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SELECTED LITERATURE OF SOYBEAN ENTOMOLOGY

Edited by

George L. Godfrey

University of Illinois at Urbana-Champaign
and
Illinois Natural History Survey

University of Illinois College of Agriculture

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FOREWORD

The International Soybean Program INTSOY is a research, education, and development program, the general mission being to encourage use of soybeans to alleviate protein-calorie deficiencies and their associated problems. The nutritional focus is on protein, the soybean being high in both protein quantity and quality. The geographical emphasis is on the tropics and subtropics; it is there that protein deficiencies loom largest. Efficiency in getting food nutrients to low-income consumers calls for special attention to direct human consumption.

As with any crop, there are many constraints to achievement of widespread use of soybeans, especially among producers and consumers with limited resources. INTSOY is concerned with all phases of soybeans from planting the seed to consumption--production, plant protection, harvesting, marketing, processing, and use. Protection of the soybean plant and seed from pests under tropical and subtropical environments is more difficult than in temperate zones. One of INTSOY's objectives is to aid the dissemination of information among scientists and other soybean workers. We are pleased to make this publication on soybean entomology available as the first in an INTSOY publication series.

William N. Thompson
Director, INTSOY

PREFACE

This publication is a contribution of the Illinois Soybean Entomology Team with support from the International Soybean Program (INTSOY), Office of International Agricultural Programs, College of Agriculture, University of Illinois, and the Illinois Natural History Survey. The Illinois Soybean Entomology Team actively participates in domestic and international soybean research and service programs. One function of the team is to assist soybean researchers in obtaining pertinent literature. This is being accomplished by publishing bibliographies on soybean insects; by providing specialized bibliographies in computer print-out format to national and international researchers who request them for specific topics; and by sending out requested papers to researchers who do not have them at their own institutions. The Team's collection of soybean literature currently contains approximately 9,000 articles and references.

Members of the Illinois Soybean Entomology Team frequently receive requests for reprints or copies of specific papers. These requests are processed very simply and present no problems. However, there also are many requests from individuals who ask for general information on soybean insects, but do not specify what papers they need. In many instances, the general inquiries come from researchers recently assigned to a soybean research project at institutions or research stations with limited library facilities. These researchers desire a quick review of the literature so they can broaden their knowledge of key entomological problems of soybeans and begin developing their experimental programs. Thus, a critical need for rapidly placing pertinent literature into the hands of these individuals is apparent.

Twenty-three papers appear in this publication, drawn from the areas of arthropod surveys and pest management, the bionomics of major species, the effects of arthropod feeding and plant resistance, and insecticide residues. This compilation represents some of the key papers on soybean arthropods and related subjects to provide a wide introduction to the literature of the expanding area of soybean entomology. The chosen writings obviously represent only a small proportion of those available as resource limitations invariably impose constraints. The Illinois Soybean Entomology Team does not endorse all of the chemical control programs for major pests that are discussed in these articles. Readers will realize that several of the chemical control measures are no longer practiced and that in some areas they are forbidden by laws and regulations.

Pest control is changing and becoming more exacting each year. The necessity for efficient insect pest-management programs for soybeans is apparent to offset possible protein and energy loss due to arthropod pests, and for environmental protection. Added competency in the basic and applied research areas of soybean entomology is needed to develop ecologically sound control programs. The availability of soybean research literature to all interested researchers is extremely important.

The greatest of appreciation is due and expressed to the authors of the papers included in this publication, and to the respective publishers, societies, and the directors of state agricultural experiment stations who graciously permitted their publications to be shared. Several members of the Illinois Soybean Entomology Team have assisted with this publication. Dr. Marcos Kogan, Team Leader, first proposed the project and offered time and

suggestions during its initial phases. Dr. William G. Ruesink and Mr. John K. Bouseman contributed by appraising the initial selection of prospective papers. The support and constructive criticisms of Dr. William H. Luckmann were helpful and appreciated. Many of the articles were drawn from the files of entomology library researcher, Ms. Martha P. Nichols. The cover was designed by Mr. Lloyd LeMere and the cover photography provided by Mr. Wilmer D. Zehr of the Illinois Natural History Survey.

Urbana, Illinois
April, 1974

George L. Godfrey
Editor

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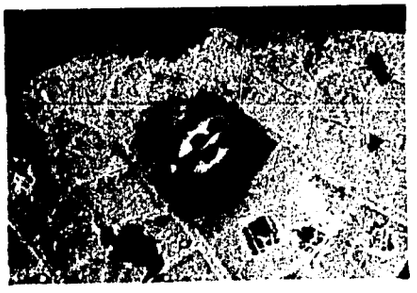
Part 1

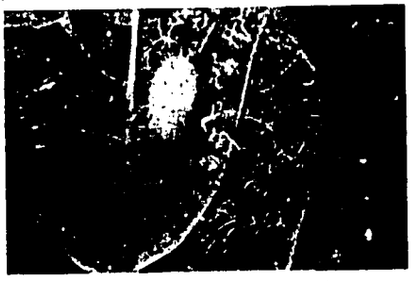
ARTHROPOD SURVEYS AND PEST MANAGEMENT

COMMON SOYBEAN INSECTS

For safe and effective use of insecticides, always identify the problem correctly.

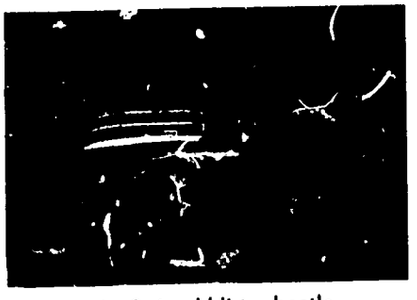


1. Bean leaf beetle

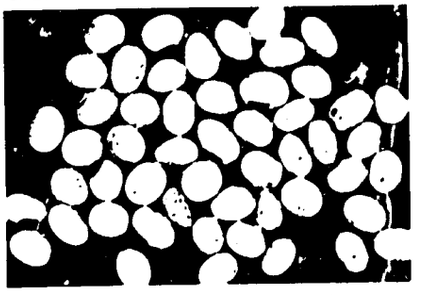


2. Mexican bean beetle and larva

3. Japanese beetle



4. Striped blister beetle



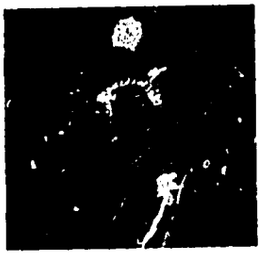
5. Green stink bug and damaged seeds

6. Two-spotted mite (not an insect)

7. Thrips (greatly enlarged)

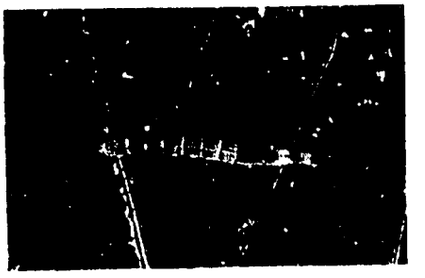
8. Grape colaspis larva

9. Seed maggot



10. White grub

11. Grasshopper



12. Green clover worm

13. Cabbage looper

14. Garden webworm

15. Corn earworm

Prepared by Extension Entomologists of the North Central States in cooperation with the Federal Extension Service, U.S. Department of Agriculture

UNIVERSITY OF ILLINOIS COLLEGE OF AGRICULTURE
COOPERATIVE EXTENSION SERVICE
and ILLINOIS NATURAL HISTORY SURVEY

NHE-122
APRIL, 1968
URBANA, ILLINOIS

COMMON SOYBEAN INSECTS

1. Bean leaf beetle adults winter in soil debris near bean fields of the preceding year. In spring, they feed on seedlings before laying eggs at the base of soybean plants. The slender, white larvae feed on nodules roots, and stems just below ground. Adults emerge in late July and August, eat irregular holes in leaves, and also feed on blossoms and pods. The effect of leaf feeding is greatest when it occurs between bloom and full pod growth. Blossom feeding may reduce pod set, and pod feeding may reduce yields seriously.

2. Mexican bean beetles are most injurious to snap beans and only occasionally to soybeans. Usually damage is restricted to small sections of a soybean field near a vegetable garden. Adults winter in debris on the ground in fence rows, roadsides, and wooded areas. They migrate to snap beans in May and June. Eggs are laid on the undersides of leaves and the larvae feed there also. Injury occurs in July and August.

3. The Japanese beetle is present only in certain localized areas in Illinois. Adults feed on soybeans, corn silks, wild grapes, smartweeds, and the foliage and fruits of trees, shrubs, and flowers. They have a one-year cycle and spend about ten months as a grub in the soil feeding on the roots of grasses and cereal crops. They winter as partly grown grubs and emerge as adults in late June and July.

4. Striped blister beetle adults and other blister beetles feed on the blossoms and leaves of soybeans and are of minor importance. The larvae feed in grasshopper egg pods in the soil and are most numerous the year after a heavy grasshopper population. There is probably one generation a year.

5. Stink bugs suck sap from soybeans. They may innoculate pods with yeast spot disease organisms causing shriveling of the bean seed. When undeveloped seeds are attacked, pods frequently are aborted. Studies indicate an average of one stink bug per foot of row reduces yields 10 percent. A few stink bugs are always present, but large numbers occur occasionally. Some stink bugs prey on insects and are beneficial.

6. Two-spotted spider mites suck the juices from the undersides of leaves that turn yellow, then brown, and drop. Mites appear as tiny moving specks that produce a fine webbing in leaves. Large numbers of mites can develop within a short time under dry conditions in July and August.

7. The yellow and black thrips rasp the leaf tissue, leaving long white streaks. They also suck the sap from the plants. Severely damaged leaves turn silvery or gray. Some feeding occurs in every soybean field during June, July, and August, but only occasionally is control required. Dry weather enhances injury by thrips.

8. Grape colaspis larvae feed on roots of seedlings. Leaves of effected plants turn yellow and some plants may be killed. Soybeans following soybeans or following a plow-down of clovers are most likely to be attacked. The insect winters as a small larva in the soil. It feeds on roots in spring and is full grown by about mid-June (Central Illinois) when it pupates and changes to a small, tan, oval adult.

9. Seed maggots tunnel into germinating seeds, thus reducing stands. Damage is usually on individual scattered plants, but occasionally stands are drastically reduced. Damage is worst during cool, wet springs when germination is slow. Soybeans planted in high organic matter soil after grass, clover, or alfalfa are more likely to be injured.

10. White grubs, young of the common May or June beetles, have a life cycle of two to four years — most commonly three years. Eggs are deposited in grass sods, but one species oviposits in soybean fields. A corn-soybean rotation is quite attractive to these beetles for egg laying. The tiny grubs feed until the first cold spell in fall when they tunnel downward. Then from the next May until October they feed heavily on roots. They again winter deep in the soil. The following May, the large, nearly mature grubs return to the surface and feed heavily. They pupate in an earthen cell in early June, and change to adults in about 4 weeks. The beetles emerge from the soil the following spring.

11. Grasshoppers hatch in fields, roadsides, ditch banks, and fence rows in June and early July. Hot, dry conditions favor survival, but heavy rains kill them. Hoppers stay in these areas until food becomes scarce, then migrate to soybeans and corn (usually late July and August). Ordinarily, damage is confined to border rows, but severe infestations may affect the entire field.

12. Green cloverworm moths lay eggs on undersides of leaves of soybeans, garden beans, clovers, alfalfa, and some small fruits in spring. The small worms eat large irregular holes in leaves, but not the pods, become fully grown in about 4 weeks, and pupate in the soil. Damage occurs in August when some fields may be 30 to 50 percent defoliated. Greatest damage occurs from leaf feeding between bloom and full pod development, so late beans suffer most from attack. The worm in the picture has two white spots behind its head — the eggs of a fly that helps keep populations low.

13. Cabbage loopers, minor pests in Illinois, have several generations each year. The dark brown moths lay pale yellow to white eggs on the leaves at night. Young loopers appear in about 10 days and are fully grown in 2 to 4 weeks.

14. Alfalfa and garden webworms feed on bean foliage. Injury in July and August to beans may be most serious. Severe infestations have destroyed entire fields of small, late beans. There is no evidence webworms attack pods.

15. Corn earworms, also called tomato fruitworms, tobacco budworms, and cotton bollworms, are minor soybean pests in Illinois. Adult moths fly into Illinois during May and June, and lay eggs on fresh corn silks and tomatoes. They are general feeders, attacking cultivated crops and weeds.

CONTROL RECOMMENDATIONS. These illustrations will help you identify some common soybean insects. The appearance, damage, and habits of insects do not change, but controls do. Illinois Extension Circular 899 gives suggestions on insecticide use and is revised annually. These fact sheets give more detailed life history and controls for these insects:

NHE-67	Bean Leaf Beetle	NHE-75	Green Cloverworms
NHE-32	Japanese Beetle	NHE-42	Webworms
NHE-72	Blister Beetles	NHE-33	Corn Earworms
NHE-25	Grape Colaspis	NHE-45	Cabbage Worms
NHE-23	White Grubs	NHE-58	Red Spider Mites
NHE-74	Grasshoppers	NHE-39	Thrips on Corn

You may obtain single copies of these publications from your county extension adviser or from the Agricultural Publications Office, University of Illinois, Urbana, Illinois 61801.

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6M—3-72—21095

EFFECT OF VARIOUS FACTORS ON SURVEYS OF PREDACEOUS INSECTS IN SOYBEANS[1]

B. A. DUMAS, W. P. BOYER, AND W. H. WHITCOMB[2]

It is important to know under what circumstances the present methods of predator sampling are reliable and what factors must be considered when estimating populations. Predator counts are being considered more and more when recommendations are made for insect control. Quaintance and Brues (1905) pointed out the importance of predaceous insects in bollworm control. Lincoln and Leigh (1957) made further reference to the role of predators in cotton insect control. The need for a control program in which chemical and biological control would complement one another was discussed by Stern and van den Bosch (1959). It was also pointed out by Stern *et al.* (1959) that biological control and chemical control are not necessarily alternative methods; in many cases they may be complementary and, with adequate understanding, can be made to augment each other.

Information dealing with the specific effect of various factors on sampling of any insect population is scarce, since comparatively few papers based on field research have been published. Lockwood (1924), in his study on the abundance of grasshoppers, reported that sweepings made at different times of day under varying climatic conditions in different crops, together with the varying speed of the sweepers, upset the uniformity of results. A reference was made by Kennedy (1927)

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[1] Published with the approval of the director of the Arkansas Agricultural Experiment Station. Accepted for publication September 5, 1963.

[2] Research Assistant, Survey Entomologist, and Entomologist, respectively, Department of Entomology, University of Arkansas.

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to an entomological clock, according to which social species of *Vespa, Polistes, Bremus* (*Bombus*), and *Apis* work earlier and later in the day when temperatures are lower than do the nonsocial species, which are largely active only during the heat of the day.

The diurnal variations in the vernal invertebrate population of a central Oklahoma prairie were studied by Davidson and Shackleford (1929). They found population peaks at midnight and noon.

Delong (1932) pointed out that many factors may influence the number of insects taken in population samples. One of these factors, temperature, causes the insect to change its position on the plant. Other factors are: wind, position of the sun, plant size, condition of the plant, and humidity.

Carpenter and Ford (1936) found that type of vegetation, personal error, and weather conditions affect the number taken in sweep-net samples. Personal error varies from day to day. They further found that dispersion in the vegetation varies under different weather conditions. In making counts of the ant, *Prenolepis imparis* Say, Talbot (1943) found that its activity varied with the temperature. Romney (1945) showed that catches of the beet leafhopper, *Circulifer tenellus* (Baker), by the sweep-net method were affected by a number of factors, of which temperature and wind velocity seemed to be most important. The effect of temperature as it changed with time of day resulted in sweep-net catches that varied as much as 200%. Davidson and Andrewartha (1948) reported on the effects of rainfall, evaporation, and atmospheric temperature on fluctuations in the size of a natural population of *Thrips imaginis* (Thysanoptera).

In studies of the beetle *Diabrotica undecimpunctata* Mannerheim, Smith and Michelbacher (1949) found that the beetles were abundant in trees having the most dense foliage when temperatures were high. During the hottest part of the day, the beetles moved to the shady side of the trees. Roeder (1953) reported that "the activities of most diurnal insects typically undergo a reduction or a cessation during the hottest part of the day." Hughes (1955) observed striking differences in the sweep catches of a species of chloropid fly when taken at different times of day.

Poinar and Gyrisco (1960) studied the effect of light, temperature, and relative humidity on the diel behavior of adult alfalfa weevils, *Hypera postica* (Gyll.).

Fewkes (1961) discovered that larger sweep-net catches were obtained by night than by day for nymphs and adults of *Nabis flavomarginatus* Scholtz, *N. rugosus* L., *N. ferus* L., *Dolichonabis limbatus* Dahlbom, and *Staelia major* Costa.

Sweep and direct plant counts of several predators taken in the morning and evening differed significantly from those taken at midday, as reported by Dumas, Boyer, and Whitcomb (1962).

Methods

In order to reduce fluctuations from migration to a minimum, an isolated soybean field, largely surrounded by trees, was chosen for this study. It was 30 acres in size and approximately one-half mile from other fields of row crops. The soybeans were planted on July 7, 1962, and the first sampling was made on July 27.

Two methods of estimating predator populations were used, the sweep-net method and plant examinations. In the first method, 25 sweeps were taken at each of four locations, using a California type, 15-inch net. In the second method, all of the aboveground portions of 50 plants were examined. To prevent undue variation in the environmental factors during the time interval, 25 plants were examined, then the 100 sweeps were made, and finally 25 more plants were examined. Counts were begun at approximately 7 AM, 1 PM, and 6 PM on Monday and Friday of each week from July 27 through September 14, 1962. For plant examinations, plants were selected in groups of five throughout the field. The same plants were examined for three consecutive weeks and then changed because of reduced growth resulting from frequent handling. None of the insects, spiders, or eggs were removed.

Counts were made of those species or groups of arthropods which could be accurately determined in the field. In some cases, only the genus or family could be recorded because of problems in field determination.

Just prior to sampling, the following eight factors were recorded: date, plant height, humidity, soil temperature, air temperature, time of day, cloud cover, and wind velocity. Temperature records in centigrade were taken from a standard mercury chemical thermometer. Relative humidity was measured with a psychrometer utilizing a battery-powered fan. Wind velocities were measured in miles per hour with a wind meter using the lift of the air on a plastic ball. A copper-capped mercury soil thermometer was used to obtain soil temperatures in centigrade. Cloud cover was recorded as tenths of sky obscured by clouds, according to the system adopted by the U. S. Weather Bureau and described by Donn (1951).

The survey counts of insects and spiders by the two sampling methods were subjected to multiple regression analyses to determine which of the factors observed were most closely correlated with the predator counts.

Results

Analyses were made on the counts of 20 predators taken by the sweep method. Table 1 shows the net regression of numbers of predators per 100 sweeps on environmental factors. Five of these predators showed a significant increase with an increase in value of the environmental factors. Three predators decreased significantly as one or more of the environmental factors increased.

TABLE 1. Net regression of numbers of predators per 100 sweeps on the recorded environmental factors. Little Rock, Arkansas, 1962

Predators	Plant height	Humidity	Soil temp.	Air temp.	Time of day	Cloud cover	Wind velocity
Coleoptera							
Coleomegilla maculata (De Geer)	−0.93	−0.29	−0.14	−0.03	−0.14	−0.07	−0.06
Coccinella novemnotata Herbst	+0.54	+0.37	−0.08	+0.34	+0.03	+0.23	+0.25
Hippodamia convergens Guerin	−0.60	−0.34	−0.52	−0.15	+0.25	−0.04	+0.10
Other coccinellid adults	−0.19	−0.18	+0.40	−0.34	+0.07	+0.10	+0.02
Coccinellid larvae	−1.74**	+0.09	+0.48	−0.09	−0.24	−0.13	+0.06
Lebia analis Dej.	+0.42	+0.80**	+0.08	+0.47	+0.07	+0.21	−0.22
Collops spp.	+0.13	−0.01	+0.20	−0.11	−0.43*	−0.04	−0.08
Hemiptera							
Nabis spp.	−0.07	+0.18	+0.34	−0.10	+0.20	+0.11	+0.19
Geocoris punctipes (Say) and *Geocoris uliginosus* (Say) adults	+1.42**	+0.26	−0.04	+0.19	+0.29	+0.19	−0.04
Geocoris spp. nymphs	−0.64	+0.15	−0.21	+0.23	+0.13	+0.14	−0.02
Orius insidiosus (Say) adults	+2.13*	−0.22	+0.29	−0.86**	+0.39**	−0.21*	−0.07
Orius insidiosus nymphs	+0.57	+0.20	+0.33	−0.31	−0.26	+0.04	−0.05
Reduviids	−0.74	+0.16	+0.17	+0.18	+0.08	+0.05	−0.24
Neuroptera							
Chrysopa adults	−0.58	−0.51	−0.42	0.00	−0.12	+0.07	+0.08
Chrysopa larvae	−0.61	+0.15	+0.07	−0.15	−0.03	−0.12	−0.20
Diptera							
Syrphids	+1.16*	+0.51	+0.33	+0.04	−0.23	−0.15	+0.18
Araneida							
Oxyopes salticus Hentz	+0.80	+0.25	−0.06	+0.30	+0.29	+0.27	−0.12
Araneus spp. and *Neoscona* spp.	+0.09	+0.13	+0.02	−0.22	+0.34	+0.04	−0.05
Misumena spp., *Misumenops* spp., and *Misumenoides* spp.	+0.50	+0.05	−0.12	0.00	+0.17	−0.06	−0.09
Phidippus spp.	+0.32	+0.13	−0.15	+0.15	+0.16	+0.38*	−0.03

* Sig. at 5% level.
** Sig. at 1% level.

TABLE 2. Net regression of numbers of predators per 100 plants examined on the recorded environmental factors. Little Rock, Arkansas, 1962

Predators	Plant height	Humidity	Soil temp.	Air temp.	Time of day	Cloud cover	Wind velocity
Coleoptera							
Coleomegilla maculata (De Geer)	−0.40	−0.07	−0.36	−0.03	+0.05	−0.23	−0.29
Coccinella novemnotata Herbst	−0.03	−0.16	−0.21	−0.09	+0.23	−0.20	−0.09
Hemiptera							
Nabis spp.	−0.47	+0.07	+0.54*	+0.28	−0.31	−0.43**	+0.10
Geocoris punctipes (Say) and *Geocoris uliginosus* (Say) adults	+0.45	−0.39	−0.55	+0.19	−0.11	+0.08	−0.07
Geocoris spp. nymphs	−0.20	−0.37	−0.65**	−0.15	+0.23	+0.23	−0.03
Orius insidiosus (Say) adults	+2.10**	+0.41	−0.01	+0.14	+0.02	−0.20	−0.04
Orius insidiosus nymphs	+0.02	+0.36	−0.56	+0.56	+0.04	+0.12	−0.18
Neuroptera							
Chrysopa adults	−0.81	−0.49	0.00	−0.55	−0.06	−0.29	−0.23
Chrysopa larvae	−0.05	−0.25	+0.45	−0.27	−0.14	−0.10	+0.07
Diptera							
Syrphids	+0.09	+0.30	+0.26	+0.12	−0.19	+0.22	+0.02
Araneida							
Oxyopes salticus Hentz	−0.07	−0.30	−0.28	+0.15	−0.26	+0.07	−0.08
Araneus spp. and *Neoscona* spp.	−0.54	−0.36	−0.54*	−0.01	+0.10	−0.09	−0.04
Misumena spp., *Misumenops* spp., and *Misumenoides* spp.	+0.40	+0.14	−0.01	+0.05	+0.06	+0.03	−0.06
Phidippus spp.	+0.26	−0.05	+0.21	+0.02	−0.27	+0.05	−0.14

* Sig. at 5% level.
** Sig. at 1% level.

Analyses were made on the counts of 14 predators found by plant examination. Table 2 shows the net regression of numbers of predators per 100 plants examined on environmental factors. Two of the predators showed a significant increase when one or more of the environmental factors increased. Three predators decreased significantly as one or more of the environmental factors increased.

Use of the multiple regression analyses of the predator counts with the factors recorded permits an estimate of the total variation in insect numbers accounted for by variations in these factors. The size of R^2, the multiple regression coefficient, reflects the cumulative correlations of all factors considered simultaneously. The R^2 values in the analyses of the counts ranged from .16 to .78 (Table 3). An R^2 value of 1.00 would indicate a complete accounting for variations in the numbers collected. It is a mistake to conclude that numbers of all species oscillate as a result of meteorological variation, as emphasized by Smith (1935). R^2 values in Table 3 indicate the degree of correlation between the differences in counts and seven environmental factors measured at Little Rock, Arkansas, in 1962.

Results can be best understood by examining counts in terms of individual predators or groups of closely related predators. Some of the more striking results of this study are presented in this form below.

Orius insidiosus (Say). Both sampling methods indicated that the numbers of the insidious flower bug, *O. insidiosus*, increased with plant height until the final two weeks of sampling, when there was a sharp drop in numbers taken. Three environmental factors affecting only the sweep-net counts of the insidious flower bug were air tempera-

TABLE 3. Total effect from all measured factors upon population variability, as indicated by R^2 values. Little Rock, Arkansas, 1962[a, b]

Predators	Sweep method	Plant examination
Coleoptera		
Coccinellid larvae	0.44	
Lebia analis Dej.	0.28	
Collops spp.	0.16	
Hemiptera		
Nabis spp.		0.48
Geocoris punctipes (Say) and *Geocoris uliginosus* (Say) adults	0.39	
Geocoris spp. nymphs	0.58	0.58
Orius insidiosus (Say)	0.78	0.43
Diptera		
Syrphids	0.33	
Araneida		
Araneus spp. and *Neoscona* spp.		0.50
Phidippus spp.	0.28	

[a] An R^2 value of 1.00 would indicate that the factors recorded accounted fo all the variability in the numbers collected by the two sampling methods.

[b] Only those R^2 values that are significant at or beyond the 5% level are shown

ture, time of day, and cloud cover. The 6 PM counts were larger than those at the other times of day. The size of the catches of the insidious flower bug decreased as the air temperature and cloud cover increased.

GEOCORIS PUNCTIPES (Say) AND *GEOCORIS ULIGINOSUS* (Say). Counts of the big-eyed bug adults, *G. punctipes* and *G. uliginosus*, became higher as the plant height increased, when the sweep method was used. Results of the plant examination method were not significantly correlated with any of the factors. The counts of nymphs decreased as the soil temperature increased, when the plant examination method was used.

NABIS SPECIES. More damsel bugs, *N. ferus* (L.), *N. roseipennis* Reuter, *N. alternatus* (Parsh), *N. capsiformis* Germar, and *N. deceptivus* Harris, were taken in plant examinations as the soil temperature increased. Fewer damsel bugs were taken as the cloud cover increased. None of these factors affected counts taken by the sweep method.

LEBIA ANALIS DEJ. Counts of the ground beetle, *L. analis*, taken by the sweep method increased as the relative humidity increased. Insufficient numbers were collected by the plant examination method to make an analysis of the results.

COLLOPS QUADRIMACULATUS Fab. AND *COLLOPS BALTEATUS* LeConte. The counts of *C. quadrimaculatus* and *C. balteatus* collected by the sweep-net method decreased as the day advanced. Analyses of the counts by plant examinations were not made because of insufficient numbers of the *Collops* species counted by this method.

COCCINELLIDS. The numbers of coccinellid adults taken by the two methods were not significantly correlated with any of the recorded environmental factors, but the number of lady beetle larvae taken by the sweep-net method decreased as the plant height increased.

SYRPHIDS. The number of syrphid fly adults taken by the two methods increased as the plant height increased but showed no significant correlation with any of the other environmental factors.

PHIDIPPUS SPECIES. The number of jumping spiders, *Phidippus* spp., taken by the sweep-net method increased as the cloud cover increased. None of the factors recorded in this study had significant correlation with counts obtained by plant examination.

ARANEUS SPECIES AND *NEOSCONA* SPECIES. Counts of orb weaver spiders, *Araneus* spp., *Neoscona arabesca* (Walck.), and *Neoscona benjamina* (Walck.), decreased as the soil temperature increased, when the plant examination method was used.

DISCUSSION

This study showed comparatively few factors affecting counts made by either method. Still further work will be necessary to clarify the significance of these results. The most important of the recorded environmental factors affecting the accuracy of techniques used in determining populations of predaceous insects and spiders was plant height.

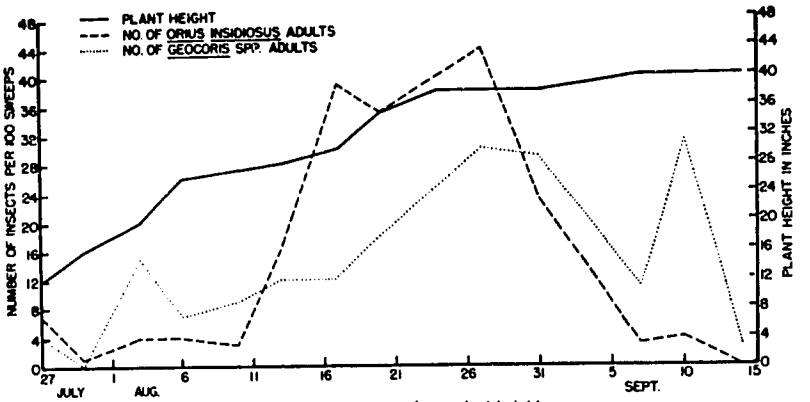

FIG. 1. Comparison of two predator counts and soybean plant height.

The ultimate factor behind this correlation may not be plant height but some other factor coincident with plant height or other correlated factor. Fig. 1 shows the comparison of two predator counts by the sweep-net method with plant height. A decrease in insidious flower bug counts is shown at the end of the season. With the exception of lady beetle larvae, more predators were found on taller plants. This was especially true when plants were swept but was also true for some plant examination counts. A good example of this was the insidious flower bug. The numbers taken were greater in the taller plants, as determined by both sampling methods. The counts of big-eyed bugs, lady beetle larvae, and syrphid fly adults were significantly correlated with plant height.

The factors next in importance were soil temperature and cloud cover. Soil temperature was significantly correlated with the counts taken by the plant examination method and not with the counts taken by sweep-net. In most cases, an increase in soil temperature resulted in a decrease in counts. The predator counts that showed significant correlation with soil temperature were those of big-eyed bug nymphs, damsel bugs, and orb weaver spiders. Cloud cover was significantly correlated with counts of predators taken by both sampling methods. The counts were generally lower when the cloud cover increased. The only predator counts that increased with increasing cloud cover were those of the jumping spiders. Predator counts that decreased with increasing cloud cover were those of the insidious flower bug and the damsel bugs.

The next most important factor was the time of day. In this study, time of day was significantly correlated with the counts taken by the sweep-net method but not with counts taken by the plant examination method. Time of day was correlated with counts of the insidious flower bug and of *C. quadrimaculatus* and *C. balteatus*; there were more in-

sidious flower bugs and fewer *C. quadrimaculatus* and *C. balteatus* in the evening than at other times of day. In a similar study in 1961, Dumas, Boyer, and Whitcomb (1962) found that there were significant differences for the time of day for three predators when using the sweep-net method and for two predators when using plant examination. Investigations in 1962 indicated that with larger populations of *L. analis*, time of day might be significant.

Air temperature and relative humidity were the factors of next importance. Both air temperature and humidity were significantly correlated with the counts taken by the sweep-net method and not with the counts by plant examination. The only predator whose counts were significantly correlated with the air temperature was the insidious flower bug. *L. analis* counts taken by the sweep-net method were the only predator counts significantly correlated with the relative humidity. Three times as many *L. analis* were taken at 7 AM than at 1 PM. The higher relative humidity at 7 AM than at 1 PM might explain the differences in counts at different times of day.

The numbers taken by the sweep-net method were significantly correlated with more factors than were the numbers taken by plant examination. This could largely be due to the fact that the insidious flower bug and other predators simply moved about on the plant when affected by these factors, either going down the plant or hiding under bracts, in blossoms, at the base of leaf petioles, or in other out-of-the-way places. Thus, they would not be as easily picked up by the sweep-net method but would be found in a careful, direct examination of the plants.

Summary

Populations of more than 20 species or groups of predaceous insects and spiders inhabiting soybeans were estimated by sweeping and by visual examination of plants. Samples were taken in the morning, at midday, and in the evening, twice a week. The following environmental factors were recorded: plant height, humidity, soil temperature, air temperature, time of day, cloud cover, and wind velocity. Some insect or spider counts increased or decreased with all of the factors, except wind velocity. Many of the factors were significantly correlated with the counts when using one sampling method but not when using the other. More factors had significant correlation with the sweep-net method than with plant examination.

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STAGE OF DEVELOPMENT DESCRIPTIONS FOR SOYBEANS, *GLYCINE MAX* (L.) MERRILL[1]

W. R. Fehr, C. E. Caviness, D. T. Burmood, and J. S. Pennington[2]

ABSTRACT

We developed stage of development descriptions which we believe apply to all soybean (*Glycine max* (L.) Merr.) genotypes grown in any environment. The descriptions apply to single plants or a community of plants and are precise and objective.

