of age produced adults that performed comparably to adults receiving a single dose of 15 krad. Field cage tests, however, indicated that population suppression with laboratory-reared adults irradiated as pupae was about 30 percent less effective than with those irradiated as adults and released (H. H. Toba, personal communication).

Chemosterilants

Ten percent sugar solutions of apholate (0.06 percent) and tepa (0.02 percent) fed to adult male cabbage loopers results in complete sterility (Howland et al. *1965*). At these dosages, neither chemical affects male longevity. A 10-fold increase in dosage is required to induce complete sterility in females. Males exposed for 2 h to 4 percent residues of tepa and 16 percent residues of metapa are completely sterilized. Males exposed for 15 min to residues of 8 percent tepa are completely sterilized, and the residues produce effective sterility for 38 days. Further tests by Henneberry and Kishaba (*1966*) showed that male moths fed a sterilizing dose of tepa mated less frequently than untreated males and that moths could be sterilized by sprays of tepa. Male moths sprayed with tepa mated as often as untreated males, but a high degree of locking occurred in copulating pairs when the male had been exposed to tepa. Metapa and apholate were less effective than tepa in sterilizing both sexes. Tepa-fed males were less responsive to the female sex pheromone than untreated males, but the response of tepa-sprayed males to the pheromone was comparable to that of untreated males (Henneberry et al. *1966*).

Field cage experiments have shown that when male cabbage loopers were fed 1 percent tepa in sugar solutions and released at a ratio of 10 treated males to 1 untreated male and 1 female, P_1 larval progeny were reduced by 73 percent over an 18-day period (Howland et al. *1966*). A 2-h exposure of males to tepa-coated glass surfaces reduced the F_1 larval populations by 97 percent at release ratios of 20 treated males to 1 untreated male and female. Further field-cage tests with a blacklight trap baited with tepa reduced larval populations by as much as 99 percent. Delayed sterility was not considered in these tests and could have caused even a greater reduction in the F_2 larval populations.

Stimmann (*1971*) demonstrated that partially sterilizing doses of tepa applied topically to adult male cabbage loopers would result in delayed sterily in the F_1 progeny. The F_1 males were able to mate, transfer sperm, and fertilize eggs, but embryos frequently failed to complete development. A dose of 25 μg applied to P_1 males caused about 90 percent P_1 mortality, and the resulting F_1 male progeny were 70 percent sterile. Female F_1 progeny were 51 percent sterile; however, a dose of 20 μg appeared to be more effective in obtaining the desired amount of delayed sterility because more progeny survived from the P_1 treatment, and F_1 sterility was about equal to that obtained at a dose of 25 μg. Further tests by Henneberry et al. (*1968, 1972*) showed that topical treatment to adults was superior to other adult treatment methods for obtaining complete sterility without the undesirable effects of reduced mating frequency and reduced response to female sex pheromone; however, moths that flew immediately after receiving topical treatments showed a reduced degree of sterility, thus indicating a loss of the chemical during flight.

Chemical sterilants often caused marked deterioration of the testes and aspermia (Lindquist et al. *1964*; Schwartz *1965*); however, tests conducted by Henneberry et al. (*1972*) indicated that topical treatments of tepa and metepa applied to adult males less than 1 day old caused no significant damage to reproductive tissue. Treatment of females less than 1 day old with tepa and metepa caused considerable initial damage to ovarioles. A few eggs were eventually oviposited, but none hatched when females were treated with 0.5 percent tepa.

Genetic Control

Knipling (*1960*) proposed a method of control through which insects with inherited lethal factors control their own populations. Theoretical calculations were made by LaChance and Knipling (*1962*) that strongly suggest that releases of males carrying multiple recessive lethal genes could drastically reduce a population. Recent reviews on the status of the development of autocidal control methods are available (Waterhouse et al. *1974*; Pal and Whitten *1974*). These reviews indicate that very few genetic strains have been developed specifically for insect control, and data on biological parameters of these strains are insufficient to fully evaluate their potential for control under field conditions. Nevertheless, some genetic strains can be used to separate sexes and as markers in population movement and density assessments.

Toba et al. (*1970*) isolated a mutant in the cabbage looper (dark body color) that is an autosomal dominant factor in the heterozygous condition and is lethal in the homozygous recessive condition. These dark mutant males respond as well as normal males to the synthetic

pheromone in the field, and a radiation dosage of 30 krad has no noticeable effect on field recovery rates (Stimmann et al. *1972*). Further tests with the dark mutant indicated that it was competitive with normal moths in laboratory and field cage tests. (Bartlett and Butler *1975*). Field release-recovery experiments indicated that the black mutant responded well to pheromone and light traps. Following release, one larvae was collected in the field that produced a black mutant adult.

Theoretical studies made by Bartlett and Butler (*1975*) indicate that the dark mutant strain is capable of reducing a population. The strain appears to be competitive with normal moths at the mating level and responds well to light and pheromone traps; however, a ratio of 20 mutants to 1 normal would be necessary to obtain even a 47 percent reduction in a population. Therefore, it is unlikely that a single recessive lethal mutation would be an efficient suppressive agent for populations of the cabbage looper. The dark mutant does, however, have great potential for measuring the production of F_1 sterile adults in the field from releases of partially sterile P_1 adults. Moreover, the dark mutant would be useful for studies of population dispersal, population density assessments, and mating behavior.

Pilot Field Test With Partially Sterilizing Dosage of Ce 137

In 1968, in anticipation of a possible pilot test of the use of sterility to suppress populations of the cabbage looper, ARS Tobacco Insects Laboratory at Quincy, Fla., in cooperation with University of Florida researchers, set up a latitude survey across Florida in an attempt to define cabbage looper population densities and movement over the state. In 1970, the survey was expanded to include Florida, Georgia, and South Carolina, and additional research was begun on overwintering potential in various areas in South Carolina, Georgia, and northern Florida. The research was accomplished through a 2-year cooperative agreement between ARS and the Universities of Florida and Georgia and was administered through the ARS, Insect Attractants and Basic Biology Research Laboratory in Gainesville, Fla. ARS laboratories in Charleston, S.C., Oxford, N.C., and Quincy, Fla., were directed to support this effort by T.J. Henneberry, former director of the Vegetable, Ornamental and Speciality Crops Research Branch of ARS.

Also, in 1968, the Quincy laboratory gave considerable thought to the selection of an area where a small pilot test could be conducted with sterile cabbage loopers. St. George Island, located about 85 miles south of Quincy, was selected for the test site because of its isolation (about 4 miles from the mainland; one-half mile wide and 28 miles long), absence of domestic crop concentrations within 50 miles, and closeness to the rearing facility in Quincy. In 1969, the Quincy laboratory set up a trapping system on the island and along the mainland parallel with the island to determine population densities on the island and communication between the island and mainland. In conjunction with this effort, Gerald L. Greene of the University of Florida began an extensive host plant survey on the island in 1970. He found a few cabbage loopers on domestic host plants, but none were found on wild host plants; however, larvae of the cabbage loopers fed and developed on several of the wild host plants in the laboratory.

From 1970 to January 1972, studies were either begun or continued on: (1) cabbage looper population densities on St. George Island, (2) communication of populations between the island and the mainland, (3) development of large scale rearing and marking techniques, (4) pupal shipment methods, (5) large cage studies on competitiveness of cabbage loopers irradiated as pupae, and (6) nocturnal behavior.

From the data obtained on population densities of cabbage loopers on St. George Island and movement between the island and the mainland, we calculated that releases of 360,000 partially sterile loopers per month between March and August would result in about 50 to 90 percent sterility in the natural population. Based on release-recovery data, we felt that adult movement between the island and the mainland would be limited during this period; however, the August-September population appeared to be too great to suppress with our rearing capabilities unless it originated primarily on the island and could be suppressed between February and July, but this did not appear likely because of the limited isolation, very small concentrations of domestic crops, and the absence of cabbage looper populations on wild host plants on the island.

A rearing method was developed for a facility in which pupae could be produced at a rate of about 400,000 per month at a cost of about $6.50 per thousand. Techniques for marking laboratory-reared adults were developed in which Basf (Badische-Anilin-and Soda Fabrik AG) dyes were fed in the larval diet to label the fat bodies of over 90 percent of the adults produced. The dyes also labeled over 90 percent of the eggs produced by laboratory-reared females. Methods were developed by which pupae could be transported by air over long distances with better than 70 percent recovery of adults.

In large cage studies (1 acre), we found that male pupae irradiated with 25 krad Ce 137 at 120 h before eclosion produced adults that were about 50 percent less competitive for mates than unirradiated males. Irradiated females, however, attracted both normal and irradiated laboratory-reared males to the same degree as unirradiated females.

In other large cage studies, nocturnal behavior patterns were established which showed that cabbage looper adults became active about 1 h after sundown. Results reported on eastern daylight time (EDT) demonstrated that peak feeding activity occurred between 8 to 10 p.m. and between 6 to 7 a.m. Ovipositional activity was most pronounced between 8 to 10 p.m. and 5 to 7 a.m. but occurred intermittently throughout the night. Mating activity began at 9 p.m. and continued until about 3 a.m. with peak activity periods occurring between 10 to 11 p.m., 12 to 1 a.m., and 2 to 3 a.m.

In February 1972, ARS contingency funds were made available for a pilot test to determine the effectiveness of sterile cabbage loopers in suppressing the natural cabbage looper population on St. George Island. Sixteen days later we began releasing cabbage loopers of both sexes that had been sterilized with 20 krad of Ce 137 as pupae (0 to 72 h prior to ecolsion).

A bioassay of the release strain of cabbage loopers (Riverside strain) conducted in March indicated that a dose of 21.3 krad of Ce 137 was required to completely sterilize P_1 females mated to normal males; the mated females oviposited less than 10 percent of a normal complement of eggs. P_1 males were about 40 percent sterile when they mated with normal females. On the basis of previous research by Ercelik and Holt (*1972*), we assumed that half of the F_1 progeny from this cross should survive and produce partially sterile adults. These F_1 adults should produce 85 to 95 percent sterile progeny upon mating with normal females. After conducting the bioassay, the irradiation dosage was changed to 21.3 krad.

Approximately 400,000 pupae per month were reared, irradiated, and released on the island from February through August 1972. Sterility of eggs collected from the island from May through July ranged between 30 and 80 percent. The ratio of sterile:wild adults ranged from 2:1 to 20:1 during this period. Calculations of expected hatch versus observed hatch indicated that the released insects were highly competitive and that partially sterile adults were present in the populations. During August, however, large numbers of native moths immigrated to the island, and the sterility was lost. Native populations then remained at high densities during September and October 1972. In an effort to overcome the problem, releases were concentrated on about one-fourth of the island. Still, little sterility was obtained because of the high population density of wild moths; however, *Trichogramma* sp. parasitized from 20 to 60 percent of the eggs during this period, and egg sterility ranged between 10 and 20 percent.

In August 1972, we began having problems with a nuclear polyhedrosis virus in our culture. Therefore, we selected a strain from the island in November 1972 and used this culture for releases made between February and June 1973.

From November 1972 through February 1973, the native population on the island was carefully monitored to determine its density during the cooler winter months. This was done to determine whether releases could be made during the period when the native population was at its lowest density level. The wild population proved adequate for monitoring the effect of sterile releases, but moths reared in the laboratory at 26.6± 2.4°C would not perform in the field at temperatures below 12.7°C. Native moths, however, were capable of limited performance at temperatures between 10 and 12.7°C and performed well at temperatures above 15.5°C.

The results of releases made in 1973 indicated that the St. George culture was very different from the Riverside strain used in 1972. The St. George strain dispersed over a much wider area and appeared to be more tolerant to irradiation than the Riverside strain. The 1973 releases resulted in very little sterility because of cold weather, loss of pupae due to a migratory bird, high densities of native moths, and movement of the released strain out of the area.

Summary

In conclusion, since the early 1960's scientists have determined the amount of irradiation or chemical sterilant required to sterilize the cabbage looper. They have also identified some of the debilitating effects of sterilization, such as reduced mating and male sperm transfer, and correlated the amount of sperm transferred with remating and oviposition of the female. Ways of alleviating the injurious effects of sterilization were explored by using ionizing radiation of different energies (gamma rays (Cobalt-60 and Cesium 137) and fast neutrons), means of applying or supplying chemosterilants, fractionating the dose of irradiation, determining the best stage for administering the sterilant and in the use of induced inherited sterility. These phenomena have been studied in the laboratory and to some extend in the field cages, but field studies have been limited because of the difficulty and costs. The field data collected indicate that laboratory-reared sterilized cabbage loopers (irridated) can be an effective tool for suppressing native cabbage looper populations.

Cabbage loopers pupae can be produced at a rate of 400,000 per month over extended periods at a cost about $6.50 per thousand. Proper facilities and development of new and improved techniques would be necessary to increase and maintain production at higher rates and lower costs. At least one strain of cabbage looper has been highly competitive with the natural population in a

small isolated area, however, considerable effort needs to be concentrated on the development and maintenance of laboratory cultures that are competitive with native populations under various conditions. A great deal more information is needed on natural vs. laboratory-reared behavior in the field in regard to mating synchrony, dispersal, habitats, and a myriad of ecological factors both known and unknown. Moreover, the performance of cabbage loopers irradiated as adults should be tested in a small pilot test along with barriers of radiosterilized females and chemosterilants before undertaking any area-wide suppression program in which sterility is a key factor.