Vegetative and reproductive development are described separately. Vegetative stages are determined by counting the number of nodes on the main stem, beginning with the unifoliolate node, that have or have had a completely unrolled leaf. Reproductive stages R1 and R2 are based on flowering, R3 and R4 on pod development, R5 and R6 on seed development, and R7 and R8 on maturation.

The stage descriptions should enhance soybean research by standardizing descriptions of soybean plant development. The system also will be used by the soybean hail insurance industry for stage determination in adjustment of losses.

Additional index words: **Pod development, Seed development, Maturation.**

THE effect of experimental treatments and the magnitude of physiological processes often are closely related to the amount of soybean (*Glycine max* (L.) Merr.) plant development at the time a treatment is applied or measurement is taken (1, 3, 4, 5). Results from physiology and production studies may be compared more easily if research workers uniformly define the stages of plant development studied. The "4-leaf stage" is an inadequate description unless there is general agreement concerning which leaves are counted and the amount of leaf development required before a leaf is counted. Full bloom is not a precise definition of plant development, particularly if single plants are being described.

The principal application of stage of development descriptions in soybeans has been made by hail insurance companies in adjustment of hail losses. Accurate stage determination is essential in hail loss adjustment because amount of yield reduction is directly related to amount of plant development at the time of injury (1, 3, 4, 5). The stage of development system which has been used by the hail industry was developed by Kalton, Weber, and Eldredge (3). The system has been useful for describing soybean development of indeterminate cultivars grown commercially in northern states of the U.S.A., but is not satisfactory for determinate cultivars grown commercially in southern states.

Our objective was to design stage of development descriptions that would apply to all soybean genotypes in all environments. The new system will apply to single plants or a community of plants so that it would be useful in all types of soybean research. The stage descriptions are precise and objective so that variation among persons utilizing the system will be minimal.

Floral development in soybeans is initiated by environmental factors, principally day and night length (2). The environmental conditions that will initiate flowering vary with the genetic requirement of a soybean genotype. For example, 'Hark' (Group I) will flower on approximately July 10 and 'Hardee' (Group VIII) on October 10 when planted at Ames, Iowa on May 20. We have observed that flowering can begin on plants with as few as 4 nodes or as many as 18 nodes on the main stem. Our system has separate descriptions for vegetative and reproductive development to accommodate the many vegetative-reproductive development relationships that can occur in soybeans (Table 1). Vegetative stage numbers are preceded by V and reproductive stages by R. Plants can be described for both vegetative and reproductive development if desired.

Vegetative stages are determined by counting the number of nodes on the main stem, beginning with the unifoliolate noue, that have or have had a completely unrolled leaf. The unifoliolate node is the first node on the plant where true leaves develop. At this node,

Table 1. Stage of development descriptions for soybeans. For describing a community of plants, the stage designated should represent the average of plants studied. The stage descriptions apply to single plants directly. Development on the main stem only is considered and branches are ignored.

Vegetative stages

Vegetative stages are determined by counting the number of nodes on the main stem, beginning with the unifoliolate node, which have or have had a completely unrolled leaf. A leaf is considered completely unrolled when the leaf at the node immediately above it has unrolled sufficiently so the two edges of each leaflet are no longer touching. At the terminal node on the main stem, the leaf is considered completely unrolled when the leaflets are flat and similar in appearance to older leaves on the plant.

Stage no.	Description
V1	Completely unrolled leaf at the unifoliolate node.
V2	Completely unrolled leaf at the first node above the unifoliolate node.
V3	Three nodes on main stem beginning with the unifoliolate node.
V(N)	N nodes on the main stem beginning with the unifoliolate node.

Reproductive stages

Stage no.	Description
R1	One flower at any node.
R2	Flower at node immediately below the uppermost node with a completely unrolled leaf.
R3	Pod 0.5 cm (1/4 inch) long at one of the four uppermost nodes with a completely unrolled leaf.
R4	Pod 2 cm (3/4 inch) long at one of the four uppermost nodes with a completely unrolled leaf.
R5	Beans beginning to develop (can be felt when the pod is squeezed) at one of the four uppermost nodes with a completely unrolled leaf
R6	Pod containing full size green beans at one of the four uppermost nodes with a completely unrolled leaf.
R7	Pods yellowing; 50% of leaves yellow. Physiological maturity.
R8	95% of pods brown. Harvest maturity.

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two leaflets (normally unifoliolate) develop immediately opposite each other on the main stem. A leaf is considered completely unrolled when the leaf at the node immediately above it has unrolled sufficiently so the two edges of each leaflet are no longer touching. A plant with 5 nodes is in stage V5, and a plant with 18 nodes is in stage V18.

Establishment of reproductive stage descriptions was complicated by differences in flowering pattern between northern and southern grown soybeans. Indeterminate cultivars grown commercially in northern states begin flowering when about half the nodes on the main stem have developed, and flowering proceeds upward on the plant as additional nodes are produced. Therefore, flowering, pod, and seed development are more advanced on the bottom portion of the main stem than on the top. This difference in development between the top and bottom half of the plant was the basis of stage descriptions by Kalton et al. (3). For determinate cultivars grown commercially in southern states, flowering frequently does not occur until all of the nodes on the main stem have developed. In this situation, flower, pod, and seed development are similar throughout the plant. Our system defines reproductive stages based on development at the upper portion of the main stem only and is suitable for genotypes in all environments.

Our choice of the portion of the main stem to use for reproductive stage descriptions was influenced by our attempt to relate our system to the old system (3) used in the northern states. We wanted to be certain that past research at particular stages could be related to future studies at these same stages. We also wanted to maintain nearly equal time intervals between reproductive stages. We examined plants growing in Iowa which were at a given reproductive stage based on the old system, then described development at the top nodes. For example, plants at stage 5 under the old system (3) had a flower at the node immediately below the uppermost node with a completely unrolled leaf. This became our description for stage R2. We used the uppermost four nodes for R3 to R6 since pod development at one node may be behind adjacent nodes due to pod abortion. Therefore, use of four nodes provides a better opportunity for accurate plant description. The most advanced development at any of the four nodes is used for determining the stage of development of a plant.

An understanding of the relationship between the old stage system (3) and our new system would be useful in relating past and future research where stage of development is considered. For stage descriptions defined by Kalton et al. (3), the following relationship applies.

Old system (3)	*New System*
1	V2
2	V4
3	V6-V7
4	V8-V9,R1
5	V10-V11,R2
6	R3
7	R4
8	R5
9	R6
10	R7

An important feature of our system is illustrated by the use of both V and R stages for the old stages 4 and 5. Under our system, the vegetative and reproductive development processes are considered independently. When desired, a plant or community of plants can be defined both for vegetative and reproductive development.

The R1 and R2 stages occur approximately 6 days apart in northern grown soybeans, but may occur simultaneously in southern grown soybeans. The time intervals between other reproductive stages are similar in northern and southern grown soybeans. Stage R8 did not occur in the old system (3), but was added since this stage is frequently measured in soybean research.

Average development of a community of plants should be considered when either vegetative or reproductive stages are evaluated. The stage descriptions apply to single plants directly. Plants with development between two whole stage numbers may be scored by tenths of a stage (for example, R6.1, V5.8, etc.).

We have evaluated the stage descriptions in Iowa and Arkansas for two crop seasons and found them useful for all genotypes and environments studied. The Crop Insurance Research Bureau and the Hail Insurance Adjustment and Research Association have adopted the descriptions for use in adjusting hail losses.

ACKNOWLEDGMENTS

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Enemigos animales del cultivo de la soja

Por el Ing. Agr. HORACIO F. RIZZO

Los cultivos de soja cuentan con algunas adversidades entre las cuales las de origen animal (insectos, nematodes, aves y roedores), en varias oportunidades han incidido notoriamente en el desarrollo de tan importante leguminosa.

A pesar de lo consignado muy poco es lo que sobre el particular se ha publicado hasta el momento en nuestro país. Por ello, mediante esta colaboración se trata de brindar un panorama general acerca de los enemigos animales de la soja en la Argentina.

Para las especies de insectos consideradas como más perjudiciales se efectúa una breve descripción del estado de desarrollo en que ocasionan los perjuicios; además, en la mayoria de los casos se detallan la naturaleza e importancia de los daños y los métodos de lucha que pueden emplearse contra las especies en cuestión.

INSECTOS

Chinche verde (Nezara viridula (L.))

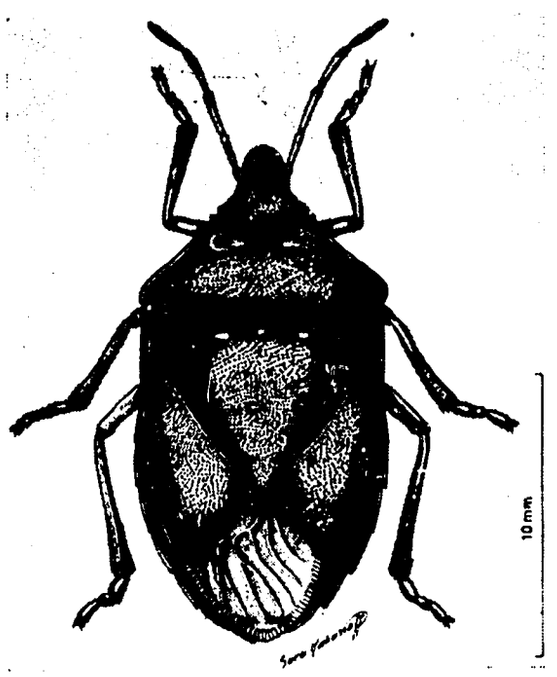

Fig. 1. Adulto de Nezara viridula. (De Rizzo).

Se trata de una especie ampliamente difundida por nuestro territorio y en la actualidad uno de los más temibles enemigos animales de esta leguminosa (Rizzo, 1968).

Los adultos tienen color general verde y miden alrededor de 15 mm de largo por unos 8 mm de ancho máximo. Las ninfas varían de tamaño y aún de coloración según el estadio en que se encuentran.

Al igual que los demás hemípteros fitófagos, estas chinches se alimentan con sustancias saviales, siendo común observarlas en gran cantidad y en todos sus estados de desarrollo en cultivos de soja, causándoles enormes perjuicios como ya lo mencionara Hayward (1942) para nuestro país.

La soja es invadida en cualquier momento de su desarrollo vegetativo, pero principalmente cuando se van formando las semillas. Además de succionar la savia inyectan sustancias tóxicas todo lo cual va debilitando las plantas, produciéndoles clorosis y hasta su muerte si son jóvenes y el ataque es intenso. Pero es durante la fructificación cuando la soja es más susceptible a la chinche verde, pues puede llegar a producir una completa paralización en la producción de semillas a la vez que resulta notoria la permanencia de hojas verdes en las plantas, fenómeno presumiblemente de orden fisiológico conocido como "retención foliar" y que es atribuible —entre otras causas— a la acción de la chinche.

Cuando menos, al hincar sus cerdas bucales en las vainas jóvenes, las chinches pueden impedir la formación o el normal desarrollo de las semillas y, en ocasiones, hasta provocar la caída de las vainas. Si las semillas alcanzan a desarrollarse, en el lugar donde estos insectos introdujeron sus cerdas quedan unas pequeñas cavidades y el tegumento en dichos lugares aparece arrugado; por su parte, en esos sitios las vainas muestran una pequeña arruga y, a veces, una mancha oscura.

El combate contra la chinche verde puede efectuarse empleando diversos insecticidas, en-

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tre ellos Paratión a razón de 250 gramos de sustancia activa por hectárea o Metil Demetón, 125 g de s.a./ha, o Carbaryl, unos 1.250 g de s.a./ha.

Pequeño barrenador de la caña de azúcar (Elasmopalpus lignosellus Zeller)

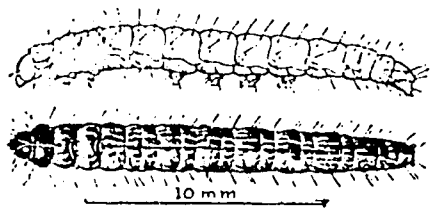

Fig. 2. Larva de **Elasmopalpus lignosellus**; vista lateral y dorsal. (De Luginbill y Ainslie).

Es una especie conocida en nuestro país por los daños que ha venido causando desde hace ya varios años en caña de azúcar, si bien con el tiempo pudo observarse que muchos otros vegetales eran atacados por este insecto. En algunas zonas de la Argentina los cultivos de soja sufren importantes perjuicios provocados por *E. lignosellus*. Los ataques de mayor intensidad generamlente se registran en lugares de suelos algo arenosos y durante épocas de sequía.

Cuando han alcanzado su total desarrollo las larvas miden alrededor de 17 mm de longitud. Presentan cabeza y escudo pronotal oscuros, el cuerpo de color verde algo azulado en el dorso, más claro lateralmente y más aun en la región ventral. Dorsalmente se observan líneas longitudinales castaño oscuras existiendo también líneas de ese color dispuestas en forma transversal.

Son larvas muy ágiles y activas que ya desde pequeñas comienzan a causar trastornos en la soja pues penetran en sus tallos a la altura del cuello o cerca del mismo. Dentro del tallo labran galerías que terminan por matar a las plantas si son jóvenes. Cuando se trata de vegetales de mayor desarrollo vegetativo, debido al ataque comienza a observarse clorosis y marchitez de los mismos. Mediante seda, partículas terrosas y otros detritos las larvas forman unos típicos tubos de pequeño tamaño generalmente sobre la tierra o muy superficialmente enterrados; dichos tubos por un extremo se comunican con la entrada a las galerías que las mismas oruguitas han practicado en los tallos y les sirven de albergue cuando no se alimentan o son perturbadas.

En nuestro país no existen referencias sobre métodos de lucha en cultivos de soja; hay publicaciones extranjeras que señalan como eficaces las pulverizaciones con Endrin sobre las líneas antes de la germinación, repitiendo el tratamiento 30 días después, pero dirigiendo en esta ocasión el líquido insecticida hacia el cuello de los vegetales.

Oruguita verde de la papa (Loxostege bifidalis (F.))

Este lepidóptero ha sido observado sobre alfalfa, algodonero, papa, verdolaga y otros varios vegetales cultivados y silvestres. Pastrana (1967) determinó como de esta especie adultos que provenían de "orugas que atacan los brotes terminales de la soja a los que destruyen casi totalmente". El material remitido al mencionado entomólogo provenía de la Estación Experimental Agropecuaria Cerrillos (provincia de Salta). Desde entonces dicha especie también ha sido localizada atacando soja en otras regiones de nuestro país.

Alcanzando su total desarrollo las larvas miden unos 22 mm de largo y tienen color verde claro con puntos negros de los que nacen pelos de similar coloración. Por lo general se encuentran en el interior de unos reparos o

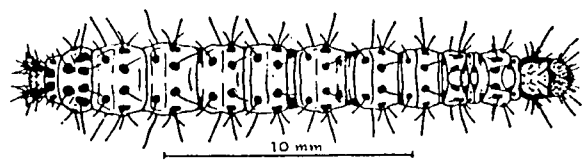

Fig. 3. Larva de **Loxostege bifidalis**. (De Sauer).

abrigos que forman al ir uniendo hojas y brotes con sus telas. Comen el parénquima de las hojas por lo cual las partes foliares afectadas se van secando y luego ocurre lo mismo con toda la hoja; también se alimentan con los brotes. Cuando se trata de vegetales jóvenes los daños adquieren mayor significación.

Si bien en nuestro país no hay mayor información sobre ensayos de lucha química, en el extranjero combaten una especie similar (*Loxostege similalis Guenée*) utilizando insecticidas tales como Paratión a razón de 300 a 500 gramos de sustancia activa por hectárea o Etil azinphos a la misma dosis.

Barrenador de los brotes Epinotia aporema (Walsingham))

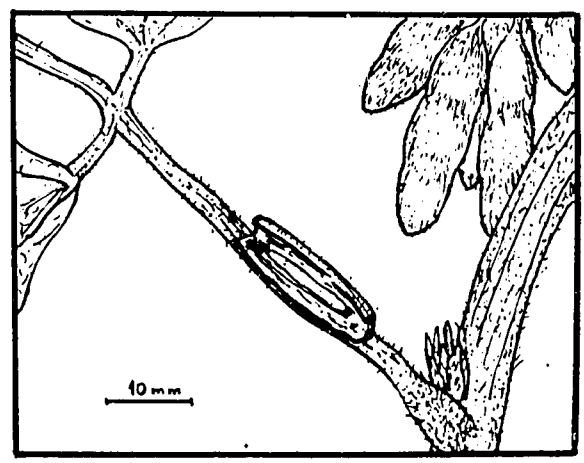

Fig. 4. Larva de **Epinotia aporema**. (Gentileza C. P. Fraga).

En determinadas zonas la soja puede resultar perjudicada por larvas de esta especie, pues

barrenan sus brotes que entonces terminan por secarse. A veces, de los brotes pasan al tallo taladrándolo algunos centímetros. Lo manifestado precedentemente incide sobre el normal desarrollo vegetativo de esta leguminosa y redunda, en definitiva, negativamente en los rendimientos.

Hay países donde se las cita como perjudiciales para las semillas de alfalfa, poroto, soja y trébol rosado y Hayward (1942) en la Argentina halló larvas atacando porotos haricot almacenados.

Las larvas completamente desarrolladas miden alrededor de 13 mm de largo y poseen coloración verde que se torna rosada antes del empupamiento.

Si bien no existe mayor información acerca de la lucha contra esta especie, hay quienes consideran efectivas las oportunas pulverizaciones con Endrin a razón de unos 250 cm³ de sustancia activa por hectárea.

Oruga de las leguminosas (Anticarsia gemmatalis (Hübner))

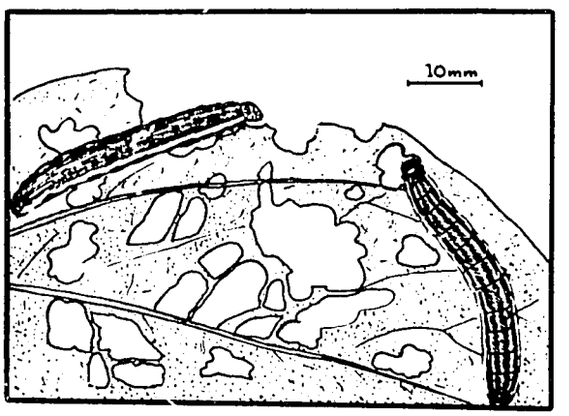

Fig. 5. Larva de **Anticarsia gemmatalis**. (Gentileza C. P. Fraga).

Hay zonas del norte argentino cultivadas con soja (por ejemplo en las provincias de Corrientes y de Misiones) donde estas orugas ocasionan daños considerables pues se alimentan con sus hojas y en ataques intensos pueden llegar a comer las vainas y hasta mordisquear los tallos.

Alcanzando su completo desarrollo las larvas miden unos 37 mm de largo; poseen coloración general verde con una franja longitudinal blanca a cada costado; además, dorsal y subdorsalmente presentan finas líneas longitudinales blancas. Próximas a empupar su tegumento se oscurece, se entierran a uno o dos centímetros de profundidad y tras preparar una camarita en la tierra se transforman en pupas, las que después de unos 9 a 11 días quedan convertidas en adultos.

Para combatir a estas orugas pueden emplearse distintos insecticidas, por ejemplo Endrin a razón de unos 250 cm³ de sustancia activa por hectárea o también Carbaryl o DDT o Paratión o una mezcla de estos dos últimos

Gusanos cortadores (Agrotis spp.).

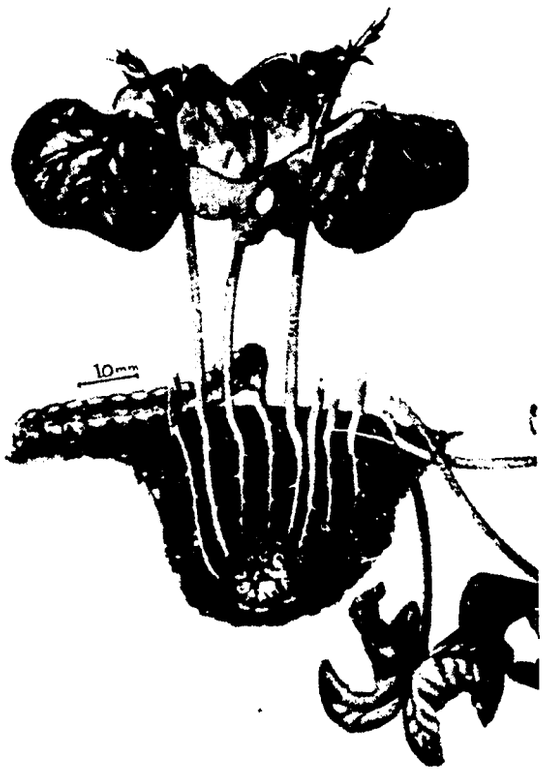

Fig. 6. Larvas de **Agrotis ipsilon**. (De Manual fitosanitario del algodón).

El alimento de estas larvas lo constituyen hojas y otros órganos tiernos de muy diversos vegetales; en algunas oportunidades hemos registrado ataques en cultivos de soja.

Cortan las plantas próximas a la superficie de la tierra o ligeramente por debajo de ella, ingiriendo por lo general sólo una pequeña parte de lo que destrozan. Durante el día están enterradas a poca profundidad, comúnmente al pie de las plantas, desarrollando actividad en la noche; si las invasiones son importantes pueden llegar a destruir elevada cantidad de vegetales en poco tiempo.

Una de las especies más difundida y perjudicial es el conocido gusano grasiento (*Agrotis ipsilon* (Hufnagel)) que totalmente desarrollado mide unos 45 mm de largo y presenta color gris brillante.

La lucha química puede llevarse a cabo con Endrin a razón de 300 cm³ de sustancia activa por hectárea o distribuyendo en el momento oportuno unos 40-50 kilogramos por hectárea de cebos tóxicos preparados con: afrecho 100 kg, melaza 5 kg, Paratión 500-700 g de s.a. (o Triclorfón 900 g de s.a.) y agua unos 50 a 70 litros.

Oruga militar tardía
(Spodoptera frugiperda (J. E. Smith))

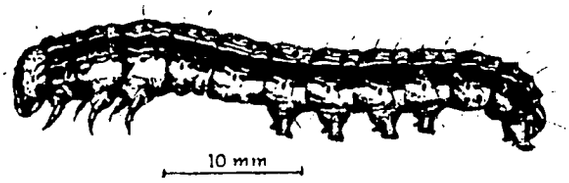

Fig. 7. Larva de **Spodoptera frugiperda.**
(De Walton y Luginbill).

Es una especie que se encuentra difundida en toda América siendo ampliamente conocidos los daños que causa a numerosos vegetales.

Alcanzado el completo desarrollo estas orugas miden de 35 a 40 mm de largo. Presentan una coloración que varía notablemente con los ejemplares pues los hay desde ocráceos hasta verdosos y aún casi negros; en el cuerpo poseen tres líneas dorsales amarillentas que partiendo de la cabeza llegan al extremo caudal; también a lo largo, pero a cada costado, hay una franja ondulada amarilla con puntitos rojos.

En algunas oportunidades las hemos encontrado comiendo hojas y brotes de soja pero sin que hasta el momento causen daños de consideración en dicho cultivo.

Químicamente estas orugas pueden combatirse con Endrin a razón de 300 cm³ de sustancia activa, por hectárea, o DDT, 750 a 1.000 g de activo por hectárea o con Carbaryl, 750 a 1.350 g de principio activo por hectárea.

Vaquita de San Antonio
(Diabrotica speciosa (Germar))

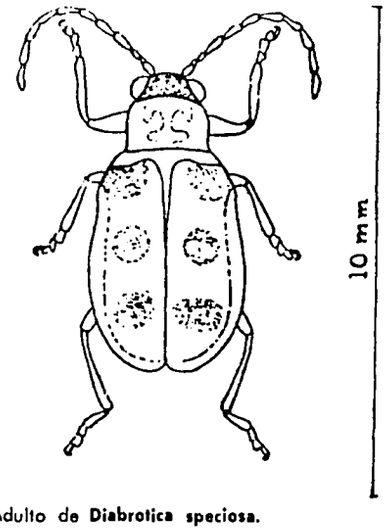

Fig. 8. Adulto de **Diabrotica speciosa.**
(De Christensen).

Esta vaquita tiene amplia difusión en nuestro país. Los adultos ingieren órganos florales, brotes y hojas de diversas plantas hortícolas, industriales, forrajeras, ornamentales y, asimismo, de algunos frutales.

En soja resulta frecuente observarlas y si el ataque es severo pueden ocasionar daños considerables ya que llegan a dejar de las hojas sólo sus nervaduras; el daño es más notorio cuando el cultivo es joven.

Las mencionadas vaquitas miden unos 6 mm de largo; tienen coloración verde en la que se destacan seis manchas amarillentas dispuestas de a tres en la parte anterior, media y posterior de cada élitro.

La lucha química puede llevarse a cabo con Paratión a razón de 80 g de sustancia activa por hectolitro o con DDT, 125 g de s.a. por igual volumen de agua.

OTROS INSECTOS

En algunas ocasiones hemos observado diferentes especies de tucuras comiendo algo del follaje de la soja, pero no se tiene conocimiento de que al menos por el momento causen daños de significación, lo que no descarta la posibilidad de que con el tiempo puedan convertirse en enemigos de riesgo para la mencionada leguminosa.

Recientemente, el Instituto Nacional de Tecnología Agropecuaria informó que en cultivos de soja de Castelar (provincia de Buenos Aires) hallaron adultos del grillo subterráneo (*Anurogryllus muticus* (*De Geer*)). "Al regarse las plantaciones, el grillo es ahuyentado por el agua, sale de su cueva y corta los brotes de soja y los come".

Además de la chinche verde ya citada al comienzo, hubo oportunidades en que hallamos otros hemípteros pero sin poder constatar daños; entre ellos figuran el alquiche chico (*Edessa meditabunda* (F.)), la chinche roja o sanguinolenta (*Athaumastus haematicus* (Stal)), *Dichelops furcatus* (F.) y *Loxa flavicollis* (Drury).

Entre los coleópteros a veces encontramos insectos del suelo tales como gusanos blancos, alambre y larvas de ciertos gorgojos, pero sin que fuese posible determinar daños; algo similar ocurrió, pero ya en la parte aérea de las plantas, con adultos del gorgojo rayado (*Naupactus xanthographus Germar*).

Además de las consignadas oportunamente existen otras orugas, isocas o gatas peludas, que en diversas ocasiones pueden encontrarse en cultivos de soja, pero sin que normalmente produzcan daños importantes. Como ejemplos cabe mencionar a la isoca medidora (*Rachiplusia nu* (Guenée)), a la oruga del maíz (*Helicoverpa zea* (Bod.)), a la gata peluda norteamericana (*Spilosoma virginica* (F.)) y a *Eurema deva* (Hewitson et Doubleday) las cuales comen hojas y brotes; también puede citarse a la oruga de la soja (*Chioides catillus* (Cramer)) que según Hayward (1941) se alimenta del follaje de dicha leguminosa.

Para la Provincia de Tucumán, además de varios de los insectos ya citados, Hayward (1942) menciona a la cochinilla acanalada de Australia (*Pericerya purchasi* (Maskell))

y a las chinches *Acrosternum fuscosa* (Berg) y *Arvelius albopunctatus* (De Geer).

Resulta de interés consignar que según Rosillo (1944), tanto las semillas de soja almacenadas como las del cultivo, pueden ser atacadas por el brucho del caupí o brucho de la China (*Callosobruchus chinensis* (L.)).

Si bien no se trata de un insecto, cabe citar a la arañuela roja común (*Tetranychus telarius* L.) ácaro que fue hallado ocasionalmente sobre soja.

NEMATODES

Anguilulosis de la raíz (Meloidogyne sp.)

Fig. 9. Raíces afectadas por Meloidogyne sp. (De Thorne).

La soja es otro de los tantos vegetales frecuentemente afectados por nematodes del género *Meloidogyne*.

Las plantas atacadas, en su sistema radicular muestran unos engrosamientos (agallas o cecidias) que pueden llegar a tener el tamaño de un garbanzo y aún más cuando se unen unos con otros. Dichas agallas dificultan la circulación de la savia y las raíces y raicillas muy afectadas finalmente mueren. En soja y otras leguminosas, las agallas podrían llegar a confundirse con nódulos formados por bacterias fijadoras de nitrógeno atmosférico, pero los nódulos, además de tener un color característico, se desprenden con relativa facilidad lo que no ocurre con las nematocecidias pues son el resultado de una hipertrofia celular de los órganos precedentemente citados.

Los vegetales afectados, en su parte aérea se muestran cloróticos, achaparrados, pudiendo llegar a sucumbir si son jóvenes o intesamente atacados; los más desarrollados presentan mayor resistencia al ataque pero igualmente consumen parte de sus energías en producir nuevas raíces.

En caso de comprobar la existencia de esta plaga en suelos a sembrar con soja, los mismos pueden tratarse con un nematodicida, por ejemplo con D.B.C.P. (dibromo cloropropano), unos 14 a 20 días antes de la siembra, si bien su empleo se ve restringido en la práctica debido a su costo.

AVES

Palomas

Algunas especies, principalmente la paloma cenicienta o montera (*Patagioenas maculosa maculosa* (Temminck)) y la torcaza o paloma mediana (*Zenaida auriculata crysauchenia* (Reichenbach)), también constituyen un problema para la soja pues ingieren las semillas recién sembradas; además, a poco de producida la germinación y ya emergidas las plantitas, dichas aves las picotean para comerles los cotiledones pudiendo llegar, en una u otra forma, a disminuir notoriamente la cantidad de plantas del cultivo.

Sin duda resulta difícil luchar contra estas aves; puede ahuyentárselas con armas de fuego o combatírselas mediante granos envenenados (utilizando por ejemplo Endrin como tóxico), que se distribuyen en el cultivo y sus proximidades.

ROEDORES

Liebre, liebre europea (Lepus europaeus europaeus (Pallas))

Ocasiona perjuicios en diversos cultivos y plantaciones; en regiones donde la densidad de población de liebres es elevada la soja puede resultar seriamente dañada por dichos roedores, especialmente si es atacada al comienzo de su desarrollo vegetativo. Los mayores daños se registran en los bordes de los cultivos por lo cual es preferible sembrar en un solo bloque. Hay zonas donde se ha constituído en uno de los principales enemigos de la soja.

Es muy difícil combatirlas. Podría impedirse que causen perjuicios alambrando perimetralmente el cultivo con alambre tejido, pero esto prácticamente es antieconómico. Por el momento sólo puede aconsejarse su caza intensiva.

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Insects in Soybeans and a Weed Host (Desmodium sp.)

By Philip Tugwell, E. Phil Rouse, and Raymond G. Thompson
Entomology Department

Results of an insect survey in soybeans (*Glycine max* (L) Merrill) and in a *Desmodium* sp. are presented in this report.

The principal objective of this survey was to classify the insects found in soybean fields in northwestern Arkansas. The insects were classified by taxa, general diet, and abundance. Species commonly found together were grouped. These groups were further classified according to: 1) type of habitat where they were most often collected, 2) relative abundance, and 3) seasonal abundance. Notes also were made on rate of parasitization and overwintering sites of certain species found in soybeans.

A secondary objective was to determine the insect species found in both Desmodium and soybeans. This particular wild host was emphasized because of the role Desmodium is suspected to play in the spread of bean pod mottle virus to soybeans (5).

Location and Methods

The survey was concentrated in the northwest Arkansas area near Van Buren (Crawford County) in the Arkansas River bottoms. Tillable lands in the area are not more than 3 to 5 miles wide, bordered by wooded areas and rolling hills on one side and the river on the other. Soybeans constitute approximately 70 to 80 percent of the crops, with the remaining land devoted primarily to vegetables (green) and pasture.

Three soybean fields were sampled twice weekly in 1969 and 1970 using a 100-sweep sample size. A standard 15-inch sweep net was used. Insects collected were transported in plastic bags to the laboratory where specimens were prepared for identification and counting.

The fields sampled were selected on planting date alone. A field planted to Clark 63 soybeans between April 10 and 20 in both years represented the **early-planted field.** It was surrounded by woods on two sides, levee and soybeans on the other two sides. Lee soybeans planted May 15 to 20 both years represented a **second planting date.** It was less than 0.25 mile from the former field, with the levee and a road separating the two. Soybeans were on the remaining sides. A field planted to the Lee variety about mid-June both years was selected as the **late-planted field.** It was approximately 6 miles from the other fields and was surrounded by pasture, alfalfa, and an abandoned field in which large concentrations of Desmodium were common.

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The survey fields were not treated with insecticides in either year. All were considered clean with respect to weeds, although the late-planted field was infested with an occasional morning glory and pigweed.

Samples were taken within a designated 5-acre block in each field. Most samples were collected between 10 A.M. and 4 P.M.

Twice weekly 20 sweeps were made in concentrations of Desmodium in the abandoned field located next to the late-planted soybean field.