Recent investigations of the ecology and behavior of tobacco budworm, *Heliothis virescens* (F.), indicate that females move very little when adequate food, ovipositional sites, and mates are available (Lingren et al. *1979*). Moreover, it is doubtful that gravid females are capable of moving great distances without some contact with land or water surfaces. Also, barriers of sterile females are capable of preventing males from penetrating a given area through intercepting them as mates (Lingren et al. *1977*).

If cabbage looper populations function like populations of the tobacco budworm, then it seems that the integration of chemosterilized and radiosterilized moths and genetic markers for population suppression would be highly desirable for the following reasons: (1) techniques are available or could be developed by which localized populations, especially females, could be treated with chemosterilants in the field, and (2) barriers of trap crops containing a chemosterilant source could be placed between barriers of sterilized females. The barriers of sterilized females should then intercept most males attempting to penetrate, and the trap crop barrier containing the chemosterilant could possibly intercept and sterilize gravid females. Finally, genetic markers, such as the black mutant, could be utilized to assess population movement and F_1 sterility in the field.

There is little doubt that any suppression program should involve the integration of all feasible control or suppression techniques available. In addition, a strong economic evaluation should be conducted prior to undertaking any area-wide suppression program for the cabbage looper.

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Part III. Handling and Shipping Techniques

Chapter 16. Handling and Shipping Laboratory Reared Live Specimens

By H. H. Toba[1] and P. D. Lingren[2]

Abstract

Shipments of large numbers of insects have become necessary as a result of new methods that are used in programs of population suppression. The literature on the shipment and handling of large numbers of live insects with emphasis on the cabbage looper, *Trichoplusia ni* (Hübner), is reviewed and methods are discussed.

At one time or another, every research entomologist has been concerned either directly or indirectly with shipment of live insects. Earlier, most of this shipping, usually small lots, involved entomophagous insects (parasites and predators) and their hosts (Peterson *1959*). More recently, shipments of large numbers of insects have become necessary as a result of new methods that are used in efforts to suppress insect pest populations (sterile releases, parasites and predators, release and recapture). These large and frequent shipments over long distances create problems.

Factors to consider when shipping and handling live insects of whatever species include the following: (1) insect species, (2) stage of development, (3) time in transit, (4) distance, (5) mode of transportation, (6) size and frequency of shipments, and (7) packaging.

We are concerned here with the shipment and handling of cabbage loopers, *Trichoplusia ni* (Hübner); however, the following synopses of some reports of shipments of large numbers of other species of insects provide much information.

Baumhover et al. *1955*; screwworm (pupae), *Cochliomyia hominivorax* (Coquerel).

> Air freight Orlando, Fla., to Curacao, West Indies, about 1,200 mi; 130 pupae/No. 1 kraft paper sack with excelsior.

Steiner et al. *1965*; melon fly (pupae), *Dacus cucurbitae* Coquillett.

> Scheduled commercial airline jet Honolulu, Hawaii, to Rota, Mariana Islands, about 3,800 mi; 24-30 hr; 70,000 pupae/chipboard tray (35.6 × 35.6 × 1.6 cm); 6 trays/kraftboard carton (well-ventilated) totaling about 400,000 pupae. (See Kamasaki et al. *1969*.)

Steiner et al. *1970*; oriental fruit fly (pupae), *Dacus dorsalis* Hendel.

> Scheduled commercial airline jet Honolulu, Hawaii, to Guam, about 3,800 mi; 24-30 hr; packaging same as above.

Tanaka et al. *1972*; melon fly (pupae).

> Scheduled commercial airline jet Honolulu, Hawaii, to Rota, Mariana Islands, about 3,800 mi; 24-30 hr; about 100,000 pupae/polyethylene bag (7.6 × 5.0 × 76.2 cm, 1.5 mil thick), and air withdrawn with vacuum; 8 bags/cardboard carton (20 × 33 × 64.8 cm) with wood shavings for insulation; total about 800,000 pupae. Method has been changed now so carton contains Blue-Ice coolant (personal communication, W. Schroeder, Agr. Res. Serv., USDA, Hawaiian Fruit Fly Laboratory, Honolulu, Hawaii 96804).

Snow et al. *1971*; corn earworm (pupae), *Heliothis zea* (Boddie).

> Commercial airlines Tifton, Ga., to St. Croix, V.I., about 1,700 mi, 1–2 days.
> Method No. 1: about 2,000 pupae mixed with wood shavings or dry vermiculite in cardboard box (2.5 × 1 × 1.2 ft) with 4 perforated tubes running lengthwise.
> Method No. 2: Compartmented (0.25 × 1.0-in. holes) layers of foam rubber (11.75 × 11.75 × 0.25 in) each hole containing a pupa; stacked in cardboard box; up to 1,000 pupae/box.

Cantelo et al. *1973*; tobacco hornworm (pupae), *Munduca sexta* (L.).

> Air freight Oxford, N.C., to St. Croix, V.I., about 1,900 mi, single layer of 100 pupae between 2 sections of 6-layered paper cushion (1 × 2 ft); rolled firmly from short side, 2-in margin on long sides secured with rubberband after rolling; 5 rolls/ft³ paper carton. In variation, paper cushion is 12 layers of thin aborbent paper sealed along the outer edge (personal communication, A. H. Baumhover, Agr. Res. Serv., USDA, Tobacco Research Laboratory, Oxford, N.C. 27565).

Raulston et al. *1976*; tobacco budworm (pupae), *Heliothis virescens* (Farbicius).

> Air mail Brownsville, Tex., to St. Croix, V.I.; about 2,500 mi, 24–48 hr; 160 pupae mixed in moist vermiculite and placed in 1-pt cartons placed in perforated cardboard box (21 × 25 × 40 cm).

[1] Research entomologist, Yakima Agricultural Research Laboratory, Agric. Res. Serv., USDA, 3706 W. Nob Hill Blvd., Yakima, Wash. 98902.
[2] Research entomologist. Western Cotton Research Laboratory, Agric. Serv., USDA, 4135 E. Broadway Rd., Phoenix, Ariz. 85040.

Graham *1970*; pink bollworm (adults), *Pectinophora gossypiella* (Saunders).

U.S. Postal Service, Brownsville, Tex., to Indio, Calif.; about 1,300 mi; < 24 hr; about 3,500 moths sprinkled into block of triangular cells (1-in Vertical having 0.5-in triangular cells, cut into 6-in squares; cheesecloth glued to bottom); 7 layers stacked into 6 × 6 × 8-in corrugated paper box topped with 1.5-in polyurethane foam; total about 24,500 moths/box. Box then placed into expanded polystyrene shipping carton (13.75 × 10.75 × 12.5 in, and having 1.5-in thick walls) together with 3 freeze packs (Ice-Pak) and crumpled paper packing.

Ridgway and Guenther *1973*; pink bollworm, (adults).

Airmail, Phoenix, Ariz., to Bakersfield, Calif.; about 500 mi, 15 hr; adults placed in 5.25-in-diam. molded plastic water (15 open cells 7/8 in diam. and 3/4 in deep with plastic screen disk glued to bottom); 9 wafers stacked in paper canister (5.5 in diam., 7.5 in high); canister placed in waterproof cardboard mailer (13.75 × 10.5 × 13.5 in and 1.5 in thick foam plastic insulating liner) together with 3 pint size Ice-Paks and held snugly in place with folded cardboard spacers. Total 40,000 adults/canister.

Riverside Laboratory, unpublished data; cabbage looper (pupa), *Trichoplusia ni* (Hübner).

U.S. Postal Service, Airmail, Riverside, Calif., to Quincy, Fla; about 2,000 mi; 2-3 days.
Method No. 1: The bottom half of 6-oz (Lily) paper rearing cut cut away, the top half with pupae attached by silk is inverted so that the lid is now on the bottom; the cups are then layered in a cardboard box (20 × 23 × 26 in), layers separated by cardboard. Total about 9,000 pupae.

Method No. 2: The bottom portion of paper bags (6-1/4 × 7-3/4 × 12-1/2 in deep) used to rear cabbage loopers (see Vail et al. *1973*) cut away; the top portion with pupae attached by silk is opened; bags layered flat in a cardboard box (28 × 13 × 12 in). Total about 5,000 pupae.

Lingren, P. D. (Cotton Insects Research Laboratory, Agr. Res. Serv., USDA, College Station, Tex. 77840), personal communication; cabbage looper (pupa).

Commercial airline Quincy, Fla., to St. Croix, V.I., about 1,500 mi; 1 day; pupae attached to top half of larval rearing cups (16 oz, containing about 45 attached pupae) placed in plywood boxes and/or styrofoam containers (about 50 cups/box) along with 3 1-qt icepacks. Total about 2,250 pupae.

Insect Species

Some insect species can withstand shipment better than others, but practically any species can be successfully shipped if the necessary time, effort, and technology are used. Interstate shipment of any insect requires the approval of the USDA's Animal and Plant Health Inspection Service, Plant Protection and Quarantine Programs, Room 662, Federal Center Bldg., Hyattsville, Md. 20782, and a permit accompanying such shipment. For example, even though the cabbage looper is ubiquitous, a permit is still required for interstate shipment. A permit may also be required for shipment abroad from the country where the insects are being transported.

Stage of Development

The stage of development of the live insects when they are shipped depends upon such factors as ability to withstand injury, requirement for food and water, duration of developmental stage, and the need for insects in a particular stage.

The eggs of cabbage loopers lend themselves well to shipping, particularly if they have been oviposited on a substrate such as paper toweling and the toweling is then rolled up and placed in a mailing tube. Or, if the eggs are oviposited on waxed paper, they can be brushed off the paper and placed in a vial; however, eggs have one disadvantage: unless the temperature is regulated, they begin to hatch in a relatively short time. The mean times to hatch 0.5-day-old eggs were 2.5 days at 32° C, 3.5 days at 27° C, 4.5 days at 21° C, and 8.2 days at 16.6° C (Toba et al. *1973*). Cabbage looper larvae, too, can withstand injury due to rough handling, but it is not feasible to provide them with the necessary food in transit. The adults can be shipped if their activity is reduced by low temperature as in the method used for pink bollworm adults (Ridgway and Guenther *1973*).

Thus, when cabbage loopers are reared at one location and shipped to another location for use as adults, they should probably be shipped as pupae, which are easy to handle, do not need food, moisture, or a low temperature, and have a relatively long period between pupation and eclosion. The mean numbers of days from pupation to eclosion were 5.9 days at 32° C, 7.1 days at 27° C, 14.8 days at 21° C, and 25.9 days at 16.6° C (Toba et al. *1973*).

Time in Transit, Distance, and Mode of Transportation

Although time in transit, distance, and mode of transportation are closely interrelated, distance is probably the most important consideration. If the distance is short, a personal vehicle can be used, thereby reducing the time in transit. If the distance is great, the choice of transportation will depend upon the cost, feasibility, and, above all, the time in transit. If regular shipments of large numbers of insects are anticipated, investigate for the best carrier

to insure proper handling, a minimum of excessive temperatures, and a minimum of delay.

Other problems arise, as noted, when large and frequent shipments of live insects are to be made. Thus, one must decide whether to make small shipments more frequently or large shipments less frequently. The answers will depend largely on the capabilities of your rearing facility and the dependability of your carrier.

Several types of carriers are available, each with its advantages and disadvantages. The U.S. Postal Service is economical and operates nationwide; however, dependability and careful treatment of the package are necessary too. Most private freight carriers have limited extent of operation, and their rates are usually higher than those of the Postal Service. A scheduled passenger carrier (railway, bus, or airline) is usually dependable, but the rates are usually high. One might contract a private air carrier if the cost was not prohibitive. One might also consider an arrangement with a military transport, thereby reducing cost, if there were assurance of proper handling and delivery.

Packaging

Packaging should receive the utmost attention and consideration. Regardless of any other considerations, the insects must be packaged as well as possible to insure that the maximum number of usable insects arrive at the destination.

Two major factors that have great effect on the condition of shipped insects are heat and physical damage; therefore, the choice of packing material should receive first consideration. Vermiculite is light and inert, but it seems to have some deleterious effects if it is in direct contact with pupae, particularly when it is dry. For example, when the Riverside Laboratory shipped cabbage looper pupae mixed in dry vermiculite and placed in mailing tubes to Germany, only about 10 percent emerged. When Snow et al. (*1971*) shipped corn earworm pupae mixed with woodshavings or dry vermiculite, 15 to 40 percent fewer adults emerged from shipped pupae than from nonshippped pupae. Similarly, Baumhover (personal communication) obtained high mortality of tobacco hornworm pupae held in dry vermiculite for more than one day. Even when he used damp vermiculite, he found pupal mortality higher than in the control; thus, he suggests that toxic factors may be present in vermiculite. When Raulston et al. (*1976*) packed 5,000 tobacco budworm pupae mixed with moist vermiculite in an uncooled styrofoam biomailer, they found that the temperature rose to about 34° C within 24 hr and that normal emergence was reduced about 90 percent compared with the control. They nevertheless felt that the high temperature did not account for all the effect observed and believed that other factors, such as anoxia from increased metabolic rate, were responsible for some of the decrease in normal emergence. This point of view was somewhat substantiated when they placed 160 pupae mixed in moist vermiculite in a 1-pt carton, placed 24 such cartons in a perforated cardboard box, and observed emergence equal to that of the control. Thus, dry vermiculite apparently has a deleterious effect on pupae, but moist vermiculite is a suitable packing material if the number of pupae per carton is regulated carefully.