In 1969, collections also were made in soybean fields located in Conway, Johnson, Lonoke, Pulaski, and Arkansas Counties. One field in each county was sampled four times in 1969: on July 16, August 6, 16, and 22. No attempt was made to determine grower practices in any of these fields, although relatively weed-free fields were chosen.

Identification was restricted to common orders excluding Thysanoptera and Diptera. Therefore, the list does not represent the total insect complex on soybeans and, of course, excludes species not usually collected by the net method. Only adults were identified except for Lepidoptera, which were identified in the larval stage of development when possible. Counts were made only of those insects identified at least to genera. Unless specified otherwise, counts will refer to those identified to species.

Special note was made of the relative abundance of certain species found in soybeans in this study as compared with the relative frequency of the same species found in sweep-net collections in a Missouri soybean-insect study reported by Blickenstaff and Huggans (2).

Scientific names including authors for all insect species identified can be found in the appendix table.

Total Soybean Collections

A total of 267 species were identified from all collections made in soybeans (appendix table); an additional 61 were identified only to the generic level. The bean leaf beetle, *Cerotoma trifurcata,* was the most abundant, averaging 35 per 100 sweeps. A leafhopper tentatively identified as the potato leafhopper, *Empoasca fabae,* was second, averaging 20 per 100 sweeps. The next most common species, averaging between 6 and 15 per 100 sweeps, in order of abundance, were: tarnished plant bug, *Lygus lineolaris;* green cloverworm, *Plathypena scabra;* big-eyed bug, *Geocoris punctipes;* three-cornered alfalfa hopper, *Spissistilus festinus;* and the leafhopper, *Agallia constricta.*

Few individuals of most species were collected. A view of the Van Buren collection which made up 91% of the total soybean collection will illustrate how infrequently most species were collected (Table 1). In both years approximately 50% of the species were represented in the collections by not more than 3 individuals and in most cases only by a

single specimen. In general, the frequency with which species occurred was characteristic of insect complexes in crop monocultures, in that there were many species made up of few individuals and few species comprising many individuals.

Table 1. Numbers of Species That Were Plant or Insect Feeders and Frequency of Individuals of Each Type in Sweeps at Van Buren, 1969 and 1970[1]

Times species occurred	Number of species, 1969			Number of species, 1970		
	Total	Plant feeders	Insect feeders	Total	Plant feeders	Insect feeders
1	58	29	17	58	28	13
2	18	7	9	18	11	2
3	18	14	4	12	5	2
4	7	0	3	12	5	2
5	1	0	1	6	5	0
6	4	1	0	13	6	4
7	9	7	0	4	0	3
8	2	0	1	3	0	1
9	2	0	2	4	3	1
10	1	0	1	0	0	0
11 to 20	11	5	5	18	9	6
21 to 30	6	3	3	6	4	2
31 to 40	2	2	0	7	2	4
41 to 50	6	3	3	5	4	0
51 to 100	8	5	2	6	3	3
101 to 200	3	2	0	6	4	2
201 to 300	2	0	2	1	1	0
301 to 400	3	2	1	3	1	1
401 to 500	2	2	0	1	0	1
501 to 1000	3	2	1	3	2	1
1001 to 2000	1	1	0	2	2	0
2001 to 3000	0	0	0	1	1	0
3001 to 4000	1	1	0	0	0	0
Totals	168	86	55	189	96	48

[1]Total of 5,200 and 6,800 sweeps in 1969 and 1970, respectively.

Also shown in Table 1 is the frequency of occurrence of species with different general diets. Plant feeders were most abundant, comprising 51% of those classified in both years, while insect feeders (predators or parasites) comprised 33% and 25% of those determined in 1969 and 1970, respectively. Undetermined and miscellaneous-type feeders made up the remainder of the collections. The ratio of the different feeding types appeared rather uniform both years.

Recurrent Groups

Particular emphasis was placed on grouping insects that often occurred together. These groupings may indicate relationships among species such as predator-prey, predator-predator, or prey-prey. The repeatable procedure developed by Fager (4) was used to classify the Van Buren collection by recurrent groups. Such groups represented the largest, most frequent separate groups within which all the species formed a nearly constant part of each other's biological environment. To form a recurrent group it was necessary to show evidence for affinity for all pairs of species within a group at the .05 level of probability. Species

that showed evidence for affinity with only certain members of a given group were called associates of that group.

Two recurrent groups and their respective associates were formed (Figure 1). The largest group is composed of 6 plant and 3 insect feeders; its associates are all plant feeders except *Melanophthalma distinguenda,* which is probably a scavenger. The second group and its associate included 4 plant feeders and 1 insect feeder, *Lebia analis.* Both groups focus attention on possible predator-prey relationships.

Large Recurrent Group	Associate Species of Large Group
Lygus lineolaris (tarnished plant bug)	
Agallia constricta (a leafhopper)	
Empoasca fabae[1] (potato leafhopper)	*Reuteroscopus sulphureus* (a plant bug)
Scaphytopius acutus (a leafhopper)	*Melanophthalma distinguenda* (a scavenger beetle)
Plathypena scabra (green cloverworm)	*Cuerna costalis* (a leafhopper)
Graminella nigrifrons (blackfaced leafhopper)	*Acrosternum hilare* (green stink bug)
Geocoris punctipes (big-eyed bug)	
Orius insidiosus (a minute pirate bug)	
Coleomegilla maculata (spotted lady beetle)	

Small Recurrent Group	Associate Species of Small Group
Graphocephala versuta (a leafhopper)	
Cerotoma trifurcata (bean leaf beetle)	*Colaspis brunnea* (grape colaspis)
Spissistilus festinus (3-cornered alfalfa hopper)	
Lebia analis (ground beetle)	

Figure 1. Species within Recurrent Groups and Their Associate Species as Determined by Method[2] Given by Fager

[1]Positive identification not made; assumed by general appearance to be *E. fabae.*

[2]The upper limit of 2 suggested by Fager (1957) for the ratio Nb/Na was lowered to the ratio of 1.5 in this case which should ensure that members of a group are a more constant part of the environment of other members of the group.

The validity of the grouping procedure for this purpose is supported by the fact that *L. analis* and the bean leaf beetle are associated during much of their life. Both overwinter in large numbers under debris along wooded hillsides. Both lay their eggs at the base of the soybean plant, and larvae of both live in the soil. Whitcomb and Bell (9) observed *L. analis* larvae feeding on bean leaf beetle pupae and larvae in the laboratory. Adult *L. analis* attack soft-bodied insects and insect eggs. It also seems plausible that such general feeders as the big-eyed bug, minute pirate bug, and spotted lady beetle (9) be placed in the large group with plant bugs, leafhoppers, and the green cloverworm.

Habitat of Groups

An estimate was made of the relative value of the different habitats for members within each group (not associates). The estimate was made

Table 2. Comparison of Soybean Fields as Habitats of Recurrent Groups, Ranked from Best (Low Rank) to Poorest Habitat (High Rank) for Each Group, 1969 and 1970[1]

Habitat of large recurrent group			Habitat of small recurrent group		
Date	Field	Rank	Date	Field	Rank
7-15-69	Late-Lee	1	6-25-70	Early-Clark 63	1
7-11-69	Late-Lee	2	6-17-70	Early-Clark 63	2
7-15-69	Late-Lee	3	6-29-70	Early-Clark 63	3
7-23-70	Late-Lee	4	6-22-70	Early-Clark 63	4
6-25-70	Late-Lee	5	6-24-69	Early-Clark 63	5
7-22-69	Late-Lee	6	7-22-69	Early-Clark 63	6
6-18-70	Late-Lee	7	6-18-70	Early-Clark 63	7
7- 6-70	Late-Lee	8	7- 2-70	Early-Clark 63	8
7-22-69	Late-Lee	9	6-15-70	Early-Clark 63	9
7-16-70	Late-Lee	10	9- 2-69	Late-Lee	10
7-27-70	Late-Lee	11	6-20-69	Early-Clark 63	11
8- 8-69	Late-Lee	12	7- 1-69	Early-Clark 63	12
6-29-70	Late-Lee	13	6-15-70	Mid-Lee	13
7-29-69	Late-Lee	14	7-22-69	Mid-Lee	14
6-18-70	Early-Clark 63	15	6-22-70	Mid-Lee	15
8- 5-69	Late-Lee	16	7- 3-69	Early-Clark 63	16
8- 3-70	Early-Clark 63	17	6-29-70	Early-Clark 63	17
8-13-70	Late-Lee	18	6-13-69	Early-Clark 63	18
7-18-69	Mid-Lee	19	7-25-69	Early-Clark 63	19
8- 6-70	Early-Clark 63	20	7-13-70	Mid-Lee	20
7- 1-69	Early-Clark 63	21	8- 6-70	Late-Lee	21
7-13-70	Late-Lee	22	7-27-70	Late-Lee	22
7- 8-69	Early-Clark 63	23	8- 6-70	Early-Clark 63	23
6-29-70	Early-Clark 63	24	7-16-70	Mid-Lee	24
7-30-70	Early-Clark 63	25	8-27-70	Mid-Lee	25
7- 2-70	Early-Clark 63	26	7-23-70	Mid-Lee	26
8-12-69	Mid-Lee	27	9-11-69	Late-Lee	27
6-22-70	Early-Clark 63	28	8-20-70	Mid-Lee	28
8- 1-69	Mid-Lee	29	7-20-70	Late-Lee	29
6-22-70	Mid-Lee	30	7- 2-70	Mid-Lee	30
7-15-69	Mid-Lee	31	6-18-70	Mid-Lee	31
6-15-70	Early-Clark 63	32	7-15-69	Mid-Lee	32
7-27-70	Mid-Lee	33	7-29-69	Late-Lee	33
			8-17-70	Mid-Lee	34
			7-11-69	Mid-Lee	35
			6-29-70	Mid-Lee	36
			8- 8-69	Late-Lee	37
			7-25-69	Late-Lee	38
			8-10-70	Mid-Lee	39
			8-12-69	Late-Lee	40

[1]Concordance among species significant at .01 and .10 level for large and small groups, respectively. Representative samples on indicated date contained all species in small group but absence of any one of the species in the large group was tolerated on any given date indicated. It was assumed that the largest number of ranked individuals within species and groups estimated goodness of a sample (4).

by first selecting samples, taken throughout the season at each location, containing members of the recurrent group. Each species, in turn, was ranked to reflect the sample(s) containing the largest numbers of a particular species. It was assumed that abundance was an indication of goodness of habitat. A test of concordance was then calculated to estimate agreement among species on what constituted a good habitat in the sense of least squares (4). Results are shown in Table 2.

These calculations indicate the late-planted field and its surroundings was the best habitat for the large recurrent group, whereas the small group tended to be associated with the early-planted field and its surroundings. These conclusions are not meant to specify the actual causative agent(s).

Relative Abundance

The relative abundance of the recurrent groups and associate species occurring in the Van Buren fields in 1969 was highly correlated with the relative abundance of the same species in 1970 (Table 3). Although populations did not seem to be of equal size both years, the fluctuations

Table 3. Relative Abundance of Species in Recurrent Groups and Associate Species Collected at Van Buren during 1969 and 1970, and Abundance of Same Species Collected in Missouri

	Relative abundance (ranked)			
	Arkansas		Totals[2]	
Species	1969	1970	Arkansas	Missouri
Cerotoma trifurcata	1	2	1	2
Plathypena scabra	2	6	4	4
Agallia constricta	3	11	6	5
Geocoris punctipes	4	5	5	8
Empoasca fabae[3]	5	1	2	1
Spissistilus festinus	6	4	....	....
Lygus lineolaris	7	3	3	6
Scaphytopius acutus	8	10	....	....
Lebia analis	9	9	....	....
Acrosternum hilare	10	17	10	10
Coleomegilla maculata	11	13	9	11
Orius insidiosus	12	7	7	3
Colaspis brunnea	13	16	....	....
Melanophthalma distinguenda	14	8	8	9
Reuteroscopus sulphureus	15	14	....	....
Graphocephala versuta	16	12	....	....
Graminella nigrifrons	17	15	11	7
Cuerna costalis	18	18	....	....

[1]Ranks significant (p=.01) using Spearman's rank correlation method.

[2]Arkansas: total numbers collected in 3 soybean fields near Van Buren in both years were ranked from high to low; Missouri data from Blickenstaff and Huggans (2).

[3]Positive identification not made; assumed by general appearance to be *E. fabae*.

did not greatly affect the relative abundance of some species with respect to others. This relationship in abundance would appear to suggest an element of stability in that some species occurred both years at about the same relative frequency.

Table 4. Seasonal Abundance of Single Stages of Selected Species within Recurrent Groups, 1969 and 1970

Species, year, and field	Numbers per 100 sweeps per week												
	June			July				August				Sept.	
	3	4	5	1	2	3	4	1	2	3	4	1	2
Cerotoma trifurcata													
1969, Early	234	159	238	191	79	132	133	26	15	2	..[1]	.....	.....
1969, Mid	.....	.....	.....	.....	40	41	34	21	5	32	63	0	.....
1969, Late	.....	.....	.....	.....	3	9	3	4	2	1	21	61	8
1970, Early	9	50	74	84	247	71	59	50	29	38	.....	.....	.....
1970, Mid	6	3	5	10	66	14	16	10	13	13	2	4	0
1970, Late	.....	6	4	4	13	1	4	3	15	.....	.....	.....	.....
Plathypena scabra													
1969, Early	59	11	49	15	5	7	8	10	15	8	.....	.....	.....
1969, Mid	.....	.....	.....	.....	9	5	3	10	69	24	19	108	.....
1969, Late	.....	.....	.....	.....	10	10	23	15	13	16	13	22	8
1970, Early	9	42	23	8	4	5	13	23	1	1	.....	.....	.....
1970, Mid	9	8	4	1	3	6	13	1	3	0	32	43	5
1970, Late	.....	1	1	1	2	1	1	1	1	.....	.....	.....	.....
Geocoris punctipes													
1969, Early	5	2	10	10	11	11	9	8	1	3	.....	.....	.....
1969, Mid	.....	.....	.....	.....	21	23	12	18	11	2	1	6	.....
1969, Late	.....	.....	.....	.....	33	32	32	27	17	8	5	10	3
1970, Early	7	12	7	0	0	0	12	22	4	1	.....	.....	.....
1970, Mid	9	6	1	0	6	0	3	4	1	1	1	1	1
1970, Late	.....	18	27	4	21	14	68	69	21	.....	.....	.....	.....
Empoasca fabae[2]													
1969, Early	7	11	16	6	4	1	2	4	0	0	.....	.....	.....
1969, Mid	.....	.....	.....	.....	8	3	3	5	1	4	1	0	.....
1969, Late	.....	.....	.....	.....	40	47	32	37	14	7	1	13	4
1970, Early	5	20	8	2	7	13	2	8	17	4	.....	.....	.....
1970, Mid	10	2	8	5	1	1	6	6	4	5	12	35	4
1970, Late	.....	34	49	47	80	67	92	105	12	.....	.....	.....	.....
Spissistilus festinus													
1969, Early	4	1	8	4	5	7	17	46	23	11	.....	.....	.....
1969, Mid	.....	.....	.....	.....	2	4	3	24	9	22	14	17	.....
1969, Late	.....	.....	.....	.....	2	3	5	5	5	7	3	7	7
1970, Early	12	7	9	4	4	9	20	16	13	0	.....	.....	.....
1970, Mid	4	11	3	1	4	2	8	12	7	9	8	12	20
1970, Late	.....	14	14	3	9	21	28	27	27	.....	.....	.....	.....
Lygus lineolaris													
1969, Early	9	12	3	4	1	0	0	0	0	0	.....	.....	.....
1969, Mid	.....	.....	.....	.....	59	14	1	0	2	0	0	0	.....
1969, Late	.....	.....	.....	.....	70	51	9	3	1	1	0	1	1
1970, Early	10	8	3	1	3	7	1	1	0	1	.....	.....	.....
1970, Mid	29	27	25	5	5	12	4	0	0	0	0	0	2
1970, Late	.....	111	92	35	68	115	90	84	16	.....	.....	.....	.....
Lebia analis													
1969, Early	53	41	11	5	7	2	1	0	2	0	.....	.....	.....
1969, Mid	.....	.....	.....	.....	7	10	7	5	0	2	2	1	.....
1969, Late	.....	.....	.....	.....	0	0	2	0	2	0	0	8	1
1970, Early	9	41	8	0	3	0	0	1	0	0	.....	.....	.....
1970, Mid	15	20	14	1	4	3	2	0	1	2	1	0	0
1970, Late	.....	8	5	3	3	1	4	1	2	.....	.....	.....	.....
Orius insidiosus													
1969, Early	11	10	8	4	0	0	0	0	0	0	.....	.....	.....
1969, Mid	.....	.....	.....	.....	2	4	0	2	0	0	0	1	.....
1969, Late	.....	.....	.....	.....	35	14	4	7	1	0	0	0	4
1970, Early	31	17	10	0	1	1	0	1	0	0	.....	.....	.....
1970, Mid	40	12	17	1	4	4	5	0	0	0	0	0	0
1970, Late	.....	7	8	9	6	6	6	1	1	.....	.....	.....	.....

[1]No sweeps made.

[2]Positive identification not made; assumed by general appearance to be *E. fabae*.

The same relationship also was suggested when the abundance of some species obtained in this survey were compared with the data collected in Missouri by Blickenstaff and Huggans (2), also shown in Table 3. Some of these insects appear to occur repeatedly in soybeans and in some cases at rather predictable levels with respect to one another. Conversely, there was a conspicuous scarcity of certain species such as the bollworm, *Heliothis zea;* soybean looper, *Pseudoplusia includens;* and the velvetbean caterpillar, *Anticarsia gemmatalis,* of which only 72, 3, and 45 were collected, respectively, in 14,000 sweeps. The number of three-cornered alfalfa hoppers collected in Arkansas contrasted greatly with the Missouri collection. A common insect throughout Arkansas, it was collected only on two occasions in the Missouri study although it has long been established in that state, though perhaps in low numbers (10).

Seasonal Abundance

The seasonal abundance of species within groups, for which at least some distinct patterns of abundance were reflected in the samples, are shown in Table 4. The bean leaf beetle peaked in numbers in June one year and in July the next. The next most common species, the potato leaf hopper, seemed to be more or less uniform in abundance within a field, with only a slight peak indicated in late July and early August in 1970. Peaks were evident in the other species shown in Table 4, but it also was most obvious that abundance of all species varied with locations to the extent that a generalized configuration of abundance could not easily be made.

Notes on Incidence of Parasitized Bean Leaf Beetles

The seasonal incidence of parasitized bean leaf beetles was studied during the growing season of 1969. Varying numbers of beetles were examined for internal parasites. Results are presented in Table 5. Beetles appeared to be more heavily parasitized in the early-planted Clark 63 field where up to 19.6% of those examined were parasitized. Parasites were found most often in mid-June; they probably were tachinids.

Table 5. Incidence of Bean Leaf Beetles Parasitized by Unidentified Parasite(s) During Growing Season, Van Buren, 1969[1]

Date	Beetles examined			Beetles parasitized					
	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late
	Number			*Number*			*Percent*		
6-13	171	0	0	4	..	..	2.3	....	....
6-17	296	0	0	38	..	..	12.8	....	....
6-20	46	0	0	9	..	..	19.6	....	....
6-24	272	0	0	30	..	..	11.0	....	....
6-27	287	0	0	18	..	..	6.3	....	....
June total	1072	0	0	99	..	..	9.2	....	....
July total	1358	396	31	17	5	1	1.3	1.3	3.2
Aug. total	84	198	52	0	3	0	0.0	1.5	0.0
Sept. total	0	42	69	0	0	0	0.0	0.0	0.0

[1]Collections from early (Clark 63), mid and late (Lee) fields.

Insects Associated with Desmodium

Both the bean leaf beetle and grape colaspis are vectors of bean pod mottle virus (7, 8, and personal communications). Bean leaf beetles were observed on Desmodium from mid-May through late September, and eggs were observed in mid-May at the base of Desmodium plants. The grape colaspis was collected on Desmodium from mid-June through late September.

In an effort to trap bean leaf beetles that developed on Desmodium, cages 3 x 3 x 3 ft. covered with a 20-mesh screen were placed over clumps of Desmodium and associated grasses in mid-May after bean leaf beetles had become established. Both bean leaf beetles and grape colaspis adults were found later in the cages. The four cages were located within approximately 50 yards of each other and paired on two different soil types. Greater numbers of bean leaf beetles and grape colaspis were collected in cages over clay loam soil than in those over sand (Table 6). The grape colaspis adults, based on a study by Rolston and Rouse (6), evidently developed from overwintering larvae. It may be that grape

Table 6. Numbers of Bean Leaf Beetles and Grape Colapsis That Developed in Association with Caged Desmodium Grown on Two Soil Types Within a 3-Acre Study Area[1], 1969 and 1970

Measure	1969	1970
Bruno, loamy fine sand, pH 7.0		
Cage 1		
Bean leaf beetles	2	0
Grape colapsis	0	0
Cage 2		
Bean leaf beetle	0	0
Grape colaspis	0	0
Norwood, silty clay loam, pH 6.5		
Cage 3		
Bean leaf beetle	9	1
Grape colaspis	21	10
Cage 4		
Bean leaf beetle	26	0
Grape colaspis	36	10

[1]Soil identification and classification provided by H. C. Dean, State Soil Scientist, SCS, and E. Moye Rutledge, assistant agronomist.

colaspis was actually overwintering in grass which happened to also include Desmodium because the larval stage is known to do well on crabgrass (6). But the adult stage, too, has long been associated with Desmodium (3, 1).

An insect common on Desmodium, which H. J. Walters of the plant pathology department of this Station has shown to be an occasional vector of BPMV, is the weevil *Apion roseae*. It develops as a larva in galls on the lower stem of Desmodium at about ground level (Figure 2). Several weevils may develop in one gall. *A. roseae*, however, was not collected in soybeans.

A total of 133 species of insects were found by sweeping clumps of Desmodium; 93 of these also occurred in soybean fields (appendix table).

Figure 2. Showing Galls (left) on Stem of *Desmodium* sp.; Pupa (center); and Adult (right) of *Apion roseae* Kiss.

Summary

A total of 267 species were identified from sweep-net collections made in Arkansas soybean fields. Many were uncommon. The bean leaf beetle, *Cerotoma trifurcata,* was the most common insect of those identified from soybeans, followed in order by *Empoasca fabae, Lygus lineolaris, Plathypena scabra, Geocoris punctipes, Spissistilus festinus,* and *Agallia constricta.*

Insects within two groups often occurred in mixed populations, suggesting possible predator-prey relationships. The relative abundance of these recurrent groups and their associate species in 1969 and 1970 were correlated. Similar relative abundance was indicated in certain comparisons between the Arkansas and a Missouri collection. In both years one of the recurrent groups tended to be found most often as a group in the early field of Clark 63 soybeans, while the other group was more often found in a late field of Lee soybeans.

The seasonal abundance of selected species emphasized that abundance varied with location. Also, the incidence of parasitized bean leaf beetles was greatest in June, when about 19% parasitization was observed.

Cerotoma trifurcata, along with the predator *Lebia analis,* was observed to pass the winter along wooded hillsides in leaf trash. *Colaspis brunnea* appeared to overwinter in association with Desmodium.

A total of 133 species were identified from a one-year collection in *Desmodium* sp. Of these species 93 also were collected in soybeans, including the vectors of bean pod mottle virus, *Cerotoma trifurcata* and *Colaspis brunnea.*

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Appendix Table 1. Total Number, Identified by Species, from Collections Made in Soybeans and Desmodium sp., Van Buren, 1969 and 1970

(Note: 5,200 and 6,800 sweeps in soybeans in 1969 and 1970, respectively; 660 sweeps in *Desmodium* sp., 1970.)

Species	Soybeans 1969	Soybeans 1970	Soybeans Total	Desmodium 1970
COLEOPTERA				
Anobiidae				
Lasioderma serricorne (Fabricius)	6	0	6	0
Anthicidae				
Anthicus cervinus LaFerte-Senectere	9	6	15	0
Notoxus calcaratus Horn	1	1	2	0
Notoxus monodon Fabricius	8	0	8	1
Notoxus murinipennis LeConte	1	4	5	0
Bostrichidae				
Rhyzopertha dominica (Fabricius)	2	0	2	0
Bruchidae				
Acanthoscelides alboscutellatus (Horn)	1	0	1	0
Acanthoscelides ochraceicolor (Pierce)	1	0	1	0
Acanthoscelides seminulum (Horn)	1	0	1	0
Bruchus brachialis Fahraeus	1	2	3	0
Callosobruchus maculatus (Fabricius)	0	6	6	0
Buprestidae				
Agrilaxia flavimana (Gory)	0	1	1	0
Pachyschelus laevigatus (Say)	0	0	0	7
Pachysthelus schwarzi Kerreman	0	0	0	6
Cantharidae				
Chauliognathus marginatus Fabricius	13	31	44	2
Carabidae				
Callida decora (Fabricius)	1	1	2	0
Colliuris pennsylvanica (Linnaeus)	0	1	1	0
Harpalus pennsylvanicus DeGeer	0	0	0	2
Lebia analis Dejean	320	349	669	1
Lebia scapularis Dejean	0	1	1	0
Lebia viridis Say	5	7	12	1
Chrysomelidae				
Agriconota bivittata (Say)	0	2	2	0
Altica ignita Illiger	0	6	6	5
Anomoea laticlivia (Forster)	0	1	1	3
Cerotoma trifurcata (Forster)	3034	1870	4904	37
Chaetocnema confinis Crotch	47	15	62	1
Chaetocnema pulicaria Melsheimer	31	56	87	4
Colaspis brunnea (Fabricius)	131	91	222	35
Coleofasciata glabrata (Fabricius)	0	3	3	0
Cryptocephalus venustus Fabricius	1	0	1	0
Deloyala guttata (Oliver)	2	0	2	0
Diabrotica undecimpuctata howardi Barber	54	49	103	7
Diachus auratus Fabricius	0	3	3	7
Labidomera clivicollis Kirby	1	1	2	0
Metriona bicolor (Fabricius)	6	3	9	0
Oedionychis gibbitarsa (Say)	0	1	1	0
Systena elongata (Fabricius)	1	0	1	1
Systena frontalis (Fabricius)	1	0	1	0
Xenochalepus horni (Smith)	1	1	2	0
Zygogramma heterothecae Linell	0	1	1	7
Zygogramma suturalis casta (Roger)	0	0	0	9
Cleridae				
Phyllobaenus lecontei Wolcott	0	4	4	0
Phyllobaenus pubescens (LeConte)	2	0	2	1
Coccinellidae				
Coccinella novemnotata Herbst	2	1	3	1
Coleomegilla maculata (DeGeer)	287	138	425	8
Cycloneda munda (Say)	12	34	46	1
Hippodamia convergens Guerin-Meneville	64	150	214	9
Neomysia pullata (Say)	0	1	1	0
Olla abdominalis plagiata Casey	1	0	1	0
Scymnus hortensis Wingo	0	32	32	2
Scymnus intrusus Horn	0	1	1	0
Scymnus loewii Mulsant	0	9	9	1
Scymnus terminatus Say	0	0	0	1
Curculionidae				
Anthanomus heterothecae Pierce	0	3	3	15
Apion griseum Smith	0	1	1	4
Apion roseae Kissinger	0	0	0	63
Apion savi Gyllenhal	1	0	1	2
Chalcodermus aeneus Boheman	0	1	1	0
Chalcodermus inaequalicollis Horn	0	1	1	0
Cosmoparis americana Casey	0	0	0	13
Elleschus ephippiatus (Say)	0	2	2	0

Species	Soybeans 1969	Soybeans 1970	Soybeans Total	Desmodium 1970
Eudiagogus rosenschoeldi Fahraeus	1	0	1	0
Hypera meles (Fabricius)	3	0	3	0
Hypera postica (Gyllenhal)	0	0	0	1
Rhodobaenus tredecimpunctata (Illiger)	1	0	1	0
Sitona hispidula (Fabricius)	0	2	2	0
Tanymecus confertus (Gyllenhal)	0	0	0	1
Trichobaris trinotata (Say)	0	0	0	1
Elateridae				
Aeolus dorsalis (Say)	1	0	1	0
Conoderus auritus (Herbst)	1	0	1	0
Conoderus lividus (DeGeer)	1	0	1	0
Conoderus vespertinus (Fabricius)	26	11	37	1
Horistonotus uhlerii Horn	1	0	1	0
Eucnemidae				
Deltometopus amoenicornis (Say)	1	0	1	0
Languriidae				
Languria angustata uhleri Horn	1	0	1	0
Languria mozardi Latrelle	2	5	7	0
Lathridiidae				
Melanophthalma cavicollis Mannerheim	12	11	23	0
Melanophthalma distinguenda Comstock	128	384	512	12
Malachiidae				
Collops balteatus LeConte	0	4	4	0
Collops quadrimaculatus (Fabricius)	4	6	10	0
Meloidae				
Epicauta pestifera Werner	1	0	1	0
Phalacridae				
Acylomus ergoti Casey	17	34	51	8
Phalacrus politus Melsheimer	6	5	11	1
Stilbus apicalis (Melsheimer)	3	8	11	0
Stilbus nitidus (Melsheimer)	0	1	1	2
DERMAPTERA				
Labiduridae				
Euborellia annulipes (Lucas)	7	0	7	0
HEMIPTERA				
Alydidae				
Alydus eurinus Herrich & Schaeffer	4	1	5	3
Alydus pilosulus (Herrich & Schaeffer)	7	4	11	0
Megalotomus quinquespinosus (Say)	0	1	1	0
Anthocoridae				
Orius insidiosus (Say)	202	454	656	37
Berytidae				
Aknisus multispinosus Ashmead	4	3	7	0
Jalysus spinosus (Say)	3	11	14	0
Jalysus wickhami Van Duzee	19	64	83	2
Coreidae				
Charlesterus antennator (Fabricius)	0	1	1	0
Euthochtha galeator (Fabricius)	0	1	1	7
Cydnidae				
Allocoris gillettii (McAtee & Malloch)	0	1	1	0
Corimelaena pulicaria (Germar)	16	40	56	27
Galgupha aterrima Malloch	0	0	0	1
Sehirus cinctus (Palisot de Beauvois)	7	7	14	5
Pangaeus bilineatus Say	0	0	0	1
Lygaeidae				
Cymus angustatus Stal	1	2	3	5
Geocoris punctipes (Say)	630	677	1307	6
Geocoris uliginosus (Say)	21	8	29	1
Hypogeocoris piceus (Say)	0	1	1	0
Lygaeus kalmii Stal	0	13	13	0
Myodocha serripes Oliver	0	0	0	2
Nysius californicus Stal	4	4	8	1
Nysius raphanus Howard	1	16	17	4
Ortholomus scolopox (Say)	0	0	0	1
Perigenes constrictus (Say)	1	0	1	0
Miridae				
Adelphocoris rapidus (Say)	1	13	14	0
Chlamydatus suavis (Reuter)	0	0	0	7
Deraeocoris nubulosus (Uhler)	1	0	1	0
Halticus bractatus (Say)	54	13	67	10
Hyaliodes harti Knight	1	0	1	0
Lopidea davisi Knight	1	0	1	0
Lygus lineolaris (Palisot de Beauvois)	473	1545	2018	25
Macrotylus amoenus Reuter	0	4	4	8
Neurocolpus nubilus (Say)	0	2	2	0
Opistheurista clandestina (Van Duzee)	12	13	25	0
Phytocoris tibialis Reuter	3	4	7	0