Packing materials other than vermiculte have been tried by workers with unsatisfactory results, often because of physical damage from direct contact with the material or because of the settling and congregation of the pupae which results in increased metabolic heat and physical damage due to the direct contact with each other. The Riverside Laboratory, however, has shipped cabbage looper pupae to Germany by placing 100 pupae in a small bag constructed of cotton organdy or cheesecloth, rolling it in cellucotton, and placing the roll in mailing tubes; emergence was consistently about 90 percent. Likewise, Cantelo et al. (*1973*) placed a layer of 100 tobacco hornworm pupae between two layers of paper cushions and then rolled up the cushions; five such rolls were placed in a paper carton. Snow et al. (*1971*) placed individual corn earworm pupae in holes cut in layers of foam rubber and then packed the foam rubber in a cardboard box, the percentage of sound adults recovered was equal to that of the control. Plainly, it is important to limit the number of pupae per container and to separate them to prevent congregation.

Another method of packaging was reported by Tanaka et al. (*1972*). Melon fly pupae were placed in a polyethylene bag, and the air was withdrawn with vacuum; several such bags were placed in a cardboard carton with wood shavings. When Raulston et al. (*1972*), tried this method with tobacco budworm pupae, however, they observed only 26 percent sound adults compared with 76 percent in the control. Might it be that these two species, which are in two different orders, have different metabolic rates? If this were so, then lepidopteran pupae could perhaps be shipped by this method if they were chilled in transit. In fact, W. Schroeder (personal communication) stated that melon fly pupae are presently shipped with a coolant (Blue Ice) included in the cardboard carton and suggested shipping chilled adults in air-nitrogen or oxygen atmosphere with Ascarite to prevent absorbtion of CO_2. This method should be investigated for shipment of lepidopteran pupae.

P. D. Lingren (personal communication), in cooperation with other ARS personnel (A. H. Baumhover and W. W. Cantelo), tested methods of shipping cabbage looper pupae from Quincy to St. Croix Island. He found that when washed pupae (cocoon removed in 10 percent

sodium hypochlorite) were shipped, the percentages of sound adults were low (20 percent and below) even when the pupae were packed in damp paper toweling or dry vermiculite. The reason was high ambient and metabolic heat. When the washed pupae were mixed with damp vermiculite and then shipped with icepacks, the percentage increased to 55 percent.

When unwashed pupae (still in cocoons) were placed between layers of foam rubber, only 18 percent sound adults were obtained, probably because the ambient and metabolic heat resulted in premature eclosion and high deformity. However, when the pupae were left in the top half of the rearing cup with their cocoons intact (that is, the bottom half of the 16-oz cup holding the rearing medium was cut away), and the cups placed in plywood boxes and/or styrofoam containers with icepacks, the percentage of sound moths was 88 percent; even without the icepacks the percentage was 79 percent. Thus, the best method of shipping cabbage looper pupae presently known is in cocoons still attached in the rearing cups because they are protected from traumatic injury and from ambient and metabolic heat.

The Riverside Laboratory (unpublished data), in cooperation with other ARS personnel (P. D. Lingren and D. L. Williamson), also tested methods of shipping cabbage looper pupae from Riverside to Quincy. As with shipments to the Virgin Islands, shipment of unwashed pupae (removed from rearing cups) produced low yields of sound adults (<20 percent); however, the percentage was higher when the pupae were shipped still attached to the top half of the rearing cups (about 75 percent). Another method that was tried and that warrants further investigation is the use of paper bag rearing containers instead of rearing cups. The paraffin-coated paper bags used to mass rear cabbage loopers (Vail et al. *1973*) appear to be ideal for mass shipment of of pupae because when the bottom portion (the rearing medium and grass) is cut away and the bag is opened flat, the opened bags with the pupae still attached can be layered into a cardboard carton. The layers act as a cushion, keep the pupae separated, and provide enough ventilation. We do not have an exact percentage of sound moths obtained by using this method, but we estimate it to be about 65 percent.

Handling

Obviously, when shipping live insects, particularly large numbers, the less handling the better. Thus, in shipping eggs, sterilization should be done at the destination. It is not advisable to ship larvae; however, if it should be necessary, plan to use the rearing container for a shipping container to eliminate handling the larvae.

The pupal stage is, next to the egg stage, the preferable stage for shipment. Pupae are more resistant to pathogenic contamination than larvae and do not move about like the larvae and adults; however, they are more prone to injury from impact than the other stages. For example, Stimmann et al. (*1972*) subjected cabbage looper pupae of different ages to impacts equivalent to free fall from three heights to various surfaces and found that pupal death and adult deformities increased with increasing impact force, but decreased with age of pupae. Pupae 6 days old were not affected. One should keep this in mind since pupae are usually shipped when they are 2 to 3 days old. Thus, pupae should be handled as gently as possible from harvesting to shipment to use.

The importance of proper handling during shipment was demonstrated by Snow et al. (*1971*) when they simulated shipping conditions by subjecting corn earworm pupae packed in various materials to 46 hr of 100° F., 2 hr on a shaker, and 20 drops from 6.5 ft. All the treatments yielded significantly lower percentages of sound adults than the control. Even the least damaged pupae, those packed in chambers in foam rubber, showed a 72 percent reduction in sound adults. In another test, they subjected pupae packaged in foam rubber to drops from various heights; 10 drops from a height of 5.25 ft yielded 15 percent fewer sound adults than the control. Likewise, when Baumhover (personal communication) subjected boxes containing tobacco hornworm pupae rolled in paper cushions to four throws of 12 ft (landing on concrete floor), the percentage of sound adults was reduced by 72 percent. Certainly, the cited examples were severe treatments, but one should anticipate, and perhaps expect, improper handling of shipments when one has no control over the handling.

With an insect such as the cabbage looper that pupates away from the rearing medium and is enclosed in silk, one might consider delaying the harveting and desilking until the pupae arrive at the destination. Thereby, the silk would be used to separate pupae from each other and would also act as a cushion during shipment. This method was demonstrated successfully by Lingren (unpublished data) and by Toba (unpublished data) with cabbage looper pupae, but more work should be done to improve the method.

Summary

The studies and experiences of researchers involved with shipping and handling live insects have contributed greatly to the common objective of getting the highest percentage of usable insects from one location to another; however, there is still much to be done and learned. Granted, each species has its own set of conditions which must be met; however, the knowledge gained from past studies and experiences could be utilized to shorten the process of finding the best shipping technique for a particular species.