Species	Soybeans 1969	Soybeans 1970	Soybeans Total	Desmodium 1970
Plagiognathus albatus (Van Duzee)	1	1	2	0
Polymerus basalis (Reuter)	0	19	19	1
Pseudatomoscelis seriatus (Reuter)	0	4	4	1
Reuteroscopus ornatus (Reuter)	0	0	0	6
Reuterscopus sulphureus (Reuter)	97	119	216	9
Spanogonicus albofasciatus (Reuter)	1	0	1	0
Trigonotylus ruficornis (Geoffroy)	0	2	2	0
Nabidae				
Nabis alternatus Parshley	64	51	115	0
Nabis capsiformis Germar	26	11	37	0
Nabis deceptivus Harris	2	0	2	0
Nabis ferus (Linnaeus)	49	14	63	0
Nabis roseipennis Reuter	43	47	90	0
Pentatomidae				
Acrosternum hilare (Say)	319	77	396	3
Euschistus euschistoides (Vollenhoven)	0	4	4	1
Euschistus servus (Say)	60	22	82	7
Euschistus tristigmus (Say)	1	3	4	0
Euschistus variolarius (Palisot de Beauvois)	1	1	2	2
Hymenarcys nervosa (Say)	0	1	1	0
Nezara viridula (Linnaeus)	1	0	1	0
Oebalus pugnax (Fabricius)	3	1	4	0
Peribalus limbolaris (Stal)	0	0	0	1
Podisus maculiventris (Say)	9	3	12	0
Thyanta pallidovirens accerra (McAtee)	20	27	47	0
Phymatidae				
Macrocephalus prehensilis (Fabricius)	0	0	0	4
Piesmidae				
Piesma cinerea (Say)	0	9	9	0
Reduviidae				
Sinea diadema (Fabricius)	0	7	7	0
Zelus cervicalis Stal	1	1	2	0
Rhopalidae				
Arhyssus lateralis (Say)	0	1	1	0
Aufeius impressicollis Stal	0	1	1	1
Harmostes reflexulus (Say)	1	1	2	2
Liorhyssus hyalinus (Fabricius)	1	1	2	2
Niesthrea sidae (Fabricius)	1	0	1	0
HOMOPTERA				
Acanloniidae				
Acanalonia conica (Say)	7	1	8	0
Cercopidae				
Clastoptera xanthocephala Germar	3	11	14	166
Lepyronia quadrangularis (Say)	3	6	9	0
Prosapia bicincta (Say)	3	0	3	0
Cicadellidae				
Acenopterus acuminatus Van Duzee	0	1	1	1
Aceratagallia accola Oman	0	1	1	0
Aceratagallia sanguinolenta (Provancher)	96	41	137	5
Agallia constricta Van Duzee	659	264	923	102
Agalliopsis novella (Say)	7	3	10	1
Balclutha neglecta (Delong & Davidson)	0	1	1	0
Carneocephala flaviceps (Riley)	2	4	6	0
Chlorotettix galbanatus Van Duzee	0	5	5	0
Chlorotettix spatulatus Osborn & Ball	0	1	1	0
Chlorotettix viridis Van Duzee	6	6	12	2
Ciminius hartii (Ball)	1	0	1	0
Cuerna costalis (Fabricius)	37	66	103	1
Draeculacephala portola Ball	0	2	2	0
Empoasca fabae[1] (Harris)	518	2098	2616	167
Endria inimica (Say)	1	13	14	1
Exitianus exitiosus (Uhler)	3	24	27	9
Graminella nigrifrons (Forbes)	45	112	157	16
Graphocephala coccinea (Forster)	1	2	3	0
Graphocephala versuta (Say)	91	150	241	10
Idiocernus snowi raphus Freytag	0	5	5	0
Macrosteles fascifrons (Stal)	15	101	116	29
Neokolla hieroglyphica form dolobrata (Ball)	0	2	2	10
Norvellina seminuda (Say)	11	29	40	1
Oncometopia orbona (Fabricius)	0	36	36	0
Opsius stactogalus (Fieber)	0	1	1	0
Paraphlepsius collitus (Ball)	0	1	1	0
Paraphlepsius continnus Delong	1	0	1	0
Paraphlepsius irroratus (Say)	3	43	46	10
Paraphlepsius tennessa (Delong)	0	1	1	1
Paraulacizes irrorata (Fabricius)	0	3	3	0
Polyamia apicata (Osborn)	1	0	1	0
Scaphytopius acutus (Say)	342	312	654	3

Species	Soybeans 1969	Soybeans 1970	Soybeans Total	Desmodium 1970
Scaphytopius frontalis (Van Duzee)	1	9	10	27
Stirellus bicolor (Van Duzee)	1	1	2	3
Texananus ovatus (Van Duzee)	1	0	1	0
Texananus superbus (Van Duzee)	2	1	3	1
Tylozygus bifida (Say)	0	1	1	1
Cixiidae				
Haplaxius sordipennis (Stal)	7	0	7	0
Oliarus aridus Ball	3	6	9	0
Oliarus sablensis Caldwell	0	1	1	0
Delphacidae				
Delphacodes puella (Van Duzee)	7	12	19	0
Liburniella ornata (Stal)	3	9	12	13
Dictyopharidae				
Rhynchomita microrhina (Walker)	1	0	1	5
Flatidae				
Metcalfa pruinosa (Say)	1	0	1	0
Fulgoridae				
Crypoptus reineckei Van Duzee	2	2	4	0
Fulgoroid nymph	0	6	6	0
Membracidae				
Campylenchia latipes (Say)	7	6	13	0
Micrutalis calva (Say)	0	2	2	1
Spissistilus festinus (Say)	497	668	1165	13
Stictocephala bubalus (Fabricius)	2	0	2	0
Tylopelta brevis Van Duzee	0	0	0	5
HYMENOPTERA				
Apidae				
Apis mellifera Linnaeus	8	2	10	0
Bombus fraternus (Smith)	4	0	4	0
Bombus pennsylvanicus (DeGeer)	1	1	2	0
Triepeolus lunatus (Say)	0	1	1	0
Braconidae				
Microgaster facetosa Weed	2	0	2	0
Microplitis croceipes (Cresson)	1	0	1	0
Wesmaelia pendula Forester	1	0	1	0
Formididae				
Conomyrma pyramicus pyramicus (Roger)	44	6	50	0
Crematogaster ashmeadi Mayr	2	0	2	0
Crematogaster laeviuscula Mayr	0	0	0	1
Iridomyrmex purinosus analis (Andre')	2	0	2	6
Lasius neoniger Emery	28	1	29	1
Monomorium minimum (Buckley)	4	7	11	226
Monomorium viridium poninsulatum (Gregg)	0	0	0	4
Pallidefulva pallidefulva Latreille	0	0	0	1
Paratrechina melanderi (Wheeler)	0	0	0	3
Pheidole bicarinata vinelandica Forel	0	13	13	0
Pheidole dentata Mayr	0	1	1	5
Tapinoma sessile (Say)	1	0	1	0
Halictidae				
Agapostemon splendens (Lepeletier)	1	2	3	0
Agapostemon texanus Cresson	0	2	2	0
Augochlorella aurata (Smith)	0	1	1	0
Augochlorella striata (Provancher)	2	2	4	0
Halictus confusus Smith	1	4	5	0
Halictus ligatus Say	0	2	2	0
Lasioglossum brassicae (Mitchell)	1	0	1	0
Lasioglossum testaceum (Robertson)	1	0	1	0
Megachilidae				
Megachille inimica Cresson	3	0	3	0
Scoliidae				
Trielis octomaculata (Say)	1	0	1	0
Sphecidae				
Cerceris clypeata Dahlbom	3	0	3	0
Cerceris compacta Cresson	1	0	1	0
Pluto sayi (Rohwer)	1	0	1	1
Vespidae				
Polistes exclamans Viereck	0	1	1	0
LEPIDOPTERA				
Arctiidae				
Estigmene acrea Drury	7	9	16	2
Lycaenidae				
Everes comyntas Godart	1	0	1	0
Strymon melinus (Hubner)	1	0	1	16
Hesperiidae				
Thorybes pylades (Scudder)	1	0	1	0
Megalopygidae				
Megalopyge crispata (Packard)	1	0	1	0

	Soybeans			Desmodium
	1969	1970	Total	1970
Noctuidae				
Anticarsia gemmatalis Hubner	44	1	45	0
Caenurgina erechtea (Cramer)	1	0	1	0
Heliothis zea (Boddie)	25	47	72	4
Lacinipolia renigera (Stephens)	1	0	1	0
Panopoda rufimargo (Hubner)	1	0	1	0
Peridroma saucia (Hubner)	0	1	1	0
Plathypena scabra (Fabricius)	1005	553	1558	198
Prodenia ornithogalli Guenee	22	11	33	0
Pseudoplusia includens (Walker)	0	3	3	0
Tathorhynchus angustiorata Grote	1	0	1	0
Trichoplusia ni (Hubner)	3	5	8	1
Zale lunata Drury	1	0	1	0
Notodontidae				
Datana ministra (Drury)	1	0	1	0
Heterocampa manteo (Doubleday)	1	0	1	0
Heterocampa umbrata Walker	1	0	1	0
Lophodonta angulosa Abbot & Smith	1	0	1	0
Nadata gibbosa Abbot & Smith	1	0	1	0
Olethreutidae				
Eucosma sombreana Kearfott	1	0	1	0
Pieridae				
Colias eurytheme Boisduval	3	1	4	0
Pyralidae				
Plodia interpunctella (Hubner)	1	0	1	0
Saturniidae				
Actias luna (Linnaeus)	1	0	1	0
Antheraea polyphemus (Cramer)	1	0	1	0
Sphingidae				
Cressonia juglandis (J. E. Smith)	1	0	1	0
Paonias excaecata Abbot & Smith	1	0	1	0
Tortricidae				
Sparganothis nigrocervina (Walsingham)	1	0	1	0
NEUROPTERA				
Chrysopidae				
Chrysopa harrisii Fitch	1	6	7	0
Chrysopa intacta Navas	2	0	2	0
Chrysopa oculata Say	3	18	21	0
Chrysopa plorablunda Fitch	10	27	37	1
Chrysopa rufilabris Burmeister	0	2	2	0
Hemerobiidae				
Micromus subanticus Walker	1	11	12	0
ORDONATA				
Libellulidae				
Perithemis tenera Say	0	1	1	0
ORTHOPTERA				
Acrididae				
Melanoplus bispinosus Scudder	0	0	0	7
Melanoplus differentialis (Thomas)	0	1	1	4
Melanoplus femurrubrum (DeGeer)	0	0	0	7
Schistocerca americana (Drury)	0	0	0	2
Syrbula admirabilis (Uhler)	0	0	0	1
Gryllidae				
Nemobius fasciatus (DeGeer)	0	0	0	1
Oecanthus nigricornis F. Walker	18	43	61	34
Oecanthus quadripunctatus Beurenmuller	111	0	111	0
Oecanthus niveus (DeGeer)	2	0	2	0
Phyllopalpus pulchellus (Uhler)	2	0	2	0
Mantidae				
Stagmomantis carolina (Linnaeus)	0	8	8	2
Tettigoniidae				
Conocephalus fasciatus (DeGeer)	1	11	12	0
Conocephalus strictus (Scudder)	0	0	0	1
Scudderia furcata Brunner von Wattenwyl	0	1	1	0
Totals	10,218	11,569	21,787	1,609

[1]Positive identification not made; assumed by general appearance to be *E. fabae*.

MANAGEMENT OF INSECT PESTS OF SOYBEANS

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Research efforts designed to manage insect pest populations on soybeans are in initial stages of development and operative successes to this end are limited. However, numerous leads are available that may be developed to provide effective and economical management systems for the pest complex. Probably no other insect complex of a major crop affords better opportunity for immediate and long-term success with a modest research effort. Although a pattern of repetitive application of conventional insecticides is developing in some areas of the southern United States, the widespread use of potentially disruptive chemicals is not prevalent.

Insect pest complexes attack the crop from planting in May or June until maturity in the fall, with major economic losses occurring from outbreaks of foliage and pod feeders from mid-August through September. Those causing economic losses individually or more often in mixed populations include the Mexican bean beetle, *Epilachna varivestis* Mulsant; the bean leaf beetle, *Cerotoma trifurcata* (Forster); the green cloverworm, *Plathypena scabra* (Fabricius); the soybean looper, *Pseudoplusia includens* (Walker); the velvetbean caterpillar, *Anticarsia gemmatalis* Hubner; the corn earworm, *Heliothis zea* (Boddie) and a complex of stink bugs, *Nezara viridula* (Linnaeus), *Acrosternum hilare* (Say), and *Euschistus servus* (Say).

The purpose of this paper is probably best elucidated in a statement by Huffaker (1971); "We must show that parasites, predators and pathogens combined with restricted usage of selective chemicals, use of resistant varieties and other integrative measures can solve many of our pest problems without resort to disturbing and polluting chemicals." The present discussion will be limited to the following areas: 1) economic injury thresholds; 2) chemical control; 3) manipulation of predators; 4) microbial control of lepidopterous larvae; and 5) host plant resistance.

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Economic Injury Thresholds

The foundation for effective pest management practices in any crop depends upon realistic economic injury thresholds. Van den Bosch et al. (1971) indicated that the general lack of established thresholds showing the need for artificial measures is a basic reason for the confusion in pest control today. This is especially true in soybean insect control.

Recommendations for control of foliage feeding insects in most states are predicated on defoliation percentages at different stages of growth. Data providing the basis for these recommendations in southern determinate soybeans were reported by Turnipseed (1962, 1972b), Begum and Eden (1965), and Todd (1972 in press). Our data indicated that mechanically-incurred foliage losses of 33 percent at bloom did not result in significant yield losses in any of 10 tests; that 17 percent defoliation did not cause significant yield losses at any stage of growth; and that defoliations of 33 to 67 percent when seeds were enlarging caused greatest yield losses. In South Carolina (Nettles et al. 1970) initiation of artificial controls is recommended when 35 percent of foliage is destroyed through the blooming stage and 20 percent thereafter.

As indicated previously, most naturally-incurred defoliations of soybeans are caused by a complex of insects rather than by one species alone. Observations were made in South Carolina in 1969 on a complex of foliage feeders that caused varying degrees of defoliation in insecticidally treated and untreated plots (Table 1A and B). Most of the defoliation was caused by the velvetbean caterpillar, but also present and contributing to foliage losses were the bean leaf beetle, the Mexican bean beetle and the soybean looper. Numbers of the velvetbean caterpillar and the bean leaf beetle on September 8, 16 and 22 in eight ft of row are shown in treated and untreated plots (Table 1A). Treatments included a side-dress soil application of aldicarb at 2.0 pounds actual per acre, foliar sprays of monocrotophos at 0.5 and carbaryl at 1.5 pounds, and an untreated check. Plots were 26.7 ft (eight rows) wide by 50 ft long and were separated by four untreated rows. On September 16 and 22 numbers of the velvetbean caterpillar were similar in aldicarb, carbaryl and check plots with good control afforded in monocrotophos plots. Numbers of the bean leaf beetle did not vary markedly in any plots on the three sampling dates. Our soybean agronomist, Dr. H. L. Musen, and I made independent estimations of defoliation on the four middle rows of each plot (Table 1B). On September 16, when blooms were present and prior to seed enlargement, defoliation had not reached the economic level of 35 percent in any plots. By September 22, when seed

TABLE 1A. Effect of insect defoliations of yield of insecticidally treated and untreated soybeans: Population levels of the velvetbean caterpillar and the bean leaf beetle.

Treatment[a]	Rate/ acre (lbs act.)	Avg. no. live in 8 ft row[b]					
		Velvetbean caterpillar			Bean leaf beetle		
		9/8	9/16	9/22	9/8	9/16	9/22
Aldicarb G	2.0	22.0b	119.0b	50.0b	22.5ab	27.5b	10.8a
Monocrotophos	0.5	0.5a	30.0a	13.0a	13.5a	27.5b	12.5a
Carbaryl	1.5	1.5a	158.5b	64.0b	15.0a	17.0a	11.5a
Check		23.5b	144.0b	40.0b	32.0b	23.5ab	10.5a

[a]Applied 8/20/69
[b]Means followed by the same letter are not significantly different at the 5% level. Duncan's multiple range test.

TABLE 1B. Effect of insect defoliations on yield of insecticidally treated and untreated soybeans: Estimated percent defoliation and plot yields.

Treatment[a]	Rate/acre (lbs. act.)	Percent defoliation[b]			Yield[a] (bu/A)
		9/16[c]	9/22[d]	10/10[e]	
Aldicarb G	2.0	12.5b	18.8b	37.3b	32.0b
Monocrotophos	0.5	5.0a	5.0a	5.5a	33.8b
Carbaryl	1.5	17.5bc	46.3c	58.3c	23.8a
Check		23.8c	41.3c	72.8c	23.3a

[a]Applied 8/20/69
[b]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.
[c]Prior to seed enlargement–blooms present.
[d]Beginning of seed enlargement.
[e]Pods 75% filled.

enlargement was beginning, economic defoliation levels had been exceeded in carbaryl and check plots, but had not reached 20 percent in aldicarb plots. On October 10, with pods 75 percent filled, defoliation thresholds were exceeded in aldicarb as in check and carbaryl plots. Yields were high in monocrotophos and aldicarb, and low in carbaryl and check plots, reflecting seasonal defoliation estimates rather than population levels of the defoliating species present.

Recommendations for control of pod feeders in South Carolina are based on numbers of insects per foot of row: three for earworms and one

for stink bugs. Recommendations in other states are similar but are usually based on somewhat lower population levels. I conducted pod removal experiments in 1962 (Turnipseed 1972c in press) that indicated excellent recovery from losses prior to seed enlargement. These data and field observations of population levels in treated and untreated plots provide the foundation for earworm recommendations. For stink bugs our thresholds were derived from small field cage tests and field observations. More recent data from Louisiana (L. D. Newsom pers. comm.) and Georgia (J. W. Todd unpublished data) indicate that economic damage from stink bugs may occur at lower population levels.

Additional research on pod-feeders is needed to establish the economic impact of different population levels and species of stink bugs at various stages of pod and seed development, and of different population levels of the corn earworm after seed enlargement has begun.

More importantly, we must begin to investigate the overall effects of the insect complexes in the different soybean agroecosystems; complexes which often include simultaneous attack by foliage, pod, stem, root and nodule feeders as well as disease-transmitting species. However, wider use and acceptance of recommendations based on presently available information would result in substantial reductions in the pesticidal load on soybeans.

Chemical Control

The use of conventional insecticides is necessary to control pest outbreaks on soybeans. Often broad spectrum chemicals are being applied when unnecessary and frequently at unnecessarily high rates. High rates are used for a number of reasons. Primarily growers prefer and have been encouraged to apply rates of broad spectrum chemicals that will "clean up" the most difficult to kill of the insect complex, often whether the insect is present or not. Second, extension personnel have not adequately communicated to growers the differences in susceptibility of various pest species to insecticides. And, third, research entomologists have not provided adequate data on effective minimum rates of recommended insecticides against different pest species.

Hopefully this rather sad state of affairs is beginning to change. Research entomologists, through cooperative efforts, conducted tests last season to determine minimum rates of conventional insecticides against major pests. The effective minimum rate in 1971 was arbitrarily defined as one providing 80 percent control in 48 hours. Data from the second

TABLE 2. Minimum effective rates of insecticides against the Mexican bean beetle—applied 9/20/71.

Insecticide	Rate/acre (lbs act.)	Avg live 48 hrs/8′ row*	
		Adults	Larvae
Methyl parathion	0.4	11.8a	7.0a
Carbaryl	0.1	9.3a	2.8a
Methomyl	0.1	10.0a	4.8a
Check		54.8b	58.5b

*Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.

TABLE 3. Minimum effective rates of insecticides against the green cloverworm and the corn earworm—applied 8/18/71.

Insecticide	Rate/acre (lbs act.)	Avg live 48 hrs/8′ row*	
		Cloverworm	Earworm
Methyl parathion	0.5	0.3a	4.5b
Carbaryl	0.75	0.3a	0.0a
	0.38	3.8b	3.3ab
Methomyl	0.13	0.8ab	1.0a
Check		10.3c	10.5c

*Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.

of two tests on the Mexican bean beetle in South Carolina in 1971 are shown in Table 2. Plots were four rows wide (13.3 ft) by 20 ft long and were separated by two untreated guard rows. Counts of two four foot sections of row indicated that carbaryl or methomyl at 0.1 pounds active gave approximately 80 percent control of adults and better than 90 percent control of larvae. Lower rates will be tested in 1972 to determine minimum rates against larvae. Data were also obtained in 1971 on the green cloverworm and the corn earworm (Table 3). Methyl parathion at 0.5, carbaryl at 0.75 and methomyl at 0.13 pounds active all afforded better than 90 percent control of the green cloverworm. Carbaryl gave 100 percent control of the corn earworm at 0.75 pounds and 70 percent control at 0.38 pounds, and methomyl afforded 90 percent control at 0.13 pounds.

In Alabama (M. H. Bass pers. comm.) 80 percent control of the velvetbean caterpillar was obtained in 1971 tests using 0.063 pounds active of

methyl parathion, carbaryl or methomyl. The bean leaf beetle and the green cloverworm were controlled in 1971 in North Carolina tests with carbaryl at 0.25 pounds active (W. V. Campbell pers. comm.).

Most states currently recommend 2-10 times the necessary rates of certain insecticides against these and probably against other pest species. These recommended rates must be scaled down as sufficient data on minimum effective dosages are compiled.

Newsom (1970) cautioned that the current furor over pesticides may discourage vitally-needed research on insecticides. Insecticidal research on soybeans must be encouraged and should be directed to the areas of minimum effective rates, use of selective chemicals alone, and use of selective chemicals in combination with microbial pathogens. Research in each of these areas should be designed to conserve natural enemies of pest species.

Manipulation of Predators

Conservation of predators in soybean fields through the judicious use of artificial control measures affords prospects for immediate improvement in the management of pest species. This may be accomplished by (1) initiating controls only when available economic thresholds so dictate, and (2) applying minimum rates of chemicals that allow maximum predator survival.

Recent research on the potential of predators in cotton, on the action of insecticides on predator effectiveness, and on pest resurgence provides a background for similar research in soybeans. Ridgway (1969) indicated that conservation and augmentation of predaceous insects may be utilized for control of the bollworm, *H. zea,* and the tobacco budworm, *Heliothis virescens* (Fabricius), in cotton. Reduction in populations of *H. zea* in cotton by predators has been demonstrated in Arkansas (Bell and Whitcomb, 1964), Texas (Lingren et al. 1968) and California (van den Bosch et al. 1969). Effects of insecticides on these predators have been discussed by the same authors, by Ridgway et al. (1967) and by Laster and Brazzel (1968). Falcon et al. (1968) indicated that numbers of the cabbage looper, *Trichoplusia ni* (Hubner), were higher and predators lower in plots treated with certain insecticides. Ridgway and Jones (1968) affirmed that certain geocorid and nabid predators fed on cotton plants to obtain water and were killed by certain systemic insecticides.

Our observations indicate that the three most active predator groups

TABLE 4. Resurgence of the corn earworm and decline of nabids, geocorids and spiders after insecticidal treatments—applied 8/26/68[a].

Insecticide	Rate/acre (lbs act.)	Earworms/15 sweeps 9/16	40' D-Vac 9/18		
			Nabids	Geocorids	Spiders
Carbaryl	1.5	1.0a	24.0b	12.6b	8.0b
Monocrotophos	0.5	23.3c	8.0a	3.3a	3.3a
Check		5.7b	24.4b	10.0b	6.7ab

[a]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.

TABLE 5. Effect of insecticides applied 8/26/70 on combined populations of *Nabis* spp. and *Geocoris punctipes*.

Insecticide	Rate/acre (lbs act.)	Avg no./8' row[a]		
		9/17	9/29	10/6
Aldicarb G	3.0	3.5a	4.5a	1.8a
Dipel B. t.[b]	0.5	12.3b	39.5c	39.0c
Monocrotophos	0.5	5.0a	10.5b	17.5b
Carbaryl	1.5	11.0b	27.0c	34.0c
Check		12.5b	31.0c	45.0c

[a]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.
[b]*Bacillus thuringiensis.*

in South Carolina soybeans are nabids, geocorids and spiders. To illustrate the importance of these predators, data will be presented on (1) resurgence of the corn earworm after insecticidal treatment, (2) effects of different insecticides on predators, and (3) activity of low rates of certain insecticides on pests and predators.

In 1968 (Table 4) foliar sprays of carbaryl at 1.5 and monocrotophos at 0.5 pound active were applied on August 26 to plots eight rows (26.7 ft) wide and 70 ft long separated by four untreated rows. On September 16, 21 days after treatment, numbers of *H. zea* in 15 sweeps were significantly higher in monocrotophos and lower in carbaryl than in untreated plots. Numbers of predators in vacuum samples on September 18 were reduced in monocrotophos but not in carbaryl plots. The high numbers of predators in carbaryl plots may have been due to initial survival within plots, or to a lack of residual kill of migrants or both.

Preliminary feeding tests (Armstrong and Turnipseed 1972) with

TABLE 6. Effect of methyl parathion applied 9/9/71 on *Nabis* spp., *Geocoris punctipes*, and spiders.

Treatment	Days after treatment	Avg no./8' row		
		Nabis	Geocoris	Spiders
Methyl parathion	5	2.0	0.8	6.5
1.0 lbs act.	11	5.8	0.0	7.5
	19	9.8	1.0	14.8
Check	5	25.5	8.8	20.8
(untreated)	11	20.8	12.0	21.3
	19	14.3	7.3	19.3

TABLE 7. Effect of insecticides applied 8/18/71 at low rates on the corn earworm and predators.

Insecticide	Rate/acre (lbs act.)	Avg no./8' row 8/21[a]			
		Earworms	Nabis	Geocoris punctipes	Spiders
Carbaryl	0.75	1.0a	4.3ab	2.5a	7.5a
Methomyl	0.13	2.0a	1.8a	3.3a	9.3a
Check		17.3b	6.0b	2.3a	9.3a

[a]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.

Nabis spp. and *Geocoris punctipes* (Say) confirmed results obtained by Lingren et al. (1968) on cotton. Large nymphs of either of these predators in small field cages consumed an average of 20 *H. zea* eggs in 24 hours.

Activity of different types of insecticides against nabids, geocorids and other predators was studied in 1970 and 1971. Data in Table 5 show combined numbers of nabids and geocorids on eight feet of row from September 17 through October 6 after treatments which included a side-dress soil application of aldicarb at 3.0 pounds actual and foliar sprays of Dipel *Bacillus thuringiensis* Berliner at 0.5, monocrotophos at 0.5 and carbaryl at 1.5 pounds. In aldicarb plots predators were significantly and progressively reduced during the season. Approximately three-fold reductions occurred in monocrotophos plots, with numbers in bacillus and carbaryl plots being similar to untreated checks.

In 1971 (Table 6) methyl parathion at 1.0 pound active was applied to plots eight rows wide by 50 feet long bordered by 6 or more untreated

TABLE 8. Effect of insecticides applied 8/10/71 on the green cloverworm, the bean leaf beetle, geocorids and spiders—Lewiston, North Carolina*.

Insecticide	Rate/acre (lbs act.)	Avg live/10' row 48 hrs posttreatment			
		Green cloverworm	Bean leaf beetle	Geocorids	Spiders
Methomyl	0.25	0.7	3.3	3.0	5.0
Carbaryl	0.25	0.0	0.0	2.0	4.3
Carbaryl	0.5	0.7	0.7	2.3	4.7
Check		3.7	11.8	3.2	6.3

*W. V. Campbell—unpublished data

rows to determine activity against *Nabis* spp., *G. punctipes*, and spiders. Counts were made 5, 11, and 19 days after application. Numbers of nabids and spiders were reduced substantially in treated plots and *G. punctipes* was essentially eliminated. No attempt was made to determine in-migration from untreated areas adjacent to plots.

Recent data from our station and from North Carolina indicate that certain conventional chemicals at low rates afford protection against pest species and allow adequate predator survival. Data in Table 7 show activity of foliar sprays of carbaryl at 0.75 and methomyl at 0.13 pounds against *Heliothis zea*, nabids, geocorids, and spiders. Excellent control of earworm was observed three days after treatment along with good predator survival. Data from North Carolina (Table 8) show that foliar applications of methomyl at 0.25 and carbaryl at 0.25 and 0.5 pounds active resulted in excellent control of the green cloverworm and the bean leaf beetle and allowed excellent survival of geocorids and spiders 48 hours after treatment.

We have shown that predators may be conserved through the judicious use of insecticides. The effect of indigenous predators on pest species in soybeans must be determined before adequate management practices can be developed. As suggested by DeBach and Huffaker (1971), such prey-natural enemy studies should include experimental analyses of the system involving paired comparisons of plots having enemies present with plots where enemies are absent.

MICROBIAL CONTROL OF LEPIDOPTEROUS LARVAE

Although affording excellent potential, research on microbial control of lepidopterous larvae in soybeans has been limited primarily to field-

screening of advanced strains of *Bacillus thuringiensis* in some states and to studies of *Entomophthora sp.* infecting the soybean looper. Populations of most lepidopterous pests have been "destroyed" at times by naturally-occurring epizootics of *Spicaria rileyi*, but efforts to enhance its effectiveness have been unsuccessful. As recently as 1971, early-developing populations of the corn-earworm in South Carolina were decimated by late August, before economic losses to pods had occurred.

Recent field-screening tests with advanced strains of *Bacillus* in South Carolina, Florida (G. L. Greene pers. comm.), and other states indicate that the green cloverworm and the velvetbean caterpillar are controlled with economical rates. Higher rates have controlled the soybean looper and given erratic suppression of the corn earworm. Additional research is necessary to determine effective rates against these two species, but it appears that present cost of applications will be prohibitive.

Populations of the soybean looper are often controlled by naturally-occurring epizootics of an *Entomophthora* species. A recent breakthrough in the study of this organism came through development of media for its culture in Alabama (Lin and Harper 1972) and Louisiana (L. D. Newsom pers. comm.).

Productive results should be obtained from additional research on improvement of the performance of bacillus alone and in combination with selective chemicals, and from basic studies on field epizootics of species of *Spicaria* and *Entomophthora*.

As suggested by Cameron (1971) we should take advantage of the selectivity of pathogens to reduce the pest, while leaving parasites and predators unharmed.

Host Plant Resistance

The greatest potential for effective management of soybean insect pests is available through development of resistant host plants. Pathak (1970) emphasized the compatability of resistance with other methods of control by indicating that insects on resistant plants are often restless and less vigorous—rendering them more susceptible to environmental variations, to predators and to insecticides.

Recent studies in South Carolina (Van Duyn et al. 1971; 1972 in press) indicated that high levels of resistance to the Mexican bean beetle were present in certain plant introductions in maturity groups VII and VIII. Research in North Carolina (W. V. Campbell pers. comm.) with groups VI and VII produced similar results.

TABLE 9. Numbers of adults, egg masses and larvae of the Mexican bean beetle on resistant and susceptible soybean lines—Blackville, South Carolina—1969.

Plant introduction[a]	Avg. no./4′ row[b]		
	Adults	Egg masses	Larvae
171,451–R	3.5b	0.5a	41.0a
227,687–R	1.8a	1.5a	63.0a
274,507–S	18.0b	12.0b	425.5b
229,358–R	3.3a	0.5a	49.3a

[a]R = resistant; S = susceptible.
[b]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.

TABLE 10. Mortality and weight gain of Mexican bean beetle larvae reared on resistant and susceptible soybean foliage—Blackville, S. C.—1970[a].

Plant introduction[b]	% Mortality in 20 days	Avg wt (gm)	
		11 days	16 days
171,451–R	61.6b	.11b	.29c
227,687–R	85.9c	.09a	.23b
274,507–S	24.2a	.12b	.37d
229,358–R	89.2c	.09a	.15a

[a]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.
[b]R = resistant; S = susceptible.

Counts of adults, egg masses and larvae in resistant and susceptible lines are presented in Table 9. In the susceptible 274,507 there were 18 adults, 12 egg masses and over 400 larvae in four feet of row. Counts of each stage were significantly and substantially lower in the three most resistant lines. In the same P. I.s (Table 10) larval mortality was 24 percent on susceptible P. I. 274,507 and 89 percent on 229,358. After 16 days, larvae weighed 0.37 grams when fed on the susceptible line; 0.15 grams on 229,358; the two other resistant lines caused intermediate weights. Life span and fecundity of adults reared on these resistant and susceptible P. I.s are indicated in Table 11. Adults reared on susceptible foliage lived twice as long as those reared on resistant foliage; egg production ranged from 137 for P. I. 274,507 to three for 227,687.

Data from North Carolina (Table 12) show percent defoliation from the Mexican bean beetle and the bean leaf beetle on resistant P. I.s 229,-

TABLE 11. Life span and fecundity of Mexican bean beetle adults reared on resistant and susceptible soybean foliage—Blackville, S. C.—1969[a].

Plant introduction[b]	Life span (days)	Avg. no. eggs/female
171,451-R	13.9a	21.1b
227,687-R	11.5a	3.1a
274,507-S	22.9b	137.4c
229,358-R	12.5a	7.4a

[a]Means followed by the same letter are not significantly different at the 5% level; Duncan's multiple range test.
[b]R = resistant; S = susceptible.

TABLE 12. Percent defoliation by the Mexican bean beetle and the bean leaf beetle on resistant and susceptible lines—Lewiston, North Carolina—1970.

Soybean line[a]	% defoliation 9/11	
	Mexican Bean beetle	Bean leaf beetle
P. I. 229,358-R	0.0	3.3
P. I. 171,451-R	0.3	6.0
P. I. 192,870-S	43.3	23.3
'Lee'-S	31.7	16.7

[a]R = resistant; S = susceptible.

358 and 171,451; on susceptible 192,870 and the Lee cultivar (W. V. Campbell unpublished). There was excellent resistance to the Mexican bean beetle and a three to five-fold reduction in damage from the bean leaf beetle. In Mississippi, Clark et al. (1970) reported that certain of the same P. I.s were resistant to the bean leaf beetle and the striped blister beetle, *Epicauta vittata* (Fabricius). Newsom (pers. comm.) indicated that in Louisiana none of the lines offered adequate resistance to the soybean looper, although slight differences in initial feeding occurred. Additional field screening of a wide range of germ plasm is necessary to determine possible resistance to other major pest species, particularly to lepidopterous larvae and stink bugs.

Advanced lines being developed for resistance to major pest species must also be checked for possible increases in population levels of minor pest species. I reported (Turnipseed 1972a) differences in populations of the potato leafhopper, *Empoasca fabae* (Harris), that were caused by

TABLE 13. Measurements of leaf pubescence and numbers of potato leafhopper adults on 'Lee' isolines and Mexican bean beetle resistant plant introductions—Blackville, South Carolina—1971.

Line	No. leaf hairs in 26 sq mm	E. fabae in 20' D-Vac (4 dates)		Leaf hair measurements	
		Adults	Nymphs	Length of longest (mm)	Errectness (%)
Glabrous	—	70.6	9.2	—	—
Normal	93	4.8	0.6	1.2	85
Dense	306	20.4	2.8	0.9	61
227,687	342	19.4	3.2	1.0	65
229,358	58	1.5	0.1	1.6	90

relative length and erectness of leaf hairs (Table 13). Hairs were absent in Lee glabrous; were of normal density in both Lee normal and 229,358; and three to five times normal density in Lee dense and in 227,687. In Lee glabrous, without hairs, there were 70.6 adults and 9.2 nymphs per 20 ft D-Vac sample. Of the four lines with hairs, populations were highest in Lee dense and in 227,687; both having longest hairs of approximately one mm and erectness of 60 to 65 percent. In Lee normal, hairs were 1.2 mm long and 85 percent erect, and adults averaged 4.8 and nymphs 0.6. Populations were lowest in 229,358 which had the longest and most erect hairs. Also, lower populations of the green cloverworm were observed on cultivars having long, erect pubescence than on shorter less erect hair types. In developing host plant resistance, presence of hairs must be maintained, and these should be of adequate length and erectness.

Lines resistant to the Mexican bean beetle have been crossed with commercial varieties and F_3 progeny were tested during 1971. Stink bug damage has been assessed on seed from single plants selected for Mexican bean beetle resistance, and a wide range in damaged seed was found. In 1972 replicated plots of similar maturity will be evaluated for possible resistance to the stink bug complex. Evaluations of advanced breeding lines will be expanded and the whole bank of germ plasm in maturity groups VII and VIII will be screened against the pest complex. In a cooperative program involving North Carolina, Illinois and United States Department of Agriculture; earlier-maturing material will be screened in adapted areas. Complete interchange of results and breeding material should enhance the possibilities of relatively early successes.

The potential contribution of host plant resistance in newly develop-

ing soybean insect management systems is both promising and exciting. In a few short years new resistant varieties should eliminate the Mexican bean beetle as an economic pest and restrict economic losses from the bean leaf beetle. Also, adequate sources of resistance to other economic species can be expected.

Summary

In summary, I did not discuss many potentially fruitful areas of investigations such as importation of predators, parasites and pathogens; inundative releases of predators and parasites; use of sex attractants and growth regulating hormones in control procedures; effects of cultural practices and cropping systems on activity of destructive and beneficial species; and use of genetic manipulation to abate pests and enhance beneficials. However, the methods discussed in this paper (economic thresholds, chemical control, manipulation of predators, microbial control of lepidopterous larvae, and host plant resistance) can with increased research efforts provide a basis for constructing effective management systems for soybean insects.

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Sampling for Bean Leaf Beetle[1] Eggs: Extraction From the Soil and Location in Relation to Soybean Plants[2]

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ABSTRACT

The Illinois Egg Separator and associated techniques provide a rapid (9.5–16 minutes per sample) and consistently accurate (93.5% mean recovery rate) method for extracting *Cerotoma trifurcata* (Forster) eggs from the soil. Practically all the eggs found in a soybean field were in cylindrical samples 4 inches (10.2 cm) in diameter and 3 inches (7.6 cm) deep centered on plants in the row. Twenty-two of 30 such samples contained eggs, but only one of 120 samples taken between the rows contained any eggs. No eggs were found in samples taken from below a 3-inch depth.

The bean leaf beetle, *Cerotoma trifurcata* (Forster), long recognized as a pest of garden beans, also attacks soybeans in most of the important soybean-growing areas of the United States. Nevertheless, very little has been published on the biology of this insect beyond the useful but limited accounts by Eddy and Nettles (1930) and Isely (1930). In fact, so little is known of its biology that it would be impossible to make a reasonably accurate assessment of its total impact on the soybean ecosystem. For example, almost nothing is known of the ovipositional preferences of the adults, and very little is known of the behavior of the larvae in the soil or of the effect of their feeding on the plants.

One of the more technically difficult prerequisites to further studies is a method for separating the eggs from the soil. This paper describes the adaptation for this purpose of a technique originally described by Horsfall (1956) for extraction of floodwater mosquito eggs from soil samples. It also gives results of a survey which determined the location of bean leaf beetle eggs in soybean fields in relation to the plants.

Materials and Methods

Collection and Storage of Samples

The soil samples were taken in a field of 'Corsoy' soybeans approximately 6 miles south of Charleston, Ill. The 1st series of 10 groups of samples was taken Aug. 8, 1972, and the 2nd series of 11 groups Aug. 15, 1972. Each group consisted of 6 samples. Fig. 1 shows the diameter, depth, and position of each sample of a group in relation to the plants in the rows.

Samples C_a and C_b were cut in one operation with a cylindrical soil corer which was 4 in. (10.2 cm) diam and was provided with a close-fitting plunger for extruding the cores. Each cut, circular in cross section, was made to a depth of 6 in. (15.2 cm) and centered in the row on 1 plant or, more often, 2 or 3, of the closely spaced plants. The deeper sample (C_b) was separated from the upper sample (C_a) by extruding and cutting off the bottom 3 in. of the core. The C samples had a surface area of approximately 82 cm^2 and a volume of approximately 625 cm^3. The mean wet weights ±SE of the C_a and C_b samples were, respectively, 1,056±15 g and 1,012±23 g, indicating a reasonably even division of the cores.

The N and S samples were taken from the north and south sides, respectively, of the east-west running rows of plants. The centers of N_2 and S_2 were midway between adjacent rows. N_1 and S_1 were closer to the plants, centering on a point midway between the center of C and the center of N_2 or S_2. These samples were cut to a depth of 4 in. with a soil corer which was only 2¼ in. (5.7 cm) diam, but was otherwise similar to the one used to cut the C samples. The N samples had a surface area of approximately 26 cm^2 and a volume of approximately 265 cm^3. The N_1 and S_1 samples combined had a mean wet weight ±SE of 375±5.1 g, while the N_2 and S_2 samples combined had a mean wet weight ±SE of 430±3.9 g. The soil midway between rows appeared to be more compact than the soil closer to the plants, and this fact may explain the considerably greater weight of the N_2 and S_2 samples.

Each sample was placed in a strong plastic bag which was closed with a tie. After being weighed, the samples were stored in a cold room at 4°C. Previous experience had shown that bean leaf beetle eggs could be stored at this temperature for at least 4 weeks without hatching or undergoing any other visible change. All samples were run through the extraction process 3–16 days after they were collected.

Extraction of Eggs

The Illinois Egg Separator and the technique described by Horsfall (1956) has for many years been used by laboratories and mosquito-abatement districts for routine separation of eggs of floodwater mosquitoes from soil. Processing samples is rapid,

[1] Coleoptera: Chrysomelidae.

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and rate of recovery is consistently high. The method consists of using tap water to wash the sample through a series of sieves of decreasing mesh and then further cleaning by flotation the portion caught on the finest sieve. The eggs and some of the residual debris float in a saturated aqueous solution of NaCl. Sand and other heavy particles sink and are discarded. When transferred to tap water the eggs and a small portion of the remaining debris sink while most of the debris floats and is decanted and discarded. Details of the method and dimensions and plans for building the apparatus are given by Horsfall (1956). Other methods for extracting eggs from the soil are discussed by Southwood (1966).

We used the following equipment (see Fig. 2–5 and Horsfall 1956): (1) plastic pans (30×20×10 cm); (2) a hose with a nozzle which delivers anything from a wide cone of spray to a forceful jet; (3) 3 large removable superimposed sieves in a rotating rack, 16, 40, and 100 square mesh from top to bottom; (4) small transfer sieves (100 mesh) and a tripod to hold them; (5) a soil separatory funnel of glass with a 12-cm opening at the top and a 2-cm opening closed with a cork stopper at the bottom; (6) the bubbling stirrer, a hollow plexiglass stirring rod through which air is passed from an aquarium pump; (7) wash bottles filled with tap water or saturated NaCl solution; (8) white porcelain casseroles (150 ml). Since our samples were relatively free of large pieces of debris we did not tumble them in Horsfall's (1956) concentric cylindrical screens.

The extraction proceeds as follows: (1) the sample is put into a plastic pan, covered with tap water, and allowed to soak for 1 or 2 hr. (2) The sample is rinsed from the pan into the top sieve (16-mesh) of the superimposed set, and washed down through the sieves with a narrow and moderately forceful cone of spray. The sieves are shaped and arranged so as to minimize loss from the sample by splashing (Fig. 2). The 16- and 40-mesh sieves are removed when no more material passes through them; the material in the 100-mesh sieve is washed until relatively free from silt. The 100-mesh sieve frequently becomes clogged, but it is easily unclogged by directing a strong jet from the hose down through the backed-up water to the surface of the screen. (3) Tap water is used to wash the sample from the 100-mesh sieve into a plastic pan (Fig. 3) and from the pan into a transfer sieve where it is allowed to drain briefly. (4) With a wash bottle filled with salt solution the sample is washed into the soil-separatory funnel which is nearly full of salt solution and in which the bubbling stirrer has been placed (Fig. 4). The bubbles rising from the bottom prevent the rapidly settling debris from trapping eggs. After stirring above the settled portion for a few seconds

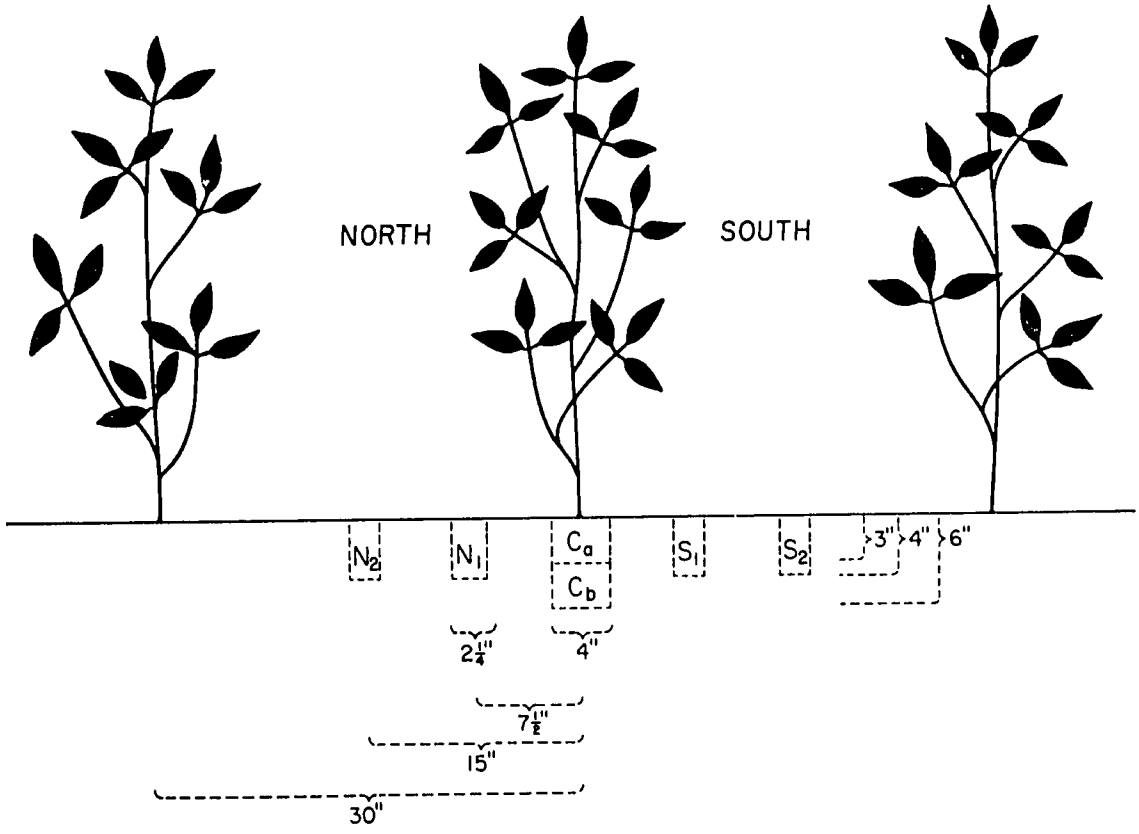

Fig. 1.—Location of samples in relation to rows of soybean plants.

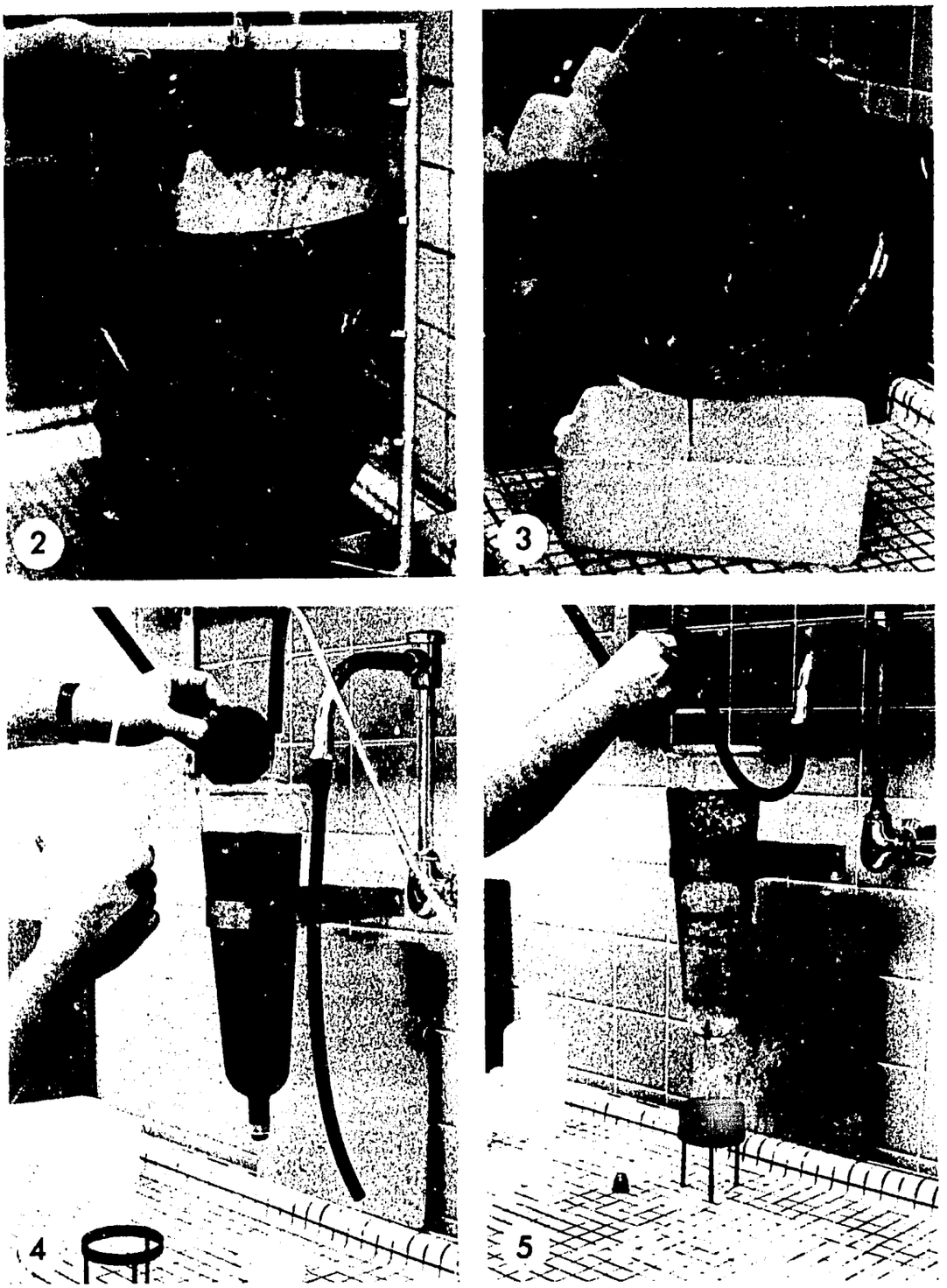

FIG. 2.—The superimposed sieves in their rotating rack. FIG. 3.—Transferring the sample from the 100-mesh sieve to a plastic pan. FIG. 4.—Washing the sample from the transfer sieve into the separatory funnel. Note the bubbling stirrer, tripod, and casserole. FIG. 5.—Washing eggs and debris caught on the side of the funnel into a transfer sieve.

Table 1.–Recovery of unhatched bean leaf beetle eggs mixed with various quantities of egg-free soil.

Wt. of soil in g	No. eggs added	No. eggs recovered	% recovery
?	11	11	100
?	10	10	100
300	10	10	100
400	10	9	90
400	10	8	80
400	20	17	85
400	20	19	95
400	20	20	100
450	9	9	100
450	9	8	89
1000	10	10	100
1000	20	19	95
1000	20	17	85
1000	20	18	90
Total or mean ±SE	199	185	93.5±1.86

the stirrer is withdrawn and the contents are allowed to settle. Within 1 or 2 min the eggs and a small amount of debris float to the top, while most of the debris settles to the bottom. (5) The deposit of sand and other heavy debris and all but 6 or 7 cm of the salt solution are drained into a plastic pan. The solution can be reused after being strained through a 100-mesh sieve. The remaining solution is drained through a transfer sieve, and all material caught on the sides of the funnel is washed into the same sieve with tap water (Fig. 5). (6) The material on the transfer sieve is washed into a casserole with tap water. Within a few minutes the eggs and some debris settle to the bottom, while a large amount of debris floats to the top. The floating debris and most of the water are decanted. (7) Under a dissecting microscope the eggs are picked out with a bulb pipette. If there is too much debris the samples can be stirred and divided among 2 or more casseroles.

The method is rapid. In one 8-hour working day one of us (G.P.W.) and a technician completely processed 51 samples including picking out and counting the eggs. This is about 9.5 min/sample. The time required to process a sample will, of course, vary with the amount of soil in the sample, its tendency to clog the sieves and the number of eggs it contains. For example, on the day just mentioned, we proceeded a little more rapidly than usual, since many of the samples were negative and we did not need to spend time picking out eggs. However, under most circumstances 2 people should be able to process at least 40 samples/day (12 min/sample). Exceptionally difficult samples might require as much as 16 min each.

During preliminary trials 1 or 2 eggs with bubbles clinging to them were found floating in tap water. Floating eggs would, of course, be lost when the debris is decanted from the casserole. Frequent examination of the material floating in the casseroles showed this to be a negligible source of error, since only 2 additional floating eggs were found. A brief immersion in 70% ethyl alcohol removes the bubbles and allows the eggs to sink in tap water. If necessary the transfer sieve could be dipped into alcohol before the sample is washed into the casserole. This would presumably remove all bubbles from the eggs.

The accuracy of the extraction method was tested by processing samples containing a known number of eggs. Soil free of bean leaf beetle eggs was taken from cornfields near Champaign. The eggs added to the soil had, in most instances, been laid in the laboratory by field-collected females; in a few instances the eggs had been extracted from field-collected soil. The soil in the Charleston soyb an field was a light silt-loam, while the soil used to test the accuracy of the method was silty clay-loam. The greater clay content of the latter made it more difficult to wash through the sieves and probably increased the rigor of the test.

The effect of the saturated solution of NaCl on the hatchability of the eggs was determined by immersing laboratory-laid eggs in the solution for varying durations. A transfer sieve containing eggs was placed in a pan containing salt solution. After the appropriate interval the eggs were rinsed by placing the sieve in a pan of tap water. The eggs were washed onto Cellucotton®, kept in covered petri dishes and examined frequently until no more hatched.

The reticulated orange eggs of the bean leaf beetle were described by Chittenden (1897) and described and figured by Eddy and Nettles (1930) and Isely (1930). The eggs we extracted from soil samples were identified by comparing them with eggs laid in the laboratory.

Results and Discussion

The Illinois Egg Separator gave a consistently high recovery of bean leaf beetle eggs from both large and small samples (Table 1). The mean recovery of 93.5% was higher than the routinely attained 80–85% recovery of mosquito eggs from samples taken on the flood plains of rivers (Horsfall 1956, and personal communication). Perhaps the difference could be accounted for by the greater size and visibility of bean leaf beetle eggs and by the lesser amount of organic debris in samples from crop fields as compared with samples from flood plains.

Table 2.–Hatchability of bean leaf beetle eggs immersed in a saturated solution of NaCl for varying durations.

Minutes in NaCl	No. eggs	No. eggs hatched	% hatched
0[a]	36	32	88.9
1	34	32	94.1
5	35	35	100.0
10	35	33	94.3

[a] Control group handled as were other groups but immersed in tap water for 1 min.

Table 3.—Numbers of bean leaf beetle eggs found in soil samples taken in a soybean field at different depths and positions in relation to the rows of plants. Each sample in Series I was replicated 19 times and 11 times each in Series II. (See Fig. 1 for sample locations.)

Sample location	No. eggs Total	No. eggs Mean per sample ±SE	Samples with eggs No.	Samples with eggs %
Series I (Aug. 8)				
N_2	0	0	0	0
N_1	12	0.6	1	5.3
C_a	213	11.2±2.9	14	73.7
C_b	0	0	0	0
S_1	0	0	0	0
S_2	0	0	0	0
Series II (Aug. 15)				
N_2	0	0	0	0
N_1	0	0	0	0
C_a	46	4.2±1.8	8	72.7
C_b	0	0	0	0
S_1	0	0	0	0
S_2	0	0	0	0

Eggs immersed in salt solution for 1–10 min were as viable as the eggs in a control group which had been immersed in tap water 1 min (Table 2). Measurements made during the routine processing of our samples showed that the eggs in 10 samples spent a mean of 2.5 min (ranging from 117 to 211 sec) in the salt solution. The exposure to salt solution during routine extraction will have no effect on hatchability of bean leaf beetle eggs. In any event, survival of the embryos is not essential to a valid sampling procedure.

Tables 3 and 4 show distribution of eggs among samples taken at various points in relation to the rows of plants (see Fig. 1 for location of the samples). The results are clear and show that practically all the eggs were in the C_a samples; that is, within a 5-cm radius of the stem of a soybean plant and at a depth no greater than 7.6 cm. The only exception was a single N_1 sample which contained 12 eggs. Thus, while eggs were found in about 73% of the C_a samples, they were found in only 1 of the 120 samples taken between the rows and in none of the deep (C_b) samples. The C_a samples contained a mean of 10.66 eggs/100 cm² of soil, while the combined N and S samples contained only 0.39/100 cm² (Table 4).

The difference in numbers of eggs found in the samples taken Aug. 8 and 15 probably reflects a decrease in the population of ovipositing adults. Unpublished data show that the number of 1st-generation adults peaked shortly before we collected our samples and was decreasing during the first 2 weeks of August.

Our findings are consistent with statements in the literature. Chittendenden (1897), Eddy and Nettles (1930), and Isely (1930) stated that the eggs are laid on or near the stem of the host plant just beneath the surface of the soil. None of them, however, presented any supporting evidence. Our own observations of field-collected beetles in the laboratory indicate that the eggs are almost always laid on or near the tissues of bean plants. A few eggs were laid on the leaves of bean plants in the cages, but most were laid in the wet Cellucotton® surrounding the stems where they entered the jars of water. In one instance a petri dish full of moist soil and another containing a moist pad of Cellucotton® were placed on the floor of the cage. Only a few eggs were laid on the Cellucotton® and none in the soil, although many were laid in the Cellucotton® surrounding the stem of the plant, and a small bud lying on the floor of the cage was covered with eggs.

In several samples we found the empty shells of hatched bean leaf beetle eggs. They have an irregular hole in one end, may be more or less collapsed, and are pink rather than orange. However, the reticulate pattern of the chorion is easily recognized. Most of them were found floating in tap water in the casserole, but a few had sunk to the bottom. We made one recovery trial using 10 empty shells in about 350 g of soil. We recovered 8; 5 were floating and 3 were sunken. The consistent recovery of a large proportion of empty shells may be feasible but will be more time consuming than recovery of unhatched eggs. Furthermore, the significance of the results will not be clear unless it is known how long empty shells survive in nature.

Our results show that a reliable technique for making a survey of bean leaf beetle eggs includes taking samples which consist of the soil around the base of a soybean plant and extracting the eggs from the samples with the Illinois Egg Separator. Future work may show that the volume of the sample (currently

Table 4.—Numbers of bean leaf beetle eggs found in soil samples taken between rows of soybean plants and at 2 depths within rows.

Sample location	Total eggs	Eggs/ 100 cm²	No. positive samples	No. samples	Total area of samples (cm²)
Centered on plants					
Surface to 7.6 cm deep	259	10.66	22	30	2432
7.6 cm–15.2 cm deep	0	0	0	30	2432
Between plant rows					
Surface to 10.2 cm deep	12	0.39	1	120	3078

625 cm^3) may be reduced without reducing the sensitivity of the survey method. This would, of course, speed up the extraction process. It may not be possible to reduce the area of the sample, but it is probably not necessary to cut to a depth of 3 in. (7.6 cm).

Acknowledgment

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Part 2

BIONOMICS OF MAJOR PESTS

Population Dynamics and Biotic Controls of the Soybean Looper[1] in Louisiana[2]

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ABSTRACT

Population levels of *Pseudoplusia includens* (Walker) were found to vary considerably among agricultural ecosystems in Louisiana. The cotton, corn, and soybean ecosystem was characterized by a dense larval population in late August or September.

Parasitism was inversely related to population density and to the amount of pesticides used in the surrounding area. *Apanteles scitulus* Riley and *Copidosoma truncatellum* (Dalman) were the predominant parasites, while *Lespesia aletiae* (Riley) was of lesser importance.

The fungal pathogens *Spicaria rileyi* (Farlow) Charles and *Massospora* sp. attacked the soybean looper larvae at different periods and densities. *S. rileyi* appeared in midsummer at relatively low population densities, while *Massospora* sp. was present only in late August or September in very dense larval populations.

In recent years, Louisiana's production of soybeans has increased rapidly. In 1968, approximately 1,436,000 acres were planted to soybeans in Louisiana (Field et al. 1968). The increase in acreage has occurred in 3 distinctly different agricultural ecosystems: (1) the area of traditional cotton, corn, and soybean production where soybeans have been grown for more than 40 years, and in which a long history of heavy pesticide application, for cotton-insect control, has occurred; (2) the recently cleared hardwood swamps in alluvial areas where over ½ million acres are now producing soybeans, and in which no pesticide application occurred prior to soybean production in 1967; and (3) the area of traditional rice production where about ¼ million acres of soybeans are now produced on land that had never been planted to soybeans prior to about 1964. This area has had little previous pesticide application except aldrin, which was used as a seed dressing for rice.

It was observed that the level of infestations of the soypean looper, *Pseudoplusia includens* (Walker), varied among the foregoing ecosystems and that this variation was proportional to the amount of pesticide presently used in the area. Thus this study was conducted to evaluate the importance of various biotic factors in the population dynamics in the 3 agricultural ecosystems.

Methods and Materials

Soybean looper larvae and pupae were obtained by making a weekly collection at sites chosen as representative of the 3 ecosystems. Collections were made from June 17 until Sept. 13, 1968, and from June 19 until Sept. 24, 1969. Three plots were sampled at each site with a 15-in.-diam cloth insect net by making 100 sweeps at 10 different locations in each plot, 1/12 of an acre. When the numbers of larvae were extremely low, additional sweeps were taken to increase the number of larvae per sample.

The number of larvae per acre was obtained by multiplying the average number of larvae collected per 100 sweeps, times the area of the insect net (1.2 ft^2) and dividing into 1 acre. This yielded a factor of 363, which was used to estimate density and mortality on an acre basis. The average percent parasitism and fungal infection were subtracted from the per-acre larval estimate to yield the average number of survivors per week during each generation. The survival ratio is formulated by dividing the estimated number of survivors by the initial sample, thus sample size is considered in each case.

The collected larvae were placed into jelly dishes

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which contained a synthetic medium for *Heliothis* spp. (Berger 1963, Burton 1969). The jelly dishes were stored on trays in a controlled-temperature cabinet at 27±2°C and a photoperiod regime of 14 hr light, 10 hr dark. The RH was maintained at approximately 80–90%.

Larvae were identified by the characteristics presented by Crumb (1956), Canerday and Arant (1967), and Eichlin and Cunningham (1969). The generation sequences were based upon laboratory and field observations as well as upon the life cycle presented by Mitchell (1967) and Canerday and Arant (1967). Collected larvae were observed at 1- or 2-day intervals, at which time the numbers of emerging parasites and deaths caused by the fungal pathogens *Spicaria rileyi* (Farlow) Charles, and *Massospora* sp. were recorded. Parasites were identified by personnel of the Systematic Entomology Laboratory, Entomology Research Division, Agr. Res. Serv., USDA.[4] Fungal pathogens were identified by Dr. Batra of the Insect Pathology Laboratory, Entomology Research Division. The nematode was tentatively identified by Dr. Birchfield of Louisiana State University. The larvae were recorded as having succumbed to *S. rileyi* if they exhibited the symptoms observed by Getzin (1961) and Behnke and Paschke (1966) on the cabbage looper, *Trichoplusia ni* (Hübner). Mortality attributable to *Massospora* sp. was based upon presence of whitish mycelium similar to *Entomophthora* sp. (Yendol and Paschke 1967), the presence of internal conidia, and matured or partially matured internal azygospores (Sawyer 1933). *Massospora* sp. identification is tentative at this time.

Results and Discussion

Seven species of parasites, 1 hyperparasite, 1 nematode, and 2 fungal pathogens attacked the soybean looper larvae collected during the 2-year study. The parasites were *Apanteles scitulus* Riley, *Brachymeria ovata* (Say), *Copidosoma truncatellum* (Dalman), *Chaetophlepsis eudryae* (Smith), *Lespesia aletiae* (Riley), *Meteorus autographae* Muesebeck, and *Rogas molestus* Cresson (Burleigh 1971). The hyperparasite, nematode, and pathogens were: *Mesochorus* sp., a mermithid, and *S. rileyi* and *Massospora* sp., respectively.

Rice Ecosystem

In 1968, the rice ecosystem soybean looper population did not exceed 3.5 larvae/100 sweeps (Fig. 1). Although the larval population was not very dense compared with the other sites, the percent parasitism was much higher. Early-season mortality was the result of parasitism alone, while later mortality was a function of parasitism and *S. rileyi* infection. *S. rileyi* played a more important role as the season progressed, until on the 10th week of the study the combined biotic factors gave approximately 100% control.

[4] P. M. Marsh, L. M. Walkley, B. D. Burks, and C. W. Sabrosky.

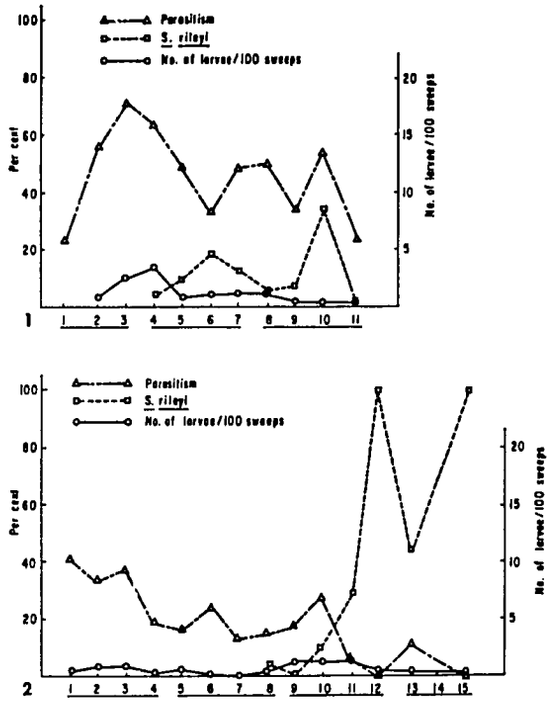

FIG. 1,2.—Soybean looper larval population levels, percent parasitism, and *S. rileyi* infection in the rice ecosystem. Fig. 1, 1968; Fig. 2, 1969.

The ratio of larvae that were not attacked by insect parasites or *S. rileyi* to the number of larvae collected per 100 sweeps was fairly constant in all 3 generations (Table 1). The data indicated that the combined effect of these mortality agents exerted approximately the same amount of control on all generations, even though the sequence of importance differed.

Parasitism was primarily due to *A. scitulus* and *C. truncatellum*, with the former being responsible for most parasitism from the 1st to 6th week and the latter from the 6th to 11th week. *S. rileyi* did not become a factor until the 8th week (Fig. 1).