The following is a summary of considerations when shipping live insects:

1. Ways to prevent heat buildup within packages:
   a. Select suitable packing material.
   b. Limit number of insects per container.
   c. Use of coolant.
   d. Permit ventilation.
   e. Reduce the time insects spend in package.
   f. Use insulated exterior carton.

2. Ways to prevent physical damage of insects:
   a. Select suitable packing material.
   b. Immobilize insects.
   c. Limit number of insects per container.
   d. Keep insects separated from each other or prevent congregation.
   e. Use sturdy container to withstand damage from external forces.
   f. Instruct personnel on insect handling procedures.

3. Other ways to reduce costs:
   a. Use lightweight materials.
   b. Decrease number and size of packages.
   c. Use inexpensive and disposable materials.
   d. Use techniques and materials that reduce labor costs.
   e. Insure proper handling of packages to insure maximum number of sound insects.

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Part IV. Research Needs

Chapter 17. Research Needs and Problems Associated With Developing Effective Control Programs

By T. J. Henneberry[1] and W. Klassen[2]

Abstract

The cabbage looper, *Trichoplusia ni* (Hübner), attacks a wide variety of vegetable and other cultivated crops. Resistance to insecticides and other behavioral characteristics of the insect have frustrated the development of effective, efficient, and dependable control methods. Much basic and fundamental biological and ecological information and new potential control strategies have been developed in recent years that provide the framework for developing control techniques within the principles of a good pest management system.

The cabbage looper, *Trichoplusia ni* (Hübner), continues to be one of the most important insect pests of vegetables. It also attacks tobacco, cotton, and some ornamental plants. Resistance to insecticides and other factors, such as larval behavior and feeding habits, have frustrated the development of satisfactory chemical control methods. The need for more efficient and effective control techniques based on fundamental biological and ecological information has stimulated much research designed to find a solution to the problem. Although considerable information has been obtained, may critical questions remain to be answered.

Population Development

The insect occurs as a pest over the entire continental United States. Sutherland (*1966*) presented considerable evidence that *T. ni* migrates into northern areas of the country each year. No evidence has been presented to indicate that it has the ability to overwinter in a diapause condition. Larvae and/or adult moth catches have been recorded every month of the year in southern California, Arizona, southern Texas, Florida, and coastal South Carolina (Anonymous *1951-71*). Chalfant et al. (*1974*) established three geographic zones in the southeastern United States and indicated that continuous reproduction and development occurred during winter only where average temperatures exceed 16° C. Reports from New Mexico, Louisiana, Mississippi, Alabama, and Georgia show larval and/or adult activity 9 to 11 months of the year, so there is a strong probability that continuous generations also occur in portions of these States. The area of "some years no freeze," as taken from weather data of the U.S. Department of Commerce, extends from the coastal areas of South Carolina along the borders of the southeastern States, and includes all of Florida, extends west along the southern coastal area to New Mexico, Arizona, and southern California, and then extends north to southern Oregon (Anonymous *1968*). Continuous generations could occur in no-freeze years in all these areas; however, at present, the source of first-generation eggs on cultivated crops outside these areas is strongly suspected to be migrating adults (Elsey and Rabb *1970*; Sutherland *1966*; Chalfant et al. *1974*). It is generally believed that adult moths can travel long distances. Flight mill data indicated that some moths can fly as far as 196 km in approximately 6.7 days (Kishaba et al. *1967*). Field releases of moths resulted in insects dispersing in all directions from the point of release and traveling nearly 3.2 km in 16 hours or less (Henneberry et al. *1967*). Reports from England indicate that the cabbage looper is capable of migrating or being carried on air currents from Europe and North Africa to England (Dannreuther *1953*; French *1953*; Rossel *1957*). Although these reports indicate that the insect can migrate long distances, no information actually exists that would prove they actually do so. Also, there are no data concerning the conditions that stimulate the insect to move and/or indicating the biological significance of migration in terms of a need for suitable wild or cultivated hosts.

McKinney (*1944*) felt that in years of high rainfall in Arizona, desert plants produce large numbers of *T. ni* that migrate to cultivated crops. Little information, however, is available concerning populations on wild host plants, the biology and ecology of the looper when small populations exist during the absence of cultivated hosts, and the importance of alternate wild hosts in maintaining a population that will later infest cultivated crops.

Rearing and Biology

Many investigators have made important contributions to a better understanding of cabbage looper biology and ecology that could lead to the development of technologies for controlling the insect in the field.

Biological information regarding the species was scarce until the development of laboratory-rearing methods. Early attempts to rear the looper were frustrated because of the occurrence of disease. The problem was first overcome by isolation, careful temperature control, the rearing of small numbers of insects per unit, proper sanitation, and the liberal use of antimicrobial agents (McEwen and Hervey *1958*). Subsequently, the development of artificial rearing media (Getzin *1962*; Ignoffo *1963*; Shorey *1963*) greatly facilitated larval rearing and made available large numbers of insects for experiments. Basic techniques for mass rearing and mechanization, however,

[1] Research entomologist, Western Cotton Research Laboratory, Agric. Res Serv., USDA, 4135 E. Broadway Rd., Phoenix, Ariz. 85040.

[2] Staff scientist, National Program Staff, Agric. Res. Serv., USDA, 338 N. Bldg. ARC West, Beltsville, Md. 20705.

need to be further developed to facilitate the evaluation of control technologies such as the use of pathogens, sterile releases, and mass releases of parasites. Present methods of rearing cost $3,000 to $5,000 per million insects. This cost should be substantially reduced by additional efforts to improve the efficiency of existing methods and to develop new and innovative methods.

Much discussion has evolved regarding the behavioral and biological characteristics of cabbage loopers reared on artificial diet and the characteristics of native insects. In mass rearing programs, careful consideration should be given to the use of the reared insects; for example, the behavioral and biological requirements of insects reared for sterile release may be vastly different from the requirements for insects of the same species reared as hosts for production of pathogens.

Chemical and Microbial Control

Insecticides remain the major weapon against cabbage loopers that attack cultivated vegetable crops; however, the chemicals now available are effective mainly against early (first, second, and third) instars. Larvae reaching the fourth and fifth instars are more tolerant. Thus, application must be made every 3 to 4 days to establish a plant stand if cabbage looper populations are high, particularly early in the season. At present (*1982*), little information is available regarding the economic threshold as it relates to the cost of treatment vs. the loss in vegetable crop yield. Thus, there is a need to develop chemical control techniques for the cabbage looper based on economic thresholds that are ecologically and/or physiologically selective and compatible with other biological systems within the agricultural community. Microbial insecticides appear to be extremely promising as a tool in cabbage looper control systems.