In 1969, the soybean looper population dynamics followed a pattern similar to 1968, except the highest level of infestation was only 1.5 larvae/100 sweeps (Fig. 2).

The rate of parasitism was lower in 1969. This reduced rate of parasitism may have been due to an abundance of larvae of the bollworm, *Heliothis zea* (Boddie), early in the season, and large numbers of velvet bean caterpillars, *Anticarsia gemmatalis* Hübner, in the late season, serving as preferred alternate hosts for some of the parasites; e.g., *A. scitulus* was observed emerging from *H. zea* larvae. However, a concurrent reduction in the rate of parasitism was observed among all sites in 1969, as opposed to 1968, suggesting that the reduced rate of parasitism was due to an unknown factor(s) and not to a change in host.

Table 1.—Effect of various mortality factors on the average number of soybean loopers per generation.[a]

Generation	Larvae/ 100 sweeps			Larvae/ acre			% parasitized			% *S. rileyi* infection			% *Massospora* sp. infection			Survivors/ acre		
	A[b]	B[b]	C[b]	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
								1968										
1	1.6	0.1	0.1	581	36	36	63.7	31.6	30.1	0	0	0				211	25	25
2	1.6	1.5	.2	581	545	73	48.6	25.5	10.3	11.5	3.2	20.3				232	389	51
3	0.5	3.2	15.7	182	1162	5699	40.3	25.5	6.3	12.1	5.0	18.9				87	808	4263
								1969										
1	.6	—	.04	218	—	15	32.4	—	0	0	—	0	0	0	0	147	—	15
2	.3	.5	.3	109	182	109	16.7	16.3	20.4	.8	0.4	0.5	0	0	2.1	90	152	84
3	1.1	12.5	46.9	399	4538	17025	13.1	12.9	5.6	35.0	10.7	.3	0	0	13.6	207	3467	13705
4	.2	2.6	66.7	73	944	24212	5.6	7.9	0	72.0	56.4	.3	0	0	71.4	16	337	6852

[a] All data are averages.
[b] A, rice agricultural ecosystem; B, cleared hardwood forest ecosystem; C, cotton and soybean ecosystem.

The ratio of surviving larvae, estimated number of larvae per acre minus mortality caused by parasitism and fungal pathogens, divided by initial number per acre, was not so constant among generations as in 1968 (Table 1). There were higher survival ratios in the 1st, 2nd, and 3rd generations, but the 4th-generation survival ratio was lower. The reduced rate of parasitism in 1969 was responsible for the higher survival ratios in the 1st 3 generations, while the reduced survival rate in the 4th generation was a function of the *S. rileyi* epizootic. The *S. rileyi* epizootic had erupted in the dense velvetbean caterpillar population and carried over onto the soybean looper larvae.

A. scitulus and *C. trancatellum* were again the major parasites and were present over the same time sequence. *S. rileyi* was thus responsible for the population decline in September. The concurrent decline in parasitism was due to interference by the fungal pathogen.

Cleared Hardwood Forest Ecosystem

In 1968, the cleared hardwood forest ecosystem soybean looper population remained at a low level of density until the last few weeks of the study (Fig. 3), at which time the population reached a level of 6.0 larvae/100 sweeps.

Parasitism was responsible for control until the 5th week, after which *S. rileyi* was a contributing factor. The level of parasitism was fairly constant but did not reach the levels obtained in the rice ecosystem in 1968. Larval survival was higher in the rice ecosystem in 1968 because of the relatively low and constant rate of mortality (Table 1).

C. truncatellum and *L. aletiae* were the predominant parasites, with both occurring in late July and August.

The soybean looper population was held fairly constant until the last few weeks of the season, at which time the fields were treated with 0.5 lb/acre of methyl parathion for control of the bean leaf beetle, *Cerotoma trifurcata* (Forster), around the last of August. The marked reduction of the beetle population by the insecticide may largely account for the subsequent increase in the soybean looper population, because their activity could have: (1) reduced the food source; and (2) destroyed some of the soybean looper eggs, thereby surpressing the population. Their removal eliminated this restraint and permitted the population to expand. To compound the picture, there was a drop in parasitism following the pesticide application (Fig. 3), thus, the soybean looper population was affected by at least 3 factors: (1) parasitism, (2) *S. rileyi* infection, and (3) competition from the bean leaf beetles.

In 1969, the soybean looper population reached a much higher density (Fig. 4). This density, 28.7 larvae/100 sweeps, was just below the economic threshold. The number of survivors in the 3rd generation was much higher than in 1968 (Table 1). The lower rate of parasitism was responsible for the higher survival rate in the 2nd and 3rd generations, while reduced survival of the 4th generation was caused by the *S. rileyi* epizootic.

Insect parasites exerted their influence during the early part of the season, and *S. rileyi* during the latter part. *C. truncatellum* was again the principal parasite, while *A. scitulus* replaced *L. aletiae* as the 2nd most abundant parasite.

The high level of *S. rileyi* infection was caused by the abundant inoculum that resulted from an epizootic in the dense velvetbean caterpillar population. This pest became so abundant that the growers sprayed the plots with 0.25 lb/acre of methyl parathion around the 10th week of the study. This application may have been partially responsible for the increase in the soybean looper population a few weeks later because of the adverse effects on the parasites and predators. Without the high incidence of *S. rileyi* in September, the soybean looper population would have reached a level of concern to the grower. The rate of *S. rileyi* infection did not approach that of the rice ecosystem, possibly because elimination of the velvetbean caterpillar population by the insecticide destroyed the primary host for

S. rileyi. This reduced the combined larval density, therefore reducing the effect of this agent.

Cotton Ecosystem

In the cotton agricultural ecosystem, the soybean looper's population dynamics differed tremendously from the previously discussed examples. The level of infestation increased slowly until early August, then the population reached a maximum density of 37.4 larvae/100 sweeps during early September and then declined abruptly (Fig. 5).

Early-season parasitism was comparable to the levels observed at the other sites but declined abruptly after the 5th week. From that point onward, parasitism was of minor significance (Fig. 5). *C. truncatellum* and *L. aletiae* were the principal parasites. Once parasitism declined, *S. rileyi* began to occur and soon became the major mortality factor. The level of *S. rileyi* infection increased with the expanding soybean looper population but then declined apruptly. This decline was caused by either absence of susceptible instars, unfavorable climatic conditions, or by interference from *Massospora* sp. infection. This fungal pathogen was responsible for the sharp decline in the soybean looper population. The mortality caused by *Massospora* sp. was not recorded in 1968 because of the lack of familiarity with identifying symptoms. However, larvae collected on the 12th week had 68% infected with

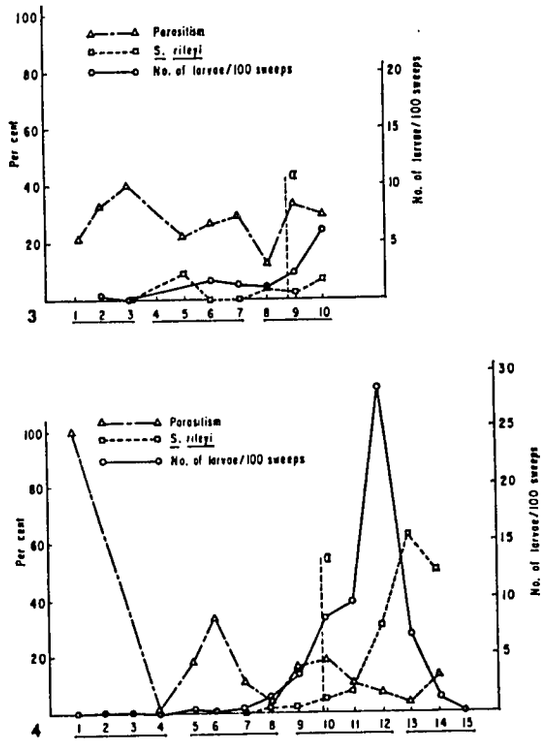

FIG. 3, 4.—Soybean looper larval population levels, percent parasitism, and *S. rileyi* infection in the cleared hardwood ecosystem. Fig. 3, 1968; Fig. 4, 1969. *a*, Pesticide applied.

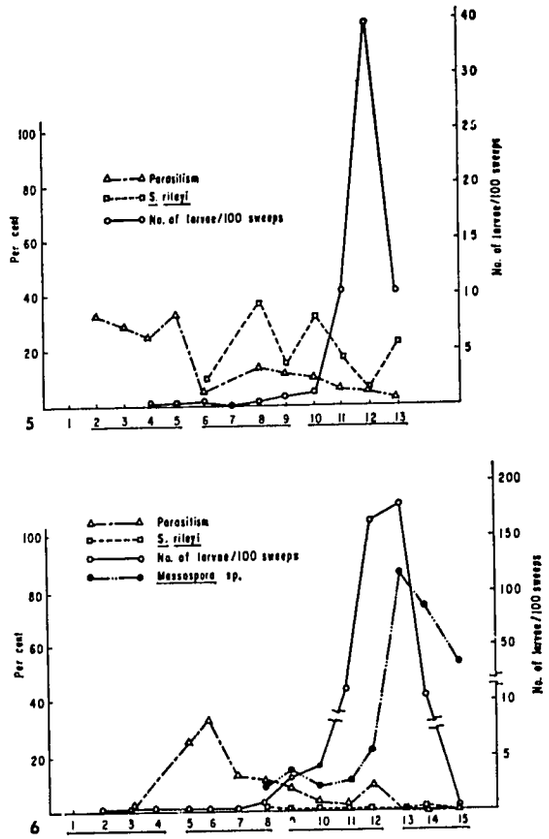

FIG. 5, 6.—Soybean looper larval population levels, percent parasitism, and *S. rileyi* infection in the cotton ecosystem. Fig. 5, 1968; Fig. 6, 1969.

Massospora sp., and most of the miscellaneous mortality during the last 2 weeks was subsequently ascribed to *Massospora* sp.

In 1969, the soybean looper population dynamics followed a pattern similar to that of the previous year, with the exception that the level of density was much higher. A maximum of 187.4 larvae/100 sweeps was recorded on the 13th week of the study (Fig. 6).

A high percentage of parasitism occurred in midseason and then declined toward the end of July. A similar pattern had occurred in 1968. This decline coincided with the application of insecticides for control of cotton pests in the adjacent fields. *C. truncatellum* was the predominant parasite, while *A. scitulus* was of secondary importance.

S. rileyi did not exert much influence on the soybean looper population in 1969 (Fig. 6). The low rate of *S. rileyi* infection and parasitism may have been the reason the population reached such a high density. There was no appreciable difference in climatic conditions between years or areas.

Massospora sp. infection was the major mortality factor of the dense soybean looper population. The appearance of this pathogen coincided with a popu-

lation density of from 20 to 50 larvae/100 sweeps. The pathogen occurred in late August through September and accounted for 86% mortality in mid-September (Fig. 6).

In both years, *Massospora* sp. occurred in late August and early September when the soybean looper population had reached a high density. In 1969, a *Massosopora* sp. epizootic did not occur in the cleared hardwood forest ecosystem even though the soybean loopers reached a level of density comparable with the 1968 cotton ecosystem population. The absence of this pathogen from the former site may have been due to (1) an inadequate host density, (2) lack of inoculum, or (3) unfavorable climatic conditions. The 1st explanation appears most reasonable, because a few larvae were observed succumbing to *Massospora* sp. Thus, a source of inoculum was present, and the climatic conditions do not vary greatly in southwest Louisiana during the summer (Anonymous 1968). Therefore, this pathogen apparently exhibited the density-dependent relationship that is generally accepted for microbial pathogens (Nicholson 1933, Tanada 1963).

The survival ratio of the 1st generation of loopers in 1969 was higher than in the cleared hardwood ecosystem because of the absence of loopers in the latter. However, the survival ratio was approximately the same in the 2 subsequent generations (Table 1). Even though these 2 areas had equal survival ratios in the latter generations, the cotton ecosystem population reached a higher density. A possible explanation for the discrepancy in population densities might lie in the fact that the amount of food, in the form of cotton nectar, is available in the cotton area only. Laboratory tests showed that unfed moths produced few or no eggs, whereas those fed 10% honey, 10% sugar water, or nectar from 10 cotton blossoms/day produced about 700 eggs/female (L. D. Newsom, Department of Entomology, Louisiana State University, personal communication). This phenomenon may account for the rapid increase in the soybean looper population in the cotton area at a time that coincides with peak flowering in cotton. The lower rate of parasitism may be caused by the abundant production of progeny because of the enhanced food supply and not by reduced parasitism caused by use of pesticides in the adjacent field. The actual number of parasitized larvae increased as the season progressed, but the percent parasitized declined (Table 1).

Conclusions

The soybean looper goes through 4 generations/year in Louisiana soybean fields. The rice ecosystem was characterized by low levels of soybean looper infestations and high rates of parasitism. The cleared hardwood forest ecosystem held a median position in both larval density and parasitism. The cotton ecosystem was characterized by a dense larval population in August or September and a reduced rate of parasitism.

Parasitism was the main mortality factor in the 1st larval generation at all sites, and *S. rileyi* became more important as the season progressed. *Massospora* sp. was an effective pathogen in the cotton ecosystem when the population density reached a high level.

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A study in East Africa of the bean flies (Dipt., Agromyzidae) affecting *Phaseolus vulgaris* and of their natural enemies, with the description of a new species of *Melanagromyza* Hend.

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Introduction

Melanagromyza phaseoli (Tryon), known as the bean fly, has been reported as a serious pest of French beans (*Phaseolus vulgaris*) in many parts of the tropics and warm temperate regions since its discovery and description by Tryon in 1895 (cited by Spencer, 1959), but it was not reported in East Africa until Harris (1937) published a list of pests of Tanganyika. Wallace (1939) reviewed the pests of beans in East Africa and gave a short account of the history of its discovery in Kenya in 1939 and in Uganda in the 1920's. Uganda specimens were identified tentatively as *M. sojae* (Zhnt.) and listed as such by Le Pelley (1959), but recent identifications, all of *M. phaseoli*, suggest strongly that this identification of *M. sojae* was erroneous.

Although, as pointed out by Wallace (1939), damage is frequently quite serious and infestations of 100% have been reported, little attention has been paid to the pest except by Walker (1960) who found that insecticidal seed dressings gave effective control, and by Swaine (1969) who confirmed this result.

The present study resulted from a request from the Mauritius Government for parasites for use in biological control of bean flies. In the course of this work it was noticed that some puparia were black, not brown as is usual, and that oviposition occurred in the hypocotyl as well as in the leaves. These discrepancies and peculiarities of parasitism led to the discovery that in East Africa there are two species of "bean fly" the adults of which are identical except for the genitalia. A third Agromyzid, *Ophiomyia centrosematis* (de Meij.), was also present and formed part of the complex of stem-mining Agromyzidae affecting beans.

Data on the life-cycle and incidence of these flies and their parasites are presented here. The life-history of *M. phaseoli* has been described in detail by previous authors (*e.g.*, Jack, 1913; Otanes y Quesales, 1918; van der Goot, 1930; Hassan, 1947) but is summarised here for comparison with the other species.

Methods

At the outset it was desired to ascertain only the identity, distribution and importance of the parasites present in East Africa. For this purpose, infested plants were placed in emergence boxes, or individually in 6×1-in. specimen tubes.

Later, when dissections were made and the presence of more than one host species was recognised, all further work was done using randomly collected bean plants from specially planted plots on research stations. The lower five inches of the plants were cut off and placed in 6×1-in. tubes with a gauze top. As emergence of adults began about 30 days after the plants had appeared above ground, samples were taken 25–30 days after appearance in order to obtain the first emergents. Such plants continued to produce adult insects for about four weeks during which most flies and parasites developing in the lower part of the plant emerged. Series of weekly or fortnightly samples were taken also from the same plantings to ascertain the course of

Editor's Note - Melanagromyza phaseoli (Tyron) and M. spencerella Greathead subsequently have been transferred to the genus Ophiomyia (ref.: Spencer, K. A. 1973. Agromyzidae of Economic Importance. *Series Entomologica*, Volume 9, Dr. W. Junk B. V., The Hague. 418 + *xi* p.).

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infestation throughout the life of the bean plant. These investigations (*e.g.*, Fig. 24–25) indicated that most flies emerge during the first month, and subsequent sampling was restricted to this period.

Whenever an insect emerged the plant was examined for the puparium from which it had issued, and after emergence was complete each plant was dissected and all unemerged puparia examined.

These studies were supplemented, on two occasions, by dissection of samples of 20 plants at two- or three-day intervals from the date of appearance above ground in order to trace the life-cycles of the flies and parasites. To check these results, adult flies of known species were placed on potted bean plants covered by a lamp glass and a mutilation experiment was carried out. This consisted of uprooting 100 plants when five days old, cutting them above the cotyledons and growing the tops in sand culture, so as to isolate larvae originating in the upper part of the plant. A second 100 plants in the field were cut off at the level of the cotyledons, so as to isolate larvae originating in the lower part of the plant. In spite of this drastic treatment sufficient plants and larvae survived to confirm the course of development of the two *Melanagromyza* species.

The bean fly complex

In distinguishing the species, use is made of characters of the ovipositor which in fresh material can be everted by squeezing the abdomen. In dry material a technique of forcing eversion has not been found but if the abdomen is soaked in potash the blades can be teased out. The ovipositor (Fig. 4) consists of a membraneous tube covered with a pattern of black thorn-like spines and bears at its apex a pair of pointed knife-like blades serrated like a saw on the outer surface, and a narrow membraneous tube on the dorsal side terminating in a pair of more heavily sclerotised rod-like processes. The opening of the oviduct lies between the blades, implying that the narrow tube and its processes represent the tenth segment and the cerci.

Melanagromyza phaseoli

Spencer (1959) gave a synopsis of the synonymy, host-plants and life-cycle as well as a description of the external characters of this species. The same author (1963) in a paper on the Australian Agromyzidae illustrated the aedeagus.

M. phaseoli belongs to the group of small black species which includes epidermal miners (Spencer, 1959, p. 259, couplet 57); within this group it is distinguished from all other species except *M. spencerella* in having an unusually elongate shining ocellar

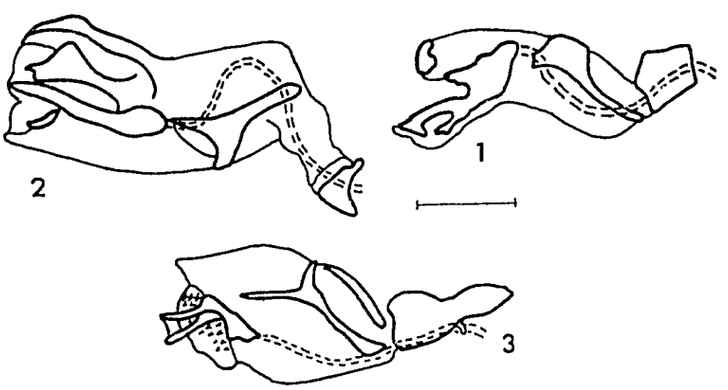

Fig. 1–3.—Aedeagus of bean flies. 1, *Melanagromyza phaseoli*; 2. *M. spencerella*; 3, *Ophiomyia centrosematis*. Scale line, 0·1 mm.

triangle reaching to or beyond the lower orbital setulae. From *M. spencerella* it is readily distinguished in the male on the form of the aedeagus (Fig. 1), and in the female with more difficulty on the shape and serrations of the ovipositor blade (Fig. 7).

In the early stages (Fig. 8–12), no morphological differences could be found except for a statistical difference in the number of openings in the posterior spiracles, mean number 8·4±1·2 (Table I), and in that the puparium is yellow brown translucent. The apices are frequently blackened but the intermediate segments are always brown.

TABLE I. *Number of pores in posterior spiracle of larvae of* Melanagromyza *spp. (each specimen scored on right or undamaged side only)*

No. of pores	*M. phaseoli* Unparasitised	*M. phaseoli* Parasitised by *O. melanagromyzae*	*M. spencerella* Unparasitised	*M. spencerella* Parasitised by *O. melanagromyzae*	*M. spencerella* Parasitised by *Eucoilidea*
5	—	1	—	1	—
6	3	5	—	—	—
7	13	22	2	—	1
8	29	33	7	5	5
9	22	14	23	6	9
10	5	5	28	5	20
11	3	—	22	—	13
12	2	—	1	—	7
13	—	—	3	—	—
No. puparia	77	80	86	17	55
Mean no. pores	8·4±1·2	7·9±1·0	9·9±1·2	8·8±0·9	10·1±1·2

Comparison of means: *M. phaseoli* v. *M. spencerella* $t = 7{\cdot}91$, $P < 0{\cdot}001$
M. phaseoli v. *M. phaseoli* parasitised by *O. melanagromyzae* $t = 2{\cdot}77$, $P < 0{\cdot}01$
M. spencerella v. *M. spencerella* parasitised by *O. melanagromyzae* $t = 3{\cdot}08$, $P < 0{\cdot}01$

Life-cycle.—The eggs (Fig. 8) are ovoid, opaque white and are inserted into a pocket in the mesophyll tissue of the leaves. The oviposition site is prepared by the ovipositor and is generally aligned with the axis of the leaf so that the opening is towards the base. Oviposition usually occurs through the upper epidermis but a few eggs are also laid through the lower surface. Many more punctures are made than are actually used for oviposition; some are used for adult feeding, as has been noticed by previous authors.

On hatching, the larva, lying on its side, mines beneath the epidermis until it meets a vein which is followed to the midrib and eventually to the petiole, by which time it moults to the second instar. The second instar mines downward and into the stem where the second moult occurs. The larva continues downwards into the tap root and returns, pupating close to the soil surface. If, however, necrotic or previously mined tissue is encountered the larva changes direction and has progressed further up the stem by the time of pupation. The puparium is formed beneath the epidermis, head upwards and ventral surface towards the axis of the stem. Before pupation the area in front of the puparium is reduced to a thin semi-transparent " window " which aids emergence of the adult. On potted plants in the laboratory the development time from egg to adult was 27–31 days, and was followed by a pre-oviposition period of about two days (mean temperature 21°C).

Plants are attacked as soon as the first pair of leaves begins to unfold, and successive attacks occur on succeeding new leaves as they unfold. Larvae from eggs in the upper leaves of old plants frequently pupate in the main stem just below a node and do not reach soil level.

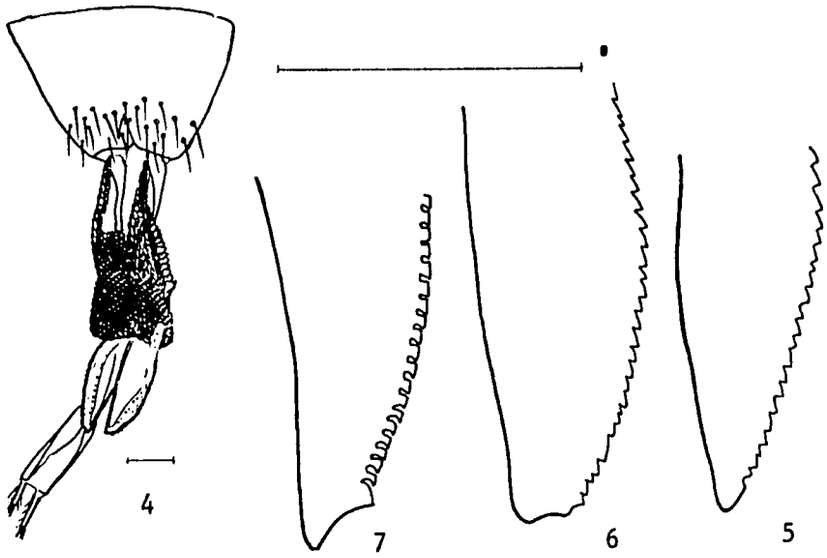

Fig. 4–7.—Ovipositor of bean flies. 4, ovipositor of *Melanagromyza spencerella*; 5, ovipositor valve of *M. phaseoli*; 6, same, *M. spencerella*; 7, same, *Ophiomyia centrosematis*. Scale lines, 0·1 mm.

Most damage is done by the larvae from the first pair of leaves, which when in the third instar destroy the medullary tissue at ground level. Later in the life of the plant, larvae do little damage.

Host range.—The authors cited record the infestation of a wide range of Leguminosae including *Phaseolus* spp., *Vigna unguiculata, Cajanus cajan, Lablab niger, Crotalaria juncea* and *Glycine max*. The present investigation in East Africa revealed attack on the species shown in Table II.

Distribution.—Spencer (1959, 1961, 1963, 1966) has confirmed the presence of *M. phaseoli* in Africa, India, Indonesia, Australia, many western Pacific islands,

TABLE II. *Occurrence of bean flies in cultivated legumes other than* Phaseolus vulgaris

Legume	Date	No. plants	No. infested	No. bean flies reared		
				M. phaseoli	*M. spencerella*	*O. centrosematis*
Phaseolus calcaratus	9.vii.68	52	7	2	6	—
	22.vii.68	75	13	11	5	—
	4.xi.68	36	2	2	—	—
P. lunatus	18.v.68	9	4	—	1	?8
	18.xi.68	100	?	3	49	9
	5.iii.68	100	17	5	11	1
P. mungo	22.vi.68	30	8	8	1	—
	4.xi.68	52	9	11	2	—
Vigna unguiculata	9.vii.68	52	26	33	—	—
	4.xi.68	100	17	14	3	1
Crotalaria mucronata	19.iii.68	78	11	—	—	12
Lablab niger	18.xi.68	100	9	9	—	—
	19.ii.68	99	8	5	4	1
	5.iii.68	100	4	4	—	—

Editor's Note - Dr. D. J. Greathead (*pers. comm.*) advised transposing the numbers 5 and 7 for the above figures. The numbers are correct as they now appear.

Mauritius and Madagascar. In East Africa it appears to be widespread, and has been confirmed at Nairobi and Mtwapa (near Mombasa) in Kenya, at Mbeya, Ilonga and Ukiriguru in Tanzania, and in the Kampala area and at Serere in Uganda.

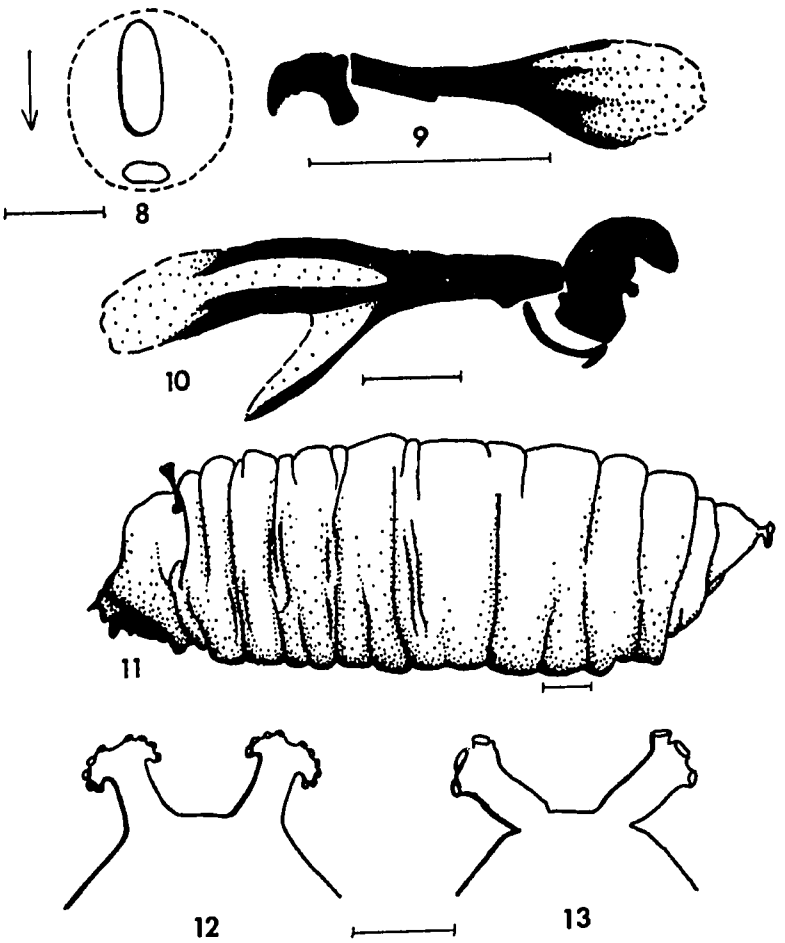

Fig. 8–13.—Early stages of bean flies. 8, diagrammatic representation of egg of *Melanagromyza phaseoli in situ* in pocket excavated in leaf tissue, as seen from above (arrow points to base of leaf); 9, *M. phaseoli*, first instar, buccopharyngeal armature; 10, same, third instar; 11, same, lateral view of third-instar larva; 12, same, posterior spiracles of puparium; 13, *Ophiomyia centrosematis*, same. Scale lines, 0·1 mm.

Melanagromyza spencerella **sp.n.**

This species cannot be distinguished from *M. phaseoli* on external adult characters. The description which follows is thus of necessity extremely brief and identification can only reliably be made from mounts of the genitalia or on the colour of the puparium.

Holotype ♂. As *M. phaseoli*, except that the aedeagus (Fig. 2) is broad and cylindrical with the vas deferens opening into a structure enclosed by the body of the aedeagus and not on a projecting arm of the aedeagus as in *M. phaseoli*.

Paratype ♀♀. As *M. phaseoli*, except that the ovipositor valves (Fig. 6) are blunt at the apex which is slightly concave and not tapering to a simple point as in *M. phaseoli*.

Puparium. As *M. phaseoli* except that it is shining black, opaque and that the posterior spiracles have an average of 9·9 ± 1·2 openings (Table I).

The other early stages are identical with those of *M. phaseoli*.

Holotype ♂. UGANDA: Kawanda, *ex Phaseolus vulgaris* 15.vii.1969 (*D. J. Greathead*). Genitalia mounted between cover glasses on same pin accompanied by puparium. In British Museum (Nat. Hist.).

Paratypes. 1 ♂, as holotype, 2 ♀ as holotype but 18.vii.1969, 3 ♂ 1 ♀ 2.iv.1968, 2 ♀ 3.iv.1968, 5 ♂ 2 ♀ iii.1968. Most specimens accompanied by puparia. In British Museum (Nat. Hist.) and collection of K. A. Spencer.

Life-cycle.—The females scarify the tissue of the leaves in the same way as *M. phaseoli* but rarely oviposit in the leaves. The bulk of oviposition occurs in the hypocotyl at ground level in the first two or three days after the first appearance of the plant above ground. A few eggs are also deposited in young stem tissue above the level of the cotyledons. The eggs resemble those of *M. phaseoli* and are laid in a similar pocket beneath the epidermis. In the stem this is usually orientated with the opening on the lower side and the egg above the opening. Larvae from eggs in the leaves follow the same life-cycle as those of *M. phaseoli*. Those laid in the hypocotyl or stem mine downwards, feeding extensively in the hypocotyl and taproot, and return to ground level or above to the nearest healthy tissue to pupate. The larva pupates in the same position as that of *M. phaseoli* after preparing a "window". On potted plants in the laboratory the development time from egg to adult was 28–35 days, followed by a pre-oviposition period of about two days (mean temperature 21°C).

Although eggs are laid in older plants the main attack is on very young plants, which by the time of the third instar are severely crippled, the subterranean parts often being completely killed.

Host range.—Very abundant in *Phaseolus vulgaris*, also detected in *P. calcaratus*, *P. lunatus*, *P. mungo*, *Lablab niger* and *Vigna unguiculata*, but in small numbers only (see Table II).

Distribution.—KENYA: Nairobi. TANZANIA: Mbeya, Ilonga, Ukiriguru. UGANDA: Kampala area, Serere.

It has not been detected in samples of beans from Mtwapa, near Mombasa, and may therefore be absent from the coast although it is present at all inland localities from which samples are available. Samples of bean fly examined from the environs of Antsirabe in Madagascar, from Botswana, Ethiopia and Mauritius consisted of *M. phaseoli* only.

Ophiomyia centrosematis

This species, originally discovered in Indonesia, was only recently detected in Africa by Spencer (1961) who recorded it as *Melanagromyza centrosematis* from Marungu, Tanzania, and illustrated the aedeagus. In 1966 he transferred it to *Ophiomyia* (Spencer, 1966).

O. centrosematis can be separated from the other two species in beans by the normal ocellar triangle and the genitalia (Fig. 3, 5). The larvae can be distinguished only in the third instar by the much longer anterior spiracles and in that the posterior spiracles have only three openings. The puparium also has these characters (Fig. 13) and is a translucent red to yellow brown. The absence of blackening of apices further distinguishes it from that of *M. phaseoli*.

Life-cycle.—This species, unlike the other two, causes no damage to the leaves. The eggs, similar to those of the other species, are laid in the stem and hypocotyl. There seems to be a less strong preference for the hypocotyl than in *M. spencerella*, otherwise its oviposition sites are indistinguishable. The larvae mine the stem and pupate in the same way as *M. phaseoli*, but a special "window" is not produced and

in most instances the anterior spiracles come to pierce the dry epidermis and project from it. On potted plants in the laboratory the development time from egg to adult was 30 days (mean temperature 21°C).

With its less specialised oviposition behaviour, attack by this species is less concentrated on young plants, and in *Phaseolus vulgaris* it is the rarest of the three species and of negligible importance.

Host-plants.—It was originally reared from *Centrosema pubescens* and is reported by Spencer (1961) from *Glycine max.* In East Africa it has been reared from *Phaseolus vulgaris, P. lunatus, Vigna unguiculata* and *Crotalaria mucronata.* Only in the last does it appear to be at all common (Table II).

Distribution.—Recorded by Spencer (1961, 1963) from Indonesia, Formosa, Australia, Malaya and Tanzania. It has been found at Nairobi and Mtwapa (near Mombasa) in Kenya, Ilonga in Tanzania and the Kampala area in Uganda. However, as it is always rare in beans, it may be present at other localities although not detected in samples.

Discussion

Samples from different widely spaced localities in East Africa show that *M. phaseoli* is present at all of them, and Hassan (1947) and Jack (1913) have recorded it in Egypt and Rhodesia, respectively. *M. spencerella* has been detected at all East African localities except that on the Kenya coast, and in most samples has been the dominant species. Unfortunately no records are available for localities outside East Africa, but the species is probably widespread in eastern tropical Africa, although not detected by K. A. Spencer (pers. comm.) in the material from his own or the British Museum collections from Africa or elsewhere. *O. centrosematis* likewise is widespread, but as it is always uncommon in the hosts examined it could easily be overlooked and in fact was not detected in Africa until 1961 (Spencer, 1961).

Data on the length of the development time from emergence from field-collected plants of known age and from eggs laid on potted plants indicate a life-cycle at Kawanda of about 30 days for all three species. However, the pattern of emergences is different (Fig. 25). *M. spencerella* shows a peak emergence at the beginning of the period with sporadic emergence throughout the life of the plant, reflecting its preference for oviposition in the hypocotyl of very young plants and occasional oviposition in the stem and leaves. *M. phaseoli* shows no such peak, but a fluctuating emergence curve over the whole life of the plant resulting from oviposition in successive leaves as they expand. The less specialised behaviour of *O. centrosematis* is reflected in its even emergence over the period.

The relative abundance of the three species is highly variable (Table III). At Kawanda *M. spencerella* has been the most abundant on each occasion, but both species are common. *O. centrosematis* is always uncommon in *Phaseolus vulgaris,* suggesting that this may not be an ideal host. Data from Nairobi can be interpreted as indicating a preference by *M. spencerella* for prolonged wet conditions. However, more data on seasonal abundance are required to decide this.

The authors cited all quote instances of heavy damage and high plant mortality as a result of infestation by *M. phaseoli.* Likewise *M. spencerella* can be a serious pest. Where both occur together, the economic damage will be caused by *M. spencerella* as the larvae of this species reach and destroy the root system before those of *M. phaseoli.* The ultimate effect of either species on the crop depends on the powers of recovery of the plants, the ability to produce adventitious roots being the crucial factor. Plants that do not rapidly respond to root damage by developing adventitious roots wilt and die; they are also liable to break off at ground level during windy periods or storms. Plants producing adventitious roots soon recover from the initial heavy infestation and are afterwards sufficiently robust to survive later damage. No attempt to assess the effect of bean fly on cropping was made but there must be a delay in growth which could be important where rainfall is low. The variety grown

TABLE III. *Infestation of* Phaseolus vulgaris *by bean flies and parasitism at three localities over successive plantings*

Date planted	No. plants	Plants infested (%)	Fly puparia				Mortality (%)						
							Opius spp.		*Eucoilidea*		Other causes		
			Total	*M. phas.* (%)	*M. spenc.* (%)	*O. centr.* (%)	*M. phas.*	*M.spenc.*	*M. spenc.*	*O. centr.*	*M. phas.*	*M. spenc.*	*O. centr.*
Kawanda													
15.xi.67	100	97	386	16·5	82·1	1·3	94·4	5·1	13·7	+	12·5	25·2	—
13.xii.67	100	92	343	31·4	66·8	1·7	73·3	7·3	57·2	+	7·4	26·2	16·7
27.ii.68	100	48	48	35·4	58·3	6·3	64·7	3·6	3·6	+	5·9	42·8	—
30.iv.68	100	97	469	17·3	76·9	5·8	69·1	1·9	1·4	7·4	12·3	11·9	7·4
28.v.68	50	82	127	10·2	89·0	0·8	30·8	4·4	3·5	—	23·0	9·7	—
17.ix.68	100	68	139	23·7	74·1	2·2	78·8	2·9	24·2	+	—	10·7	—
25.ix.68	100	81	230	25·2	71·3	3·5	69·0	2·4	23·2	+	10·3	10·4	—
11.ii.69	100	36	56	28·6	44·6	26·8	87·5	—	48·0	73·3	4·0	—	—
5.iii.69	100	38	51	45·1	49·0	5·9	82·6	—	4·0	+	4·3	28·0	—
Nairobi													
22.iv.68	50	54·0	27	92·6	—	7·4	44·0	—	—	50·0	8·0	—	—
23.v.68	102	78·4	139	91·3	6·5	2·2	59·8	—	—	—	15·7	1·1	—
15.vi.68	127	81·8	174	67·8	28·2	4·0	76·3	14·3	8·2	—	16·1	20·4	28·6
26.vi.68	99	100·0	453	5·6	93·8	0·02	55·6	5·6	22·1	—	25·0	22·8	—
31.vii.68	100	95·0	230	12·2	86·1	1·7	35·7	1·5	12·1	25·0	57·1	47·0	25·0
8.viii.68	100	98·0	284	4·2	92·6	3·2	78·9	3·0	14·8	55·6	8·3	29·3	—
24.ix.68	55	81·8	147	25·2	57·1	17·7	57·8	1·2	6·0	—	10·8	28·6	34·6
15.x.68	100	93·0	192	39·1	55·2	5·7	54·7	2·8	25·5	18·2	18·7	35·8	18·2
6.xi.68	100	97·0	284	10·9	88·0	1·1	67·7	0·4	14·4	—	22·6	22·4	33·3
Mtwapa													
25.vii.68	122	26·2	51	92·1	—	7·8	29·8	—	—	—	10·6	—	—
30.vii.68	115	44·3	120	98·3	—	1·7	27·9	—	—	—	8·5	—	—
28.viii.68	100	20·0	32	96·8	—	3·1	67·7	—	—	—	9·7	—	+
26.ix.68	100	47·0	118	85·6	—	14·4	80·2	—	—	11·8	6·9	—	29·4
4.xi.68	100	26·0	29	89·6	—	10·3	76·9	—	—	—	15·4	—	—
*ca.*18.xii.68	100	32·0	58	87·9	—	12·1	39·2	—	—	—	5·9	—	85·7
5.i.69	100	47·0	70	64·3	—	34·3	86·7	—	—	50·0	8·9	—	20·8
4.ii.69	66	47·0	41	92·7	—	7·3	86·8	—	—	+	7·9*	—	—

Percentages of parasitism, *etc.*, based on total number of puparia and not adjusted to allow for those damaged in sampling and transit.

*Includes one *Eucoilidea* sp.

is also an important factor, as it has been noticed that varieties in trials at Ilonga showed striking differences in the damage suffered. Again, casual observation suggests that imported varieties from temperate regions suffer more severely than varieties selected from peasant holdings in East Africa. This is to be expected, as beans in temperate climates where *Melanagromyza* spp. are unknown have not had to evolve the facility for developing adventitious roots to combat infestation, whereas selection for this character must have been practised where the flies occur.

Investigations by Ingram (1969) indicate that few insecticides give effective control when sprayed on to plants. Of the ten insecticides tested only dicrotophos gave any diminution of the number of infested plants. It seems likely, especially in areas where *M. spencerella* is present and damage occurs very early on in the life of the bean plant, the dieldrin seed dressings as developed by Walker (1960) in Tanzania and Taylor (1959) in Rhodesia provide the best means of protection. Such dressings are in fact widely used in East Africa to protect bean seed from insect pests. A comparative study of insecticidal control measures against *M. phaseoli* in Ceylon by Wickramasinghe & Fernando (1962) leads to conclusions similar to those of workers in Africa.

The parasite complex

Two important primary parasites are widespread in East Africa: *Opius melanagromyzae* Fisch., chiefly a parasite of *M. phaseoli*, and *Eucoilidea* sp., which has not been reared from *M. phaseoli*. Both species have been followed from the egg stage to emergence, and aspects of their life-cycles and illustrations of characteristic stages follow. There are two relatively uncommon primary parasites, a second *Opius* sp. and an indeterminate Pteromalid near *Herbertia*, and also an assemblage of Chalcidoids which are reared in small numbers from samples. Owing to their rarity and sporadic appearance the life-cycle and status of most of them have not been satisfactorily worked out. Hence the notes on these species are incomplete, but it is hoped they will prove useful for their identification. Beans in East Africa are also liable to infestation by other mining and boring insects, especially the weevil *Alcidodes leucogrammus* (Erichs.) and, when severely damaged, to attack by a variety of saprophagous organisms, particularly Diptera, so that care is needed in interpreting the results of mass-rearing from infested plants.

Examination of infested plants shows that, in addition to mortality from parasites, the Agromyzids suffer from predators attacking the puparia. It is rarely possible to identify the predators and only ants have been positively associated with such damage.

Unfortunately, parasite rearing from samples from a number of localities was done before it was realised that more than one Agromyzid was present so that the earlier records are only of use in indicating distributions and have not been tabulated. The other records from Kawanda, Nairobi and Mtwapa are summarised in Table III and give some idea of relative abundance and fluctuations during 1968.

Opius melanagromyzae (*Braconidae*)

O. melanagromyzae is the dominant parasite of *M. phaseoli*, and thus its life-history is more completely known than that of most of the other parasites. The description which follows is based on larvae in this host.

The eggs are laid in first-instar larvae in the leaves within a day of hatching, but apparently not in the eggs. The eggs are elongate fusiform with a double wall, from one to five (as a rule two to three) being laid in each larva.

Hatching occurs soon after the host has moulted to the second instar, about two days after the parasite oviposited. The first-instar larva (Fig. 14) is typical of the Opiinae (Clausen, 1940), having a large rectangular brownish head bearing sickle-shaped mandibles (Fig. 15) and a narrow tapering trunk with two pairs of ventral papillae. Comparison with a figure of *O. ilicis* Nixon (Cameron, 1941) suggests that

the outline of the anterior dorsal margin of the head and its two spine-like protrusions may prove to be a diagnostic character.

The first-instar larva grows slightly but does not moult until the host reaches the pupal stage. During this time all but one of the *Opius* larvae are suppressed. It appears that the largest larva is able to kill the others, as punctured larvae are found, and able to suppress hatching and growth, as unhatched eggs and unfed larvae can be found up to the time that moulting occurs in the host pupa. During the first instar the larva doubles its size.

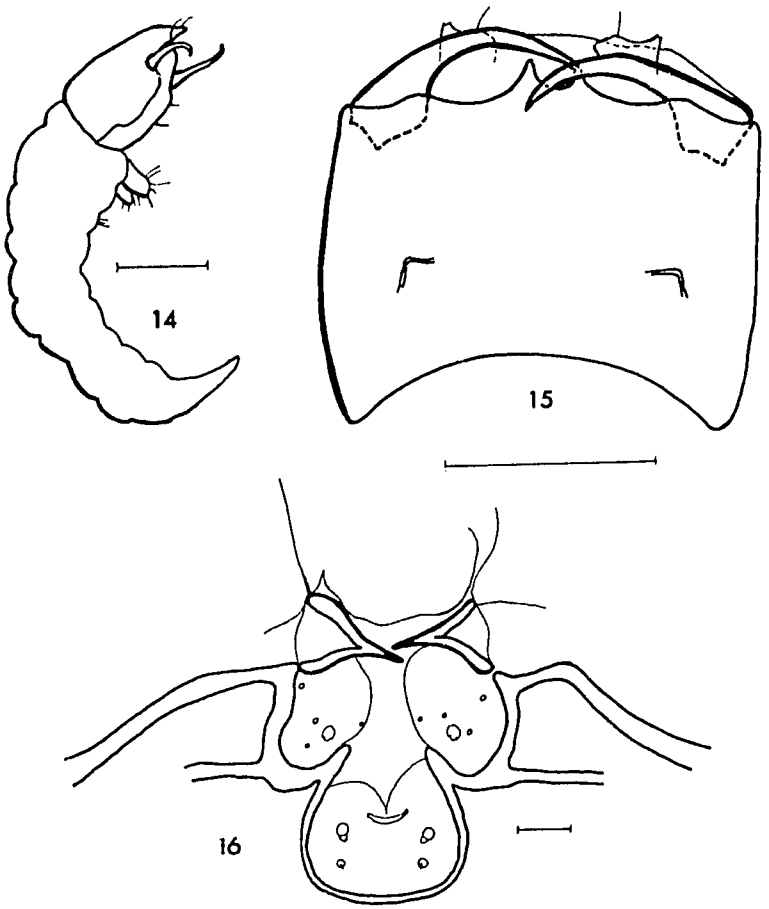

Fig. 14–16.—Early stages of *Opius melanagromyzae*. 14, first-instar larva, lateral view; 15, same, head capsule, dorsal view; 16, final-instar larva, mouthparts. Scale lines, 0·1 mm.

At least two smooth intermediate instars separate the first from the final instar which has the spiculate cuticle characteristic of the genus (Short, 1952). The head capsule is shown in Fig. 16. The spiracles are also typical of the genus. The body contents are opaque white with greenish material in the posterior part of the gut, thus contrasting with the appearance of *Eucoilidea* sp. Development is rapid and takes about four days. Occasionally, healthy mature larvae have been found in puparia after emergence of adults has ceased, both in freshly collected plants and in plants that

have been held in the laboratory; the reason for this is unknown. As the stems in corked tubes in the laboratory remain very damp it is unlikely that arrested development is a response to adverse climate. Such larvae held in the laboratory pupated and emerged up to two months later irrespective of being kept under damp or dry conditions.

The pupa lies in the host puparium, head towards the anterior end in the same position as a fly pupa. The pupal cuticle and larval exuviae of the parasite are pushed to the posterior end and the faeces deposited as a white blob with a greenish core against the ventral wall towards the middle. There is a thin membranous cocoon surrounding the pupa. The pupal instar lasts a minimum of four days, and emergence begins about 30 days after appearance of the host-plant above the ground.

The adult emerges from the pupa inside the fly puparium and escapes through a rounded hole chewed to the dorsal side of the anterior end of the puparium.

Parasitism at Kawanda is usually well over 50%, and up to 93% has been recorded. In addition to parasitism of *M. phaseoli*, *O. melanagromyzae* parasitises less than 10% of *M. spencerella*. As no *Opius* eggs or larvae have been found in larvae in the hypocotyl, it is suggested that the larvae parasitised are those from eggs laid higher up the stem or in the occasional eggs laid in the leaves. *O. melanagromyzae* has also been reared twice from *Ophiomyia centrosematis*.

Opius melanagromyzae has been reared from almost all samples from East Africa and is known from Mauritius, Madagascar, Botswana and Ethiopia.

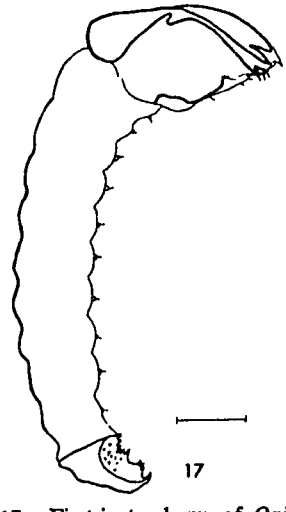

Fig. 17.—First-instar larva of *Opius* sp.
Scale line, 0·1 mm.

Opius *sp.* (*Section A of Fischer, 1963*)

First-instar larvae were occasionally found in dissections but could not be related to reared adults. Individual rearing established that the adult was similar in general appearance to a dark specimen of *O. melanagromyzae* and had been confused with it. *Opius* sp. has been reared only from *M. phaseoli*, suggesting that it oviposits in leaves but not stems. The egg was not detected but is likely to be similar to and confused with that of *O. melanagromyzae*. The first-instar larva was found in third-instar host larvae and may have been present earlier but, owing to its rarity, not detected. It is elongate (Fig. 17), with a large blackish head and a yellow sclerotised apical

Editor's Note - "Opius sp. (*Section A of Fischer, 1963*)" has been named Opius importatus Fischer (D. J. Greathead, *pers. comm.*).

segment, the ventral side of the trunk segments with pairs of minute papillae bearing tiny hairs, and is quite unlike the larva regarded as typical of the genus.

Like *O. melanagromyzae*, *Opius* sp. develops rapidly in the host pupa, and the adults emerge from 33 days after appearance of the plants above soil. It also resembles *O. melanagromyzae* in its position within the host and escape behaviour.

Opius sp. was reared from Kawanda samples between November 1967 and April 1968 at a rate of 3–9%. This incidence is in agreement with the occurrence of larvae in dissections. It has been found associated with first-instar larvae of *O. melanagromyzae* that are suppressed. Since April 1968 it has not been reared, nor has it been detected in samples from any other locality.

Eucoilidea *sp.* (*Cynipidae*)

Eucoilidea sp. is the dominant parasite of *M. spencerella* and *Ophiomyia centrosematis*. Dissections of the latter species form the basis of the following description.

The eggs, like those of *Opius melanagromyzae*, are laid in the first-instar larvae and have not been found in the eggs. They are elongate fusiform, double-walled and with a narrow single-walled tail-like process at the posterior end (Fig. 18). The eggs hatch within two days. Usually one occurs in each host, but up to three have been found.

The first instar is transparent "eucoiliform" (Clausen, 1940) (Fig. 19), and like that of *Opius* suppresses supernumerary eggs and larvae. Growth is slight until the pupation of the host, when the larva rapidly swells and moults. The number of intermediate instars is not known. Development is very rapid, taking about three days.

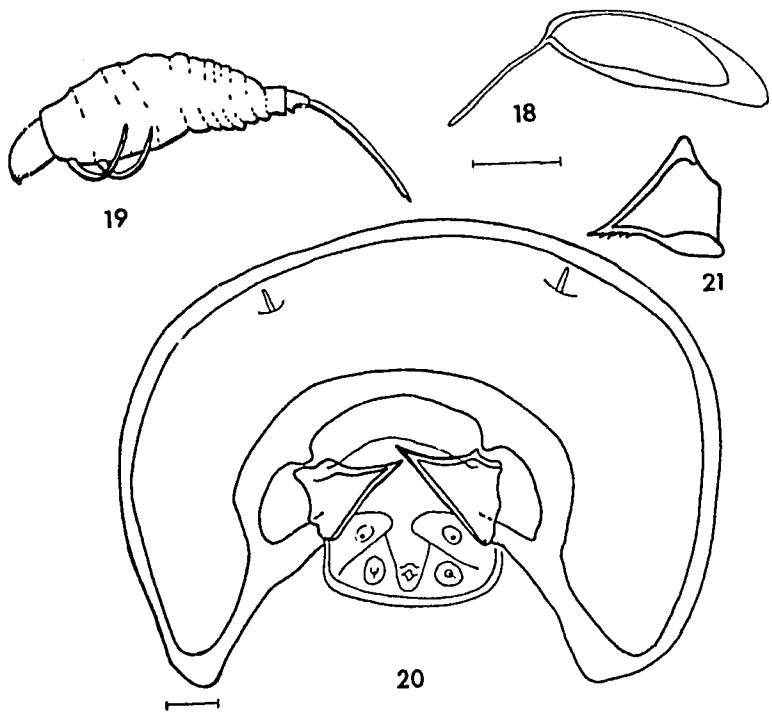

Fig. 18–21.—Early stages of *Eucoilidea* sp. 18, egg; 19, first-instar larva, lateral view; 20, final-instar larva, head capsule, dorsoventral view; 21, mandible, dorsal view. Scale lines, 0·1 mm.

The head capsule of the mature larva is shown in Fig. 20. The cuticle is smooth and bears scattered hairs, the body contents are transparent with white granular spots, and with a clear dorsal stripe. The last-instar larva and pupa lie at right angles to the host's dorso-ventral axis, head towards the anterior end.

Before pupation, the remains of the host and the faeces are deposited as an irregular blob at the posterior end. The adult emerges by chewing off the anterior end of the puparium.

Parasitism of *M. spencerella* at Kawanda was up to 57% but is usually less than 20%. It was reared from samples from almost all localities, so is probably distributed throughout East Africa. The same *Eucoilidea* sp. has also been reared from the stem-miner of *Striga* spp., *Ophiomyia strigalis* Spencer, in western Kenya (Davidson, 1963), Tanzania and Uganda, and from *Melanagromyza chalcosoma* Spencer from pods of *Vigna unguiculata* in Uganda. It is thus not confined to either Agromyzidae in legumes or to those species mining stems. However, it has only once been reared from *M. phaseoli*, and in dissection the early stages have been found only in larvae from eggs laid in the stem and hypocotyl, indicating that the ovipositing female searches the stems and pods but not, as a rule, the leaves.

Norbanus *sp.* (*Pteromalidae*)

From dissections of puparia and examination of the remains after emergence, it was established that *Norbanus* sp. usually emerges from pupae parasitised by *Opius melanagromyzae*. It is not clear whether this is always so as on a few occasions no remains of *O. melanagromyzae* were found and it is not certain whether they had been lost or whether *Norbanus* sp. can also develop as a primary parasite on the fly pupa.

Comparison of details in Clausen (1940) and deductions from dissections indicate that the eggs are narrow elongate, rounded at the ends, laid between the puparium and the fully grown *Opius* larva. Two eggs appear to be laid as a rule, but never more than one adult emerges. The larvae feed externally on the host. The pupa has a rugose pale yellow cuticle. Emergence occurs in the manner of *O. melanagromyzae*.

The incidence of *Norbanus* sp. is very variable both within and between localities. It has been reared from Kawanda, Serere and Kigezi District in Uganda, from Nairobi in Kenya and from Ilonga and Mbeya in Tanzania. At Kawanda it appeared in samples taken in January–March and July–August 1967, but not in samples from the same site in November–December 1966 or November 1968–January 1969. In all cases its incidence when present was less than one per cent of the *Opius* reared. Where the beans were old, as in Kigezi and at Kawanda, incidence rose, as would be expected in a hyperparasite not able to oviposit until its host had completed its larval development (see Fig. 24). The first emergences occurred about two weeks after the emergence of the first *Opius*, giving a life-cycle of about 2½ weeks.

Gen. et sp. indet. nr Herbertia (*Pteromalidae*)

Emerging adults were associated with the head exuvium of a larva corresponding with that described by Clausen (1940) for related genera of the Pireninae, *i.e.*, head broad with large falcate transverse mandibles. The remains of the pupal casts were found, but were indistinguishable from that described from *Norbanus* sp. Pairs of mandibles indicating at least three larval instars have been recovered. Except on one occasion when it was associated with the remains of first-instar *O. melanagromyzae*, no other parasite remains were present, suggesting that it is usually a primary parasite. As emergence occurs from two weeks after the emergence of the first flies, it is concluded that it oviposits in puparia.

Like *Norbanus* sp., its occurrence in samples is erratic. It has been detected at Kawanda and Serere in Uganda, at Ilonga and Mpanda in Tanzania and once at Mtwapa in Kenya, and with the same temporal distribution as *Norbanus* sp. Its incidence on each occasion was well below one per cent of total emergences. It is evidently polyphagous as it has also been reared from *Ophiomyia strigalis* in *Striga*

hermonthica at Magoro, Teso District, Uganda, as well as from *M. phaseoli* and *M. spencerella.*

Sphegigasterinae gen. et sp. indet. (*Pteromalidae*)

Small numbers of a Sphegigasterine have been reared from samples at Serere (Uganda) and Ilonga (Tanzania). However, their hosts were not identified, and they might, like other Chalcidoids, be parasites of the weevil *Alcidodes leucogrammus* or one of the saprophagous Diptera infesting rotting tissue.

Eupelmus *sp. nr* popa *Gir.* (*Eupelmidae*)

As with the other Chalcidoids only a few examples were discovered in dissections. These indicated that it is secondary on *Opius melanagromyzae.* On one occasion it was reared from *Opius* sp.

The egg (Fig. 22), which is typical of Eupelmidae (Clausen, 1940), is large and oval, and bears two processes, the anterior one wide bent into a loop and tinged brownish, and the posterior narrow short and membranous. The anterior part persists after hatching. Traces of webbing on the inside of the puparium were also found covering the inside of the oviposition puncture. The exuvium of the final-instar larva also persists and is characterised by the sclerotised labrum with a dentate margin (Fig. 23). The pupal exuvium resembles that of the Pteromalids but is thicker and tougher.

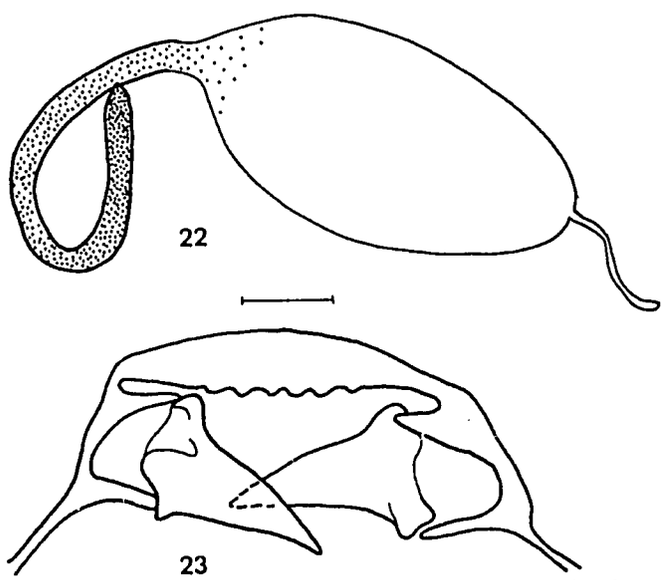

Fig. 22–23.—Early stages of *Eupelmus* sp. 22, egg; 23, last-instar larva, mouthparts. Scale line, 0·1 mm.

This species has been reared from samples from Kawanda and Serere (Uganda) and Ilonga (Tanzania) in small numbers like the other Chalcidoids. As males are far more abundant than females there must be other hosts, possibly larger than *O. melanagromyzae.*

Eurytoma *sp.* (*Eurytomidae*)

Two male specimens of *Eurytoma* sp. were reared from a sample collected in September 1968 at Mtwapa. They both emerged from puparia of *M. phaseoli* situated

above the second node of the host-plant. Dissection of the empty puparium failed to reveal any larval remains, suggesting that the two individuals developed as primary parasites. The single record implies that the host is accidental and that *Eurytoma* sp. is not normally a parasite of bean flies.

Pediobius *sp.* (*Eulophidae*)

This parasite has only been reared in association with *O. melanagromyzae* and from Kawanda only. Like the other parasites, its appearance is sporadic but it has been present in samples collected during January–March but is very rare at other times.

The early stages have not been identified except the pupa which is easily recognised by the shiny black cuticle. Those examined were all associated with the remains of last-instar larvae of *O. melanagromyzae.*

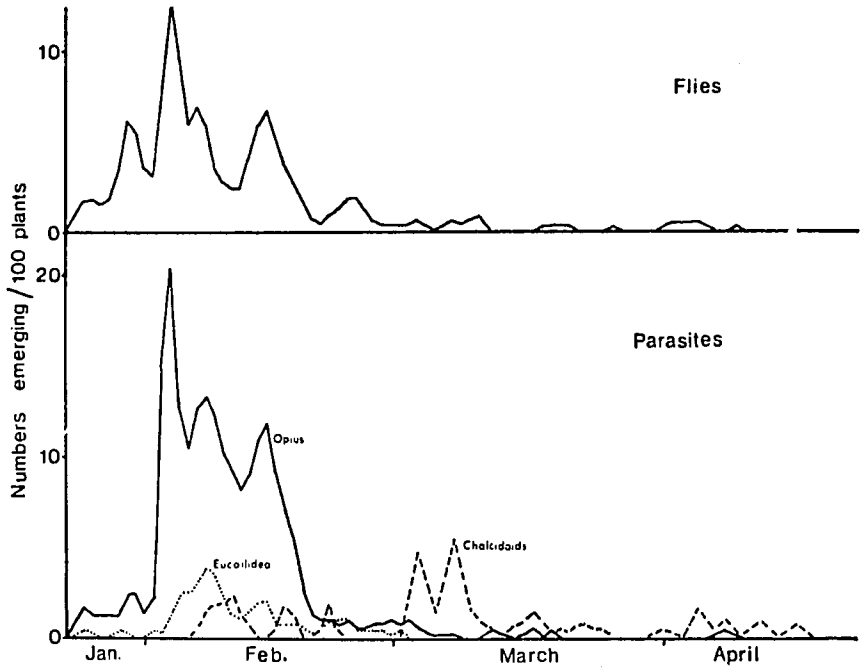

Fig. 24.—Emergence pattern of bean flies and parasites from *Phaseolus vulgaris* (basal 5 in. of stem) planted 6.xii.66 (data averaged from overlapping samples of 100 plants).

The role of the parasite complex

As shown from serial samples (Fig. 24, 25), most emergences from the lower part of the plants occur during the first four weeks after appearance above ground. Fig. 24 has been included because, although the different species of hosts are not separated, there was on this occasion a relatively large number of Chalcidoids as well as considerable parasitism by *Opius* spp. and *Eucoilidea* sp. This shows the pattern of emergence which is typical (compare with Fig. 25) in that most Chalcidoids appear after the emergence of the other species. This reflects their status as pupal parasites, but also suggests that parasitism by Chalcidoids may be higher in larvae from old plants. Even if this is so, these larvae are relatively few and have little injurious

effect. Thus parasitism by *Opius* spp. and *Eucoilidea* is not only higher, but more effective in controlling the fly population during the period of the main infestation, although they are unable to prevent damage to the plants in which the larvae develop. Thus, observations were carried out chiefly on samples collected so as to obtain the insects issuing during the main emergence period.

Rates of parasitism (Table III) and inferences from early samples indicate that heavy parasitism of *M. phaseoli* by *O. melanagromyzae* is usually of the order of 70–90% and that this pest is also liable to attack by the assemblage of Chalcidoids which exert little effect. Parasitism of *M. spencerella* is lower, of the order of 20–60%, mainly due to *Eucoilidea* sp. which does not parasitise *M. phaseoli*. These differences can be accounted for by differences in life-history of the hosts. *M. phaseoli* is exposed to *O. melanagromyzae* which evidently searches only the upper parts of the host-plant, and as most, or sometimes all, of the life-cycle is passed above ground level the pupae are exposed to attack by the Chalcidoids. These are apparently almost exclusively secondary parasites, but this may be the result of the heavy parasitism by *Opius* which

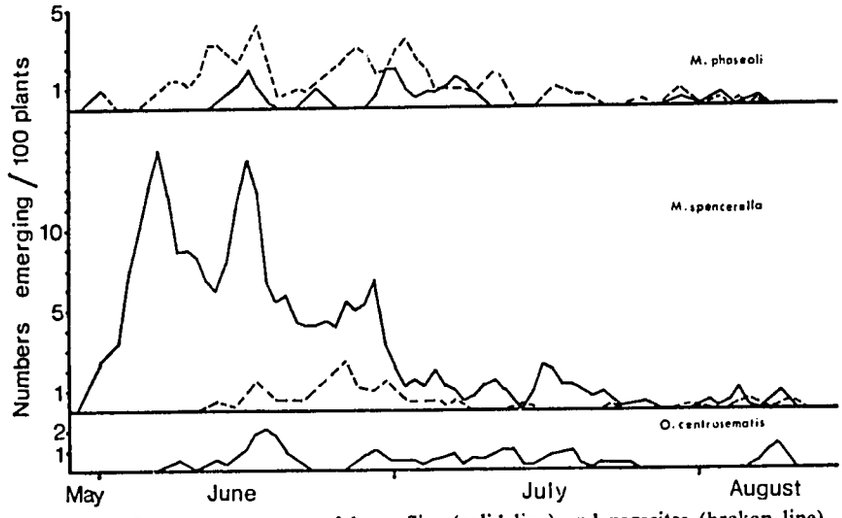

Fig. 25.—Emergence pattern of bean flies (solid line) and parasites (broken line) from *Phaseolus vulgaris* (basal 5 in. of stem) planted 30.iv.68 (data averaged from overlapping samples of 100 plants).

means that the chances of a parasite that oviposits at random finding a healthy pupa are slight. By contrast except for the first few days, the majority of *M. spencerella* larvae are protected from parasites by the soil, so that pupal parasites are less common in this species. A proportion of larvae from eggs laid away from ground are attacked by *O. melanagromyzae*, suggesting that at least with this species discrimination is a result of searching behaviour and not the differential acceptability of the two host species. The mutilation experiments where *O. melanagromyzae* emerged only from the cut tops of the plants and *Eucoilidea* sp. from the lower parts confirm this division of oviposition behaviour between the two parasites.