Diseases of the cabbage looper have been known for many years. Riley (*1883*) observed the mortality of larvae caused by a greenish mold later described by W. G. Farlow as *Botrytis rileyi* Farlow. Serrine (*1894*) was apparently the first to describe the symptoms of a disease induced by nuclear polyhedrosis virus, but Chapman and Glaser (*1915*) were the first to observe the virus in cabbage looper larvae. Since that time, considerable work with the nuclear polyhedrosis virus has shown that it has potential as a control agent in the field (Hall *1957*; McEwen and Hervey *1958*; and Elmore *1961*).

Much work has still to be done to develop the virus for use. Researchers need to address themselves to the problems of formulation, application techniques, and loss of pathogen activity after spraying, and they need to determine how the virus is disseminated in nature and how it infects the insect.

Present advances in the development of cell culture for the production of entomogenous viruses (Ignoffo and Hink *1971*) may provide the stimulation for mass production of pathogens for application in the control of insect pests. A nuclear polyhedrosis virus isolated from the alfalfa looper, *Autographa californica* (Speyer), infects suspended cells from *T. ni*, replicates extensively, and is as infectious qualitatively and quantitatively as polyhedra obtained in vivo (Vail et al. *1973*). Continued efforts to develop methods of producing entomogenous viruses efficiently and economically appear to be of the highest priority.

Sterility Methods

The sterile-release method of suppressing or controlling insect populations was among the outstanding recent contributions to economic entomoloty. Basic studies of radiobiology (North and Holt *1968*, *1969*) and of chemosterilization (Howland et al. *1966*; Henneberry and Kishaba *1966*) have indicated that the cabbage looper can be sterilized by either method. Some of the important problems associated with induced sterility are reduced longevity, mating aberrations, and failure to transfer normal complements of eupyrene sperm. For example, relatively high doses of irradiation (compared with those that sterilize some other insect orders) are required to completely sterilize Lepidoptera in general and cabbage loopers specifically. Mechanisms by which chemicals and irradiation induce sterility in Lepidoptera, however, are not yet understood and need further in-depth study. On the other hand, sterility can be introduced into progeny of cabbage looper if the male parent is exposed to substerilizing doses of irradiation. The importance of this finding was not recognized until Knipling (*1970*) showed how it could be used to advantage in sterile releases. Toba et al. (*1972*) subsequently demonstrated in field cages that releases of partially sterile male moths were effective in suppressing cabbage looper populations. The results were encouraging, and additional investigations are needed to demonstrate the feasibility of the method in the field.

Pheromones

The sex pheromone of the cabbage looper was isolated, identified, and synthesized (looplure) as (*Z*)-7-dodecen-1-ol acetate (Berger *1966*). The synthesized material could then be tested for potential usefulness in controlling populations of the insect in the field.

Three approaches to the use of pheromones for controlling insect populations have been suggested. These are (1) luring and killing the insect, (2) prevention of orientation to inhibit mating, and (3) luring and sterilizing native insects, which then return to the native population.

A number of traps have been designed to lure and trap the cabbage looper (Henneberry and Howland *1966*; Toba et al. *1970*; Kishaba et al. *1970*; Sharma et al. *1971*)' however, effort to control the insect by trapping has not been successful. Indeed, one of the serious difficulties in evaluating the potential of pheromones has been the problem of determining the efficiency of the traps. For example, Hartstack et al. (*1971*) evaluated the efficiency of electric insect traps and estimated that only about 8 to 38 percent of the insects attracted to the light were caught. Limited attempts have also been made to increase the efficiency of trapping techniques. Nevertheless, regardless of the large numbers of insects caught, no accurate estimate of potential effectiveness of the method can be made without a reasonably accurate estimate of the total population.

The use of pheromones to inhibit behavior involves permeation of the atmosphere so that orientation of the insects to the normal sources of pheromone in nature is prevented. Several authors (Babson *1963*; Beroza and Jacobson *1963*; Wright *1948*) have suggested such an approach to insect control. For example, Shorey et al. (*1967*) demonstrated that the orientation of the cabbage looper male to virgin females was reduced in cabbage fields by maintaining a concentration of about 1×10^{-10} grams of looplure per liter of air. Shorey et al. (*1972*) postulated that better than 90 percent disruption of male orientation to females could be accomplished with less than 1 mg of looplure per hectare per night. These results appear promising enough to warrant a large-scale field trial to determine the potential of the technique in reducing infestations of the insect on susceptible cultivated hosts such as lettuce, cabbage, and other cole crops.

Luring insects to a pheromone source, sterilizing them, and returning them to the native population has great theoretical potential for suppressing a population of cabbage loopers. The need for, and problems associated with, mass rearing and release of large numbers of the insect would be eliminated, and the sterilized insects would compete sexually with native insects, which would give the system an additional bonus. Laboratory and field cage tests, in which the chemosterilant tepa was used in combination with blacklight traps (Henneberry et al. *1965*), demonstrated the feasibility of the concept. Further development of chemosterilants, however, has been delayed because some may have carcinogenic or mutagenic effects. A program to develop effective chemosterilants without these handicaps could renew interest in the validity and feasibility of the concept.

Host Plant Resistance

One of the most satisfactory methods of preventing damage to plants is through the development of varieties resistant to insect attack. Limited attempts have been made to find resistant germ plasm and to incorporate it into commercially acceptable vegetable host plants of the cabbage looper (Kishaba et al. *1973*; Whitaker et al. *1974*; Stoner *1970*); however, most reports of resistance in these crops result from observations of differences in levels of infestation between horticulturally adapted varieties. An intensive effort should be made to screen the available germ plasm of vegetable hosts of the cabbage looper and to establish reliable indices of resistance. A concentrated research effort could lead to the determination of the nature and inheritance of resistance in vegetable crops. The potential of host plant resistance is indicated by the significant differences found in insect resistance in vegetables despite the relatively limited effort.

Biological Control

Sutherland (*1966*) found that 22 species of Hymenoptera and 9 species of Diptera were reported to attack various stages of the cabbage looper. *Copidosoma truncatellum* (Dalman) and *Voria ruralis* (Fallen) appear to be important parasites of *T. ni* in Arizona (McKinney *1944*; Brubaker *1968*). *C. Truncatellum* was the principal parasite of *T. ni* in New York although it seemed ineffective as a biological control agent. Other workers (Clancy *1969*; Pimentel *1961*; Brubaker *1968*; Butler *1958*; Serrine *1894*; and Chittenden *1902*) were not able to determine that any biological agent had a high potential for controlling populations of the cabbage looper in nature. Likewise, mass culture and periodic colonization of parasites have had varying degrees of success. The area appears one that should be carefully examined. Detailed ecological studies of these parasites may reveal possible ways to augment alternative host materials when parasite populations are low and to maintain high parasite-to-looper ratios.

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Part V. Updated Bibliography

Chapter 18. A Contribution to a Bibliography of the Cabbage Looper, *Trichoplusia ni* (Hübner)

By D. W. S. Sutherland and A. V. Sutherland[1]

Abstract

The importance of the cabbage looper, *Trichoplusia ni* (Hübner), as an agricultural pest and its usefulness as a laboratory animal have stimulated a tremendous amount of research since the late 1960's. This has been accompanied by a corresponding increase in publications dealing with the cabbage looper and a need for updating the *T. ni* bibliography published in 1972 by Sutherland and Sutherland.

This selective compilation covers the period from 1969 through 1974 and includes a few earlier references overlooked or unavailable for consideration by us previously. A few early 1975 publications are also included.

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Chemicals Mentioned in This Publication

Common Name	*Chemical Name*
acephate	*O,S*-dimethyl acetylphosphoramidothioate.
agar	agar
aldicarb	2-methyl-2-(methylthio)propionaldedehyde *O*-(methylcarbamoly) oxime.
allyl isothiocyanate	$(CH_2=CH_2-CH_2)SCN$.
American Cynamid (CL 47041)	2-(diethoxyphosphinylimino)-1,3-dithiolane.
aminocarb	4-(dimethylamino)-*m*-tolyl methylcarbamate.
antizonants	*N-N'*-disubstituted *p*-phenylenediomines.
apholate	2,2,4,4,6,6-hexakis(1-aziridinyl)-2,2,4,4,6,6-hexahydro-1,3,5,2,4,6-triazatriphosphorine.
ascorbic acid.	vitamin C.
azinphosmethyl	*0,0*-dimethyl *S*-[(4-oxo-1,2,3-benzotriazin-3(4*H*)-yl)methyl] phosphorodithioate.
Bt = Biotrol	*Bacillus thuringiensis*.
Bt = Thuricide = HD-1	*Bacillus thuringiensis*.
Bt = Dipel = HD-1	*Bacillus thuringiensis*.
carbaryl	1-napthyl methylcarbamate.
carbofuran	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate.
carbon dioxide	CO_2
carbophenothion	*S*-[[(*p*-chlorophenyl)thio]methyl] *O,O*-diethyl phosphorodithioate.
catalase	catalase.
chitin	chitin.
chloranil	2,3,5,6-tetrachloro-1,4-benzoquinone.
chlordimeform; Fundal	*N'*-(4-chloro-*o*-tolyl)-*N,N*-dimethylformamidine.
chlorpyrifos	*O,O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl) phosphorothioate.
CPV	cytoplasmic polyhedrosis virus.
DA	dodecyl acetate.
DDA = looplure	(*Z*)-7-dodecen-1-ol acetate.
DDT	1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane. (by common usage, an isomeric mixture of dichlorodiphenyltrichloroethane in which the *p,p'* isomer is not less than 60 to 70 percent).
DDT and toxaphene	See DDT and toxaphene.
diazinon	*O,O*-diethyl *O*-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate.
dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-*endo-exo*-5,8-dimethanonaphthalene, 85 percent minimum.
dimethoate	*O,O*-dimethyl *S*-(*N*-methylcarbamoylmethyl) phosphorodithioate.
endosulfan	6,7,8,9,10,10-hexachloro-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin 3-oxide.
endosulfan + parathion	See endosulfan and parathion.
endosulfan + pyrenone	See endosulfan and pyrenone.
endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-*endo-endo*-5,8-dimethanonaphthalene.
EPN	*O*-ethyl *O*-(*p*-nitrophenyl) phenylphosphonothioate.
ether	dimethyl ether.
ethion	*O,O,O',O'*,-tetraethyl *S,S'*-methylene bis(phosphorodithioate).
ethyl parathion	See parathion.
fenvalerate	cyano(3-phenoxyphenyl)methyl 4-chloro-α-(1-methylethyl)benzeneacetate.
fuelgen	fuelgen.
heptachlor	1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene.
inhibitory alcohol	(*Z*)-7-dodecen-1-ol.
leptophos	*O*-(4-bromo-2,5-dichlorophenyl) *O*-methyl phenylphosphonothioate.
lipid	Fatlike compound.

malathion	*O,O*-dimethyl phosphorodithioate of diethyl mercaptosuccinate.
methamidophos	*O,S*-dimethyl phosphoramidothioate.
methidathion	*O,O*-dimethyl phosphorodithioate *S*-ester with 4-(mercaptomethyl)-2-methoxy-Δ^2-1,3,4-thiadiazolin-5-one.
methomyl	*S*-methyl *N*-[(methylcarbamoyl)oxy]thioacetimidate.
methyl parathion	*O,O*-dimethyl *O*-(*p*-nitrophenyl) phosphorothioate.
mevinphos	methyl (*E*)-3-hydroxycrotonate dimethyl phosphate.
mexacarbate	4-(dimethylamino)-3,5-xylyl methylcarbamate.
microperoxisomes	microperoxisomes.
monocrotophos	dimethyl phosphate ester with (*E*)-3-hydroxy-*N*-methylcrotonamide.
naled	1,2-dibromo-2,2-dichloroethyl dimethyl phosphate.
NPV	nuclear polyhedrosis virus.
Ortho 9006	See methamidophos.
parathion	*O,O*-diethyl *O*-(*p*-nitrophenyl) phosphorothioate.
penethyl alcohol	2-phenylethanol.
pehnylacetaldehyde	phenylacetaldehyde.
Pyrenone	6 percent pyrethrins + piperonyl butoxide, α-[2-(2-butoxy)ethoxy]-4,5-(methylenedioxy)-2-propyltoluene.
pyrophyllite	aluminum silicate monohydrate.
RNA	ribonucleic acid.
rhodamine B	*N*-[9-(2-carboxyphenyl)-6-(diethylamino)-3*H*-xanthen-3-ylidene] -*N*-ethylethanaminium chloride.
Rohm and Haas Q-137	1,1 dichloro-2,2-bis(*p*-ethylphenyl)ethane.
rotenone	1,2,12,12a-tetrahydro-2-isopropenyl-8,9-dimethoxyl[1]benzopyrano [3,4-*b*]furo[2,3-*h*][1]benzopyran-6(6a*H*)-one.
rubidium	Rb.
sinigrin	1-thio-β-*D*-glucopyranose 1-[*N*-(sulfooxy-3-butenimidate] monopotassium salt.
sodium fluorscein	uranine yellow.
stirofos	2-chloro-1-(2,4,5-trichlorophenyl)vinyl dimethyl phosphate.
sucrose	β-*D*-fructofuranosyl-α-*D*-glucopyranoside.
tepa	tris(1-aziridinyl)phosphine oxide.
tepp	tetraethyl pyrophosphate.
toxaphene	chlorinated camphene containing 67 to 69 percent chlorine.
trichlorfon	dimethyl (2,2,2-trichloro-1-hydroxyethyl)phosphonate.

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