Results from Kawanda, Nairobi and Mtwapa (Table III), as well as less complete data from other localities, show that the two principal parasites are widespread and equally effective in the different climatic zones. A tendency is shown by *Eucoilidea* to be more effective in the latter part of the year during the short rains (October–November) and during the dry season following it. A similar impression is gained from the more meagre data for the Chalcidoids.

No obvious correlation is shown between parasitism and the percentage of plants infested. The latter is more related to season in that infestation tends to be less severe at beginning of the first or long rains (March–May) and the latter part of the preceding dry season. While this may result from the generally heavier parasitism in the second half of the year, it is more likely to be due to a reduced level of breeding success during the dry season when few oviposition sites are available.

Southwood (1969) has demonstrated that some of the techniques developed for the analysis of the effect of mortality factors from life-table data can be applied to serial data obtained from crops, provided that estimates of population density are available. Plotting population density as number of puparia per 100 host-plants or the log.

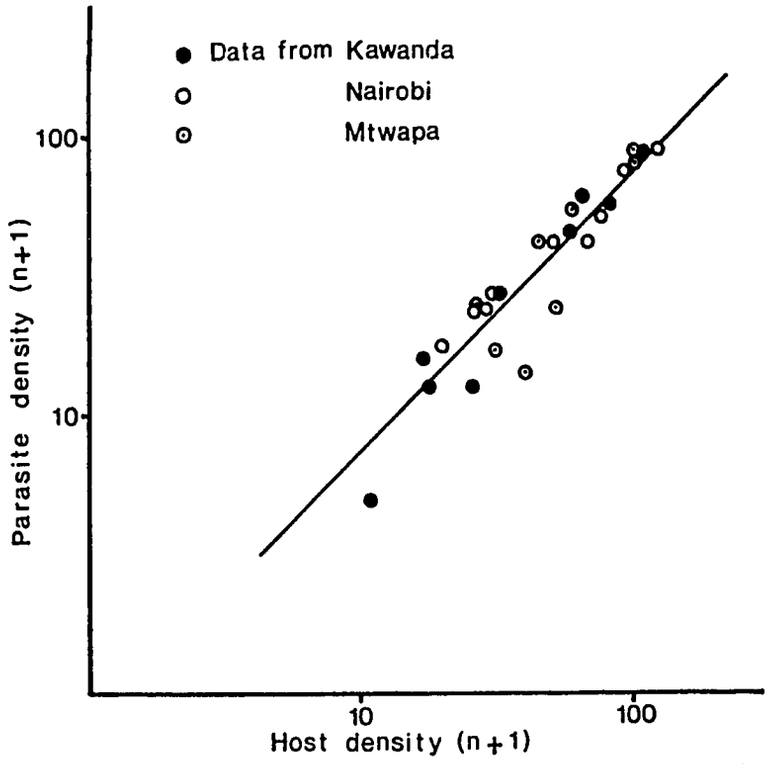

Fig. 26.—The relationship between *Melanagromyza phaseoli* and *Opius melanagromyzae*, shown by host and parasite densities per 100 plants plotted on logarithmic scales. Data from Table III, but parasite density corrected by apportioning dead puparia between parasitised and healthy hosts. Trend line, calculated from regression (log. $y = -0{\cdot}129 + 1{\cdot}004$ log. x) with correlation coefficient 0·935.

$(n+1)$ of this number against percentage parasitism showed no correlation. However, plotting the log. $(n+1)$ of the population density against the log. $(n+1)$ density of parasites per 100 plants reveals a correlation which is indicative of the degree of density dependence shown by the parasites. Fig. 26 shows such a plot of the population densities of *M. phaseoli* and *O. melanagromyzae* at Kawanda, Nairobi and Mtwapa. Calculated correlation coefficients (0·899, 0·983 and 0·821, respectively) for these localities are probably not significantly different from one another ($\chi^2 = 4{\cdot}577$; d.f.$=2$; $P > 0{\cdot}10$). This indicates that the interactions of host and parasite are not affected by

the different environment at these contrasting sites and that there is a strongly density-dependent relationship between *M. phaseoli* and *O. melanagromyzae*. It may be concluded therefore that the parasite is an important factor in limiting the population of the host.

Similar plots for *M. spencerella* and its chief parasite *Eucoilidea* sp. at Kawanda and Nairobi (the host is absent from Mtwapa) show no such clear relationship (Fig. 27). The correlation coefficients (0·448 and 0·747, respectively) are not significant and not highly significant ($P>0{\cdot}10$ and $<0{\cdot}02$, respectively). This could indicate density-independence or delayed density-dependence (Southwood, 1966, 1969). If the points were to represent the successive generations and are joined in chronological order a delayed density-dependent relationship would be revealed by an anti-clockwise spiral. As the interval between samples does not fulfil this condition (the number

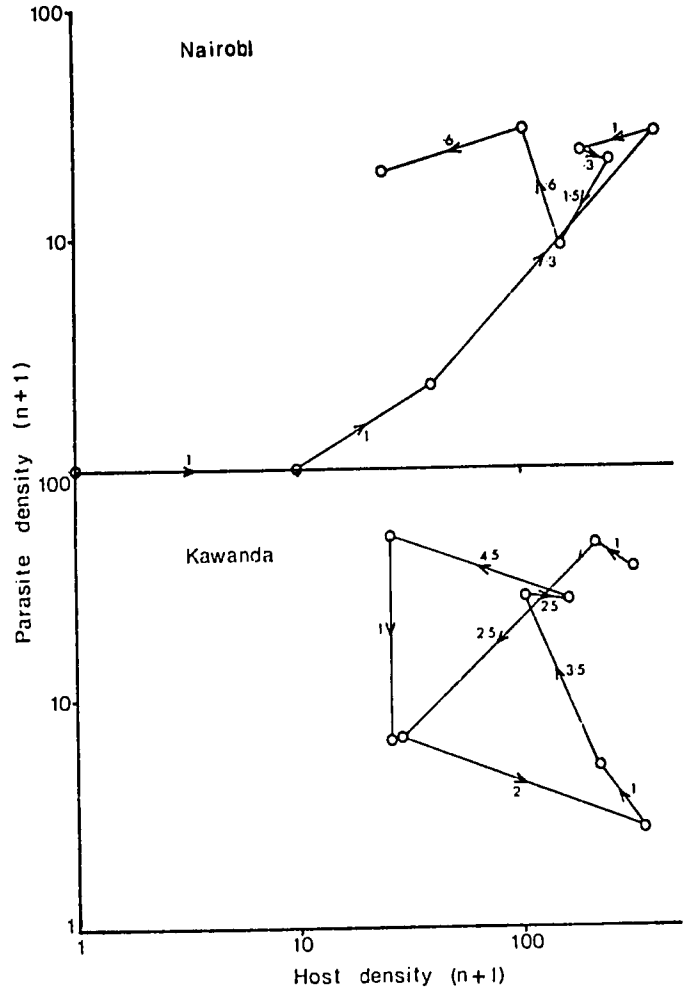

Fig. 27.—The relationship between *Melanagromyza spencerella* and *Eucoilidea* sp. at Kawanda and Mtwapa. Data from Table III, but parasite density corrected by apportioning dead puparia between parasitised and healthy hosts. Numbers on graph indicate intervals between samples expressed in host generations.

of generations between points is shown on the graphs) and the number of samples is rather small, linking the points cannot be expected to demonstrate a delayed density-dependent relationship clearly. However, at Kawanda the points do tend to form such a spiral and it is possible that a delayed density-dependent relationship exists. At Nairobi it should be noted that *M. spencerella* was absent from the first sample and populations of both built up during successive samples, an unstable situation which cannot be expected to display the final relationship. The sequence does suggest a stabilising influence due to the parasite, since the later points indicate a stabilisation of the parasite population and a progressive reduction of the host population. Comparison of the abundance of the two bean flies in samples also shows that *Eucoilidea* sp. is less effective as a controlling factor, since *M. spencerella* is both more abundant and its parasite achieves consistently lower rates of parasitism (up to 50%).

Mortality due to other causes includes damage to pupae by predators, and death during the pupal stage. A proportion of this is due to the removal of plants to the laboratory, damage caused when digging up the plants and possibly also to fungal attack and inviability, although it was not possible to apportion individual puparia among these categories. Pupal death is thus partly an artefact and the generally higher mortality from other causes in the Nairobi samples is due to damage in transit by post. On one occasion a nematode was found in a pupa, and once a pupa was found bearing the fruiting bodies of *Cordyceps* sp. (an entomogenous fungus); otherwise no nematodes or pathogens were positively linked with death in the pupal stage. Dead larvae were also occasionally found but, as they decay rapidly, no accurate assessment of the numbers could be made. However, this cause of death would appear to be unimportant and chiefly due to crushing of larvae by the cells of the plant during growth.

TABLE IV. *Parasitism of* Melanagromyza phaseoli *reported from other areas*

Country	Species present	Average parasitism	Authority
Java	*Trigonogastra agromyzae* Dodd *Eurytoma poloni* Gir. *Eurytoma* sp. Cynipid	5%	van der Goot (1930)
Egypt	*T. agromyzae* *Eurytoma larvicola* Gir.	—	Hassan (1947)
Philippines	*Paratrigonogastra stella* Gir. *E. poloni*	17%	Otanes y Quesales (1918)
Rhodesia	Braconid "*Opius liogaster* Szépl."	ineffective effective most seasons	Jack (1913) Taylor (1958)
Madagascar	*Opius melanagromyzae*	38% (3 samples)	Author's observations
Mauritius	*Opius melanagromyzae*	*ca.* 20%	A. Joomaye (pers. comm.)

The parasite present in Rhodesia is probably *O. melanagromyzae* as this parasite has recently been found in Botswana.

It is concluded that in East Africa *O. melanagromyzae* is the chief biotic factor affecting *M. phaseoli*, and *Eucoilidea* sp. the chief biotic factor affecting the other two species of bean fly, but that *Eucoilidea* sp. is considerably less effective. In spite of heavy parasitism, sufficient flies survive to cause heavy infestations of subsequent generations of plants, so that parasites are ineffective in preventing damage in East Africa. Even so, in areas where these parasites are not present their introduction might contribute to reducing the level of infestation. It is noteworthy that recorded levels of parasitism in other areas are considerably lower (Table IV). The low rate of parasitism in Mauritius cannot be explained at present. It is suggested that it is either due to a different strain of *O. melanagromyzae* or that it is not in fact the same species as that in Africa.

In 1968 *M. phaseoli* was discovered for the first time in Hawaii. The authorities were made aware of the work being done in East Africa and requested shipments of *O. melanagromyzae*. Four shipments of 100–200 puparia of *M. phaseoli* collected from the field were sent in April–May 1969. In spite of the fact that only two shipments were received in good condition, a laboratory culture was established and releases began in June. About one month later the first recovery was made (C. J. Davis, unpublished, Monthly reports of the State Entomologist). This is an encouraging result and ensuing events will be followed with interest to see to what extent the views expressed in this discussion are verified.

Summary

Examination of infested bean plants (*Phaseolus vulgaris*) showed that "bean fly" in East Africa consists of three species, *Melanagromyza phaseoli* (Tryon), *M. spencerella* sp. n. and *Ophiomyia centrosematis* (de Meij.). *M. spencerella* is described, and notes are given on the life-cycle, host-plants and distribution for all three species. Their importance in East Africa is discussed and it is concluded that *M. spencerella* is the most damaging because it oviposits and feeds in the hypocotyl, is frequently the most abundant species and is less effectively parasitised. Bean plants able to produce adventitious roots freely are able to grow away from the important early attack in the stems. Published work on chemical control measures is summarised.

The parasite complex associated with bean fly in East Africa was studied, and notes are given on the species present, the recognition of their early stages, their host ranges and abundance. Parasitism is discussed in relation to the infestations found on beans, with special reference to *Opius melanagromyzae* Fisch., the most important parasite of *M. phaseoli*, and *Eucoilidea* sp., the most important parasite of *M. spencerella*. It is concluded from graphical analysis that *O. melanagromyzae* is density-dependent and an important factor in limiting *M. phaseoli* populations in East Africa. *Eucoilidea* sp., on the other hand, shows signs of delayed density-dependence and is less effective in controlling its principal host. *O. melanagromyzae* has recently been sent to Hawaii for release against *M. phaseoli*; some field recoveries have been made already.

Acknowledgements

The author is deeply indebted to Mr. K. A. Spencer for confirming the status of the new species, examining material in the United Kingdom to check its distribution, for his advice in describing the species and comments on the draft manuscript. Grateful thanks are also due to T. J. Crowe, J. C. Davies, F. Mathez, W. Reed and I. A. D. Robertson for growing beans and sending samples.

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The Biology of the Bean Leaf-Beetle[1]

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The bean leaf-beetle is the most destructive insect pest attacking vegetative parts of beans and cowpeas in Arkansas. It is usually considered a garden pest, but the injury caused in the field is proportionately as great as that in the garden. With the advent of the Mexican bean beetle in the South and the publicity which it received, the bean leaf-beetle has become inadvertently the object of a good deal of attention in addition to that which it normally would have received. Specimens sent to the Department of Entomology by correspondents are usually referred to by them as the Mexican bean beetle. Although both are pests of beans and similar legumes, the habits and life histories of the two insects are quite different. The bean leaf-beetle is closely related to the striped cucumber beetle and the southern corn rootworm. Like them, the adult feeds upon the foliage and tender stems of its hosts, while the larvae attack the plants under ground.

The life history studies reported in this bulletin were carried on during 1928 and 1929, at Fayetteville, Arkansas.[2] Field observations in various parts of the state have been made from 1922 to 1929. Experiments with remedial measures are not included, although a summary of recommendations for control is appended.

DISTRIBUTION

The bean leaf-beetle is distributed over the United States east of Minnesota, Kansas, and New Mexico, and occurs in southern Canada. It is more destructive in the southern than in the northern states. The beetle occurs in all parts of Arkansas.

HISTORY

This species was first described by Forster in 1771. A single synonym occurs, *C. caminea*, described by Fabricius in 1801 *(5)*.

The first reference in literature to this insect as a pest was by Popenoe *(8)* from Kansas in 1876. Webster *(10)* reported it as a species of economic importance from Louisiana and Indiana in 1887 and later from Ohio in 1894. Chittenden *(1)* first describ-

[1]*Cerotoma trifurcata* Forst.; order Coleoptera, family Chrysomelidae.

[2]In the life history studies the writer was aided by Allen W. Dowell, student assistant. Credit is also due to other members of the staff of the Department of Entomology for preparation of illustrations, to David G. Hall for drawings of the adult beetle, to H. H. Schwardt for the drawing of the egg and inking the drawings of the larva and pupa, and to W. J. Baerg for photographs of injury.

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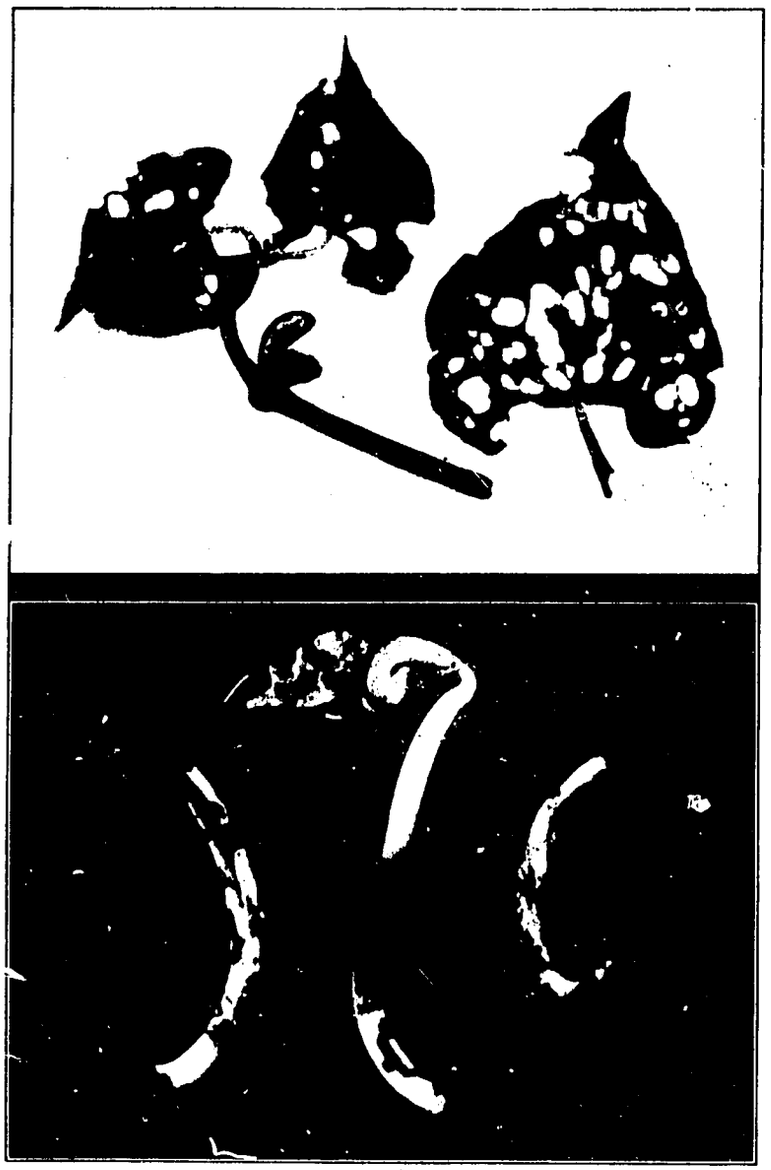

Figure 1. Injury to cowpeas caused by the bean leaf-beetle. (Upper) Typical feeding marks of adult beetles on foliage; (lower) injury to seedling stems caused by larvae.

ed the immature stages and sketched the life history. Further studies of life history were made by McConnell *(7)* and by Eddy and Clarke *(2)*. No detailed life history studies have been published hitherto.

FOOD PLANTS

The bean leaf-beetle most commonly attracts attention as a pest of garden beans, cowpeas, and soybeans. Among its other hosts Chittenden *(1)* lists Japanese clover, *Lespedeza* sp., beggarweed, *Desmodium* sp., the tick trefoil, *Meibomia* sp., and the hog peanut, *Falcata comosa.*

In Arkansas the quail pea, *Strophostyles helvola*, a plant adapted to light sandy soil, seems to be the wild host of most importance. This plant is usually more abundant in situations where serious injury occurs, and larvae have been collected more readily in the nodules on its roots than on any other host. The tick trefoil is also a common host.

The bean leaf-beetle in both the adult and larval stages attacks the same host plants, the adult feeding upon the foliage and tender stems and the larvae upon the underground stems, roots, and nodules. Eddy states (in correspondence) that "in South Carolina the chief hosts of the larval stages are the roots of soybeans, cowpeas, and snap beans, the infestation being greatest on the first and least on the last, when all of the hosts were abundant."

ECONOMIC IMPORTANCE

The bean leaf-beetle usually attracts attention of growers as a pest of garden beans, and in most references to it in entomological literature it is considered from this point of view. It is probable that it causes a greater monetary loss as a field crop pest, particularly because of its injury to cowpeas.

In gardens, injury caused by this pest is usually to early beans in the seedling stage, by the adults feeding upon the foliage and stems, which may destroy the stand entirely. Such injury comes to the attention of the entomologists in Arkansas every year. If the plants are not killed in the seedling stage, they usually appear to outgrow this injury.

Its importance as a field pest was emphasized by McConnell *(7)*, working in Mississippi in 1915. He found that in addition to the direct injury caused by beetles and larvae feeding upon the plants and roots, that the larvae also fed upon the nitrogen-forming nodules. Injury caused by this type of feeding was most pronounced in fields where the soil was very poor and most in need of nitrogen fixation. It may be concluded from McConnell's

work that this damage at times may exceed the direct injury to the plants themselves.

Leonard and Turner *(6)* confirmed McConnell's work. They found that "Damage to the mutual nitrogen fixing functions of the cowpea plant may be caused by these insect larvae without superficial indication of such damage, except the presence of beetles and leaf injury". They also reported the killing of stands of cowpeas on light sandy soils.

Its importance as a field crop pest is further emphasized by Eddy and Clarke *(2)*, working in South Carolina, who state "that during late summer and fall, especially in dry years, the damage to cowpeas is enormous. The quantity of damage done in 1927 was so great that many growers did not plant cowpeas during 1928, since they feared a recurrence of the injurious activities of the previous year. This recurrence, however, did not materialize."

In Arkansas the bean leaf-beetle is probably not so destructive as a field crop pest as it is in South Carolina. The writer has noted whole fields of cowpeas sown after oats in June and early July, which were destroyed a few days after coming up, by beetles feeding on foliage and stems. These fields were all on light sandy soil. This type of injury was most extensive in southwestern Arkansas in 1923, and in central and southeastern Arkansas in 1924. Such injury is exceptional, however, for as a rule the attack of the beetles results in thinning the stand rather than killing it outright, and injury by thinning is not readily recognized nor is it easy to estimate. Severe injury by the adults, after the plants are three or four weeks old, has not been noted. This injury has not been extensive enough in Arkansas to limit materially the growing of its host plants. Because of its insidious nature, the larval injury is seldom recognized by farmers.

INSECTS CONFUSED WITH THE BEAN LEAF-BEETLE

The bean leaf-beetle is occasionally referred to by correspondents as the Mexican bean beetle, an insect which is not known to occur in Arkansas but which is very destructive in the southeastern states. The two insects are quite different in appearance. The Mexican bean beetle is about one-fourth of an inch in length, hemispherical in shape, and each of its brown wing covers has eight black spots. In general it resembles the lady beetles to which it is related. Both the adult and larva of the Mexican bean beetle feed upon foliage.

The 12-spotted cucumber beetle may also be confused with the bean leaf-beetle in the field. The 12-spotted cucumber beetle is often common on leguminous plants, feeding on their floral parts. It resembles in shape the bean leaf-beetle, to which it is

related. However, it may be distinguished by its greater size and by the color of its wing covers, which are light green and which are marked by 12 spots.

LIFE HISTORY

The adult stage of the bean leaf-beetle, which feeds upon foliage, is the stage commonly observed. The other stages live below the surface of the ground. The eggs are deposited in the soil around the host plants. The slender white larvae may be found in the soil attacking the underground stems and roots of their hosts. If the plants are well supplied with nodules, the larvae which are drilling into them are more easily collected than those feeding upon roots. Larvae may also be collected in young hosts by splitting the underground stem. Between instars the larva leaves the host plant and forms an earthen cell in which it molts.

When full grown, the larva forms an oval cell in the earth, one to four inches beneath the surface, where it gradually shortens and undergoes physiological changes preparatory for pupation. This is known as the prepupal period. Here it molts its larval skin and transforms to the pupal stage, and later transforms to a soft callow adult. The adult beetle breaks out of the cell and comes to the surface of the ground as soon as it hardens.

In habits and in general appearance, the bean leaf-beetle resembles the 12-spotted and the striped cucumber beetles.

DESCRIPTION OF STAGES

THE ADULT

The beetle varies from 3.5 mm. to 5 mm. (or one-sixth to one-fifth of an inch) in length. In color it varies from a pale yellowish buff to a dull red on the dorsal aspect. In typical specimens the elytra are marked on the outer margins with black and have near the median line three pairs of black spots which sometimes are fused and form three transverse bands. The marking of the dorsal aspect is exceedingly variable; buff or reddish specimens almost without black markings are frequently collected, and gradations between the extremes are common. (Figures 2 and 3.)

A technical description of the beetle by Horn *(4)* is as follows:

"*C. trifurcata* Forst., Nov. Spec. Ins. 1771, p. 29.—Oval, narrower in front, moderately convex, body beneath and head black, above yellow. Elytra with black, forming a narrow basal band extending in a triangle about the scutellum and prolonged along the sides nearly to apex, sometimes broken, three black spots on each side of and close to the suture, the posterior smaller. Antennae pale, darker externally. Head black, clypeus very coarsely punctured. Thorax nearly twice as wide as long, slightly narrowed in front, sides feebly arcuate, margin broader posteriorly, disc moderately convex, finely

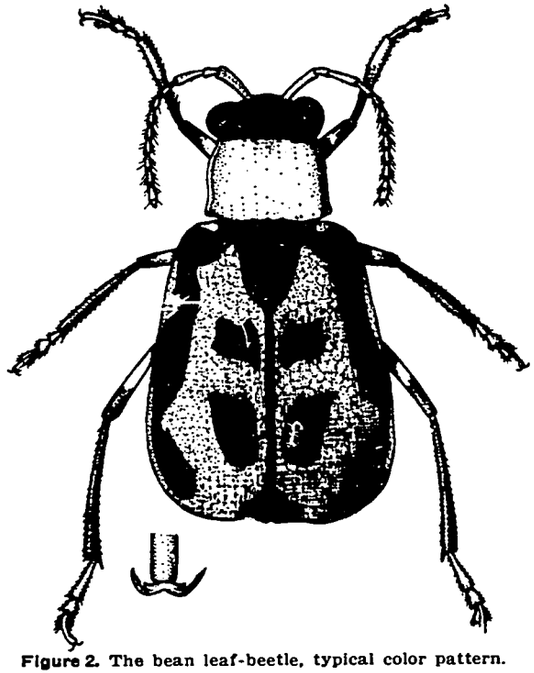

Figure 2. The bean leaf-beetle, typical color pattern.

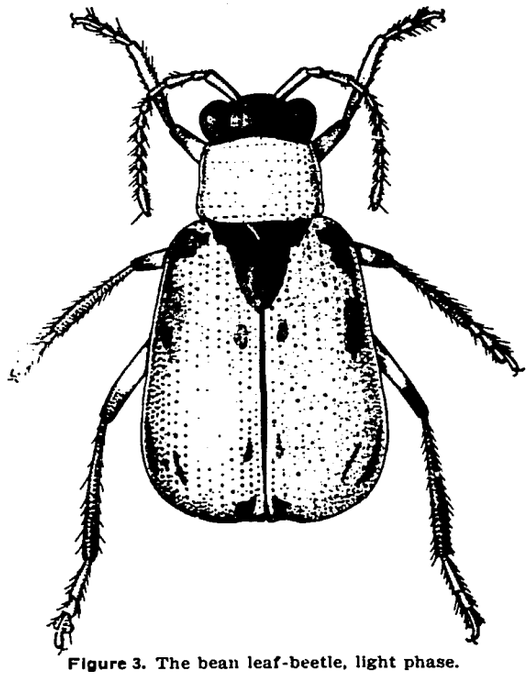

Figure 3. The bean leaf-beetle, light phase.

alutaceous, very obsoletely, finely and sparsely punctate; scutellum black. Elytra irregularly subseriately punctate, the punctures not large nor closely placed. Body beneath black, meso- and metapleurae punctate; abdomen nearly smooth. Legs yellowish testaceous, the front and middle tibiae in part, the posterior tibiae entirely black, the femora of the latter black at apex. Length .14-.20 inch.; 3.5-5 mm.

"In the male the antennae do not differ notably from the female, although they are shorter and stouter. The entire front of the male is yellow, only the portion behind the eyes is piceous; the last ventral segment is truncate.

"In the female the last ventral is oval and granulately punctate.

"The usual coloration of the elytra consists of a triangular scutellar spot, which often sends a narrow stripe along the base to the humeri. From the umbone a moderately wide stripe extends nearly to apex; this stripe is often interrupted. Near the suture are four subquadrate spots arranged in a quadrangle; near the apex are two smaller spots.

"The variation from this observed are as follows: The larger spots forming the quadrangle may be divided longitudinally, producing two linear spots in the place of one. On the other hand, these spots may be longitudinally confluent, so that the two on each elytron form a short vitta. Specimens may occur with pale elytra with merely a small scutellar triangle and a small humeral black spot."

The Egg

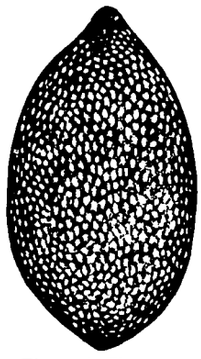

Figure 4. The egg.

The egg is spindle shaped, .8 mm. in length and .35 mm. in diameter. Its color is usually a dull reddish orange. The surface is coarsely reticulated. (Figure 4.)

The Larva[3]

The full grown larva at the end of its feeding period varies from 7 to 10 mm. in length. It is white in color, except the head and the anal shield, which are almost black. In shape it is sub-cylindrical, tapering slightly anteriorly, and is very slender. For locomotion it depends upon its thoracic legs and the fleshy anal proleg which is a development of the tenth abdominal segment. (Figure 5.)

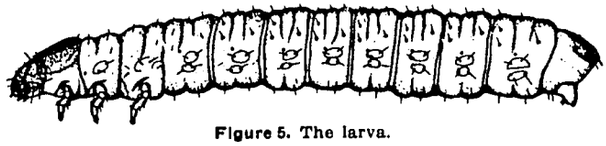

Figure 5. The larva.

There are three larval instars. The width of the heads of larvae of each instar is as follows:

First instar	.17 to .19 mm.
Second instar	.27 to .30 mm.
Third instar	.40 to .42 mm.

[3]A technical description of the larva is being prepared for publication elsewhere by Dr. Adam G. Boving, of the U. S. Bureau of Entomology.

THE PUPA

The pupa is clear white in color and in general resembles the pupae of the species of Diabrotica. The length varies from 3 mm. to 4.5 mm. The elytra and wings overlap the sixth abdominal segment; the femora and tibia are exposed and the tarsi reach the seventh segment. The caudal segment bears a pair of long nearly straight spines. (Figure 6.)

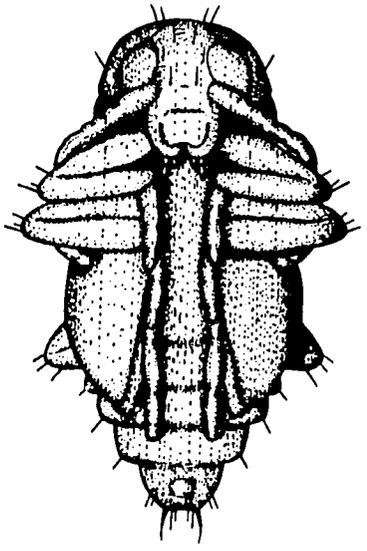

Figure 6. The pupa.

DURATION OF STAGES

The life history studies of the bean leaf-beetle were carried on in a screen sided insectary which insured as nearly normal temperatures as possible. The period during which immature stages were being reared extended from May 29 to October 10 in 1928 and from April 24 to September 23 in 1929. Temperature was recorded by a thermograph checked daily by maximum and minimum thermometers. In addition to the insectary records, observations were made on a relatively small number of larvae, prepupae, and pupae reared in incubators at temperatures of 31° and 32° C., since the mean temperature for any day seldom passed above 30° C.

The mean temperature for the period of development of each stage was computed by averaging the mean temperature for each day during the entire period of development of each individual reared. These developmental periods were then classified according to temperature, and all means within half a degree of a unit of temperature were classified together. (For example, all individuals with a developmental period at a mean temperature between 24.51° C. and 25.50° C. were classified as having developed at 25° C.) The mean for each day was determined by taking an average of the thermograph records for each two-hour period.

The cages used for rearing the immature stages were one-ounce tin salve boxes about two inches in diameter. These boxes were half filled with slightly moistened earth. Adults were kept for oviposition and longevity records in battery jars capped with muslin or paper, or in four-ounce screw-capped glass vials. The

screw-capped vials were used exclusively for oviposition records of pairs.

The usual food of the larvae was the radicles of cowpeas, sprouted three to five days in an incubator. Other food was tried, but this will be discussed elsewhere. Foliage and flowers of beans and cowpeas were used as food for adults.

THE INCUBATION PERIOD

The incubation period of 2,856 eggs of the bean leaf-beetle, recorded at temperatures ranging from 20° to 30° C., varied from 6 to 15 days, the greater period being required for the lower temperatures. The average time required for each temperature and the extremes of variation are summarized in Table 1. The

TABLE 1. *Cerotoma trifurcata.* DURATION OF INCUBATION PERIOD. 1928 AND 1929.

Temperature		Duration of incubation period (days)			Number of eggs
°C.	°F.	Average	Minimum	Maximum	
20	68.0	15.00	15	15	48
21	69.8	13.60	12	15	129
22	71.6	12.45	12	14	161
23	73.4	11.30	10	13	191
24	75.2	10.25	9	12	163
25	77.0	9.60	7	11	325
26	78.8	8.65	8	11	913
27	80.6	7.94	7	10	418
28	82.4	7.24	6	8	95
29	84.2	7.32	7	9	313
30	86.0	7.00	7	7	100
Total					2,856

rate of acceleration of the incubation period with the increase in temperature is graphically illustrated by Figure 7. The index of correlation between temperature and the incubation period is .944.

The incubation period may be greatly prolonged by intermittent waves of cold weather. Eggs deposited in the earlier part of the season, April 24 to May 1, required from 22 to 25 days for incubation. During this incubation period, the daily mean temperature averaged 17° C., and frequently was as low as 10° C. Unfortunately, the number of records from this part of the year was small, and no records were secured for the greater part of May. Hence these data are not included in the general summary.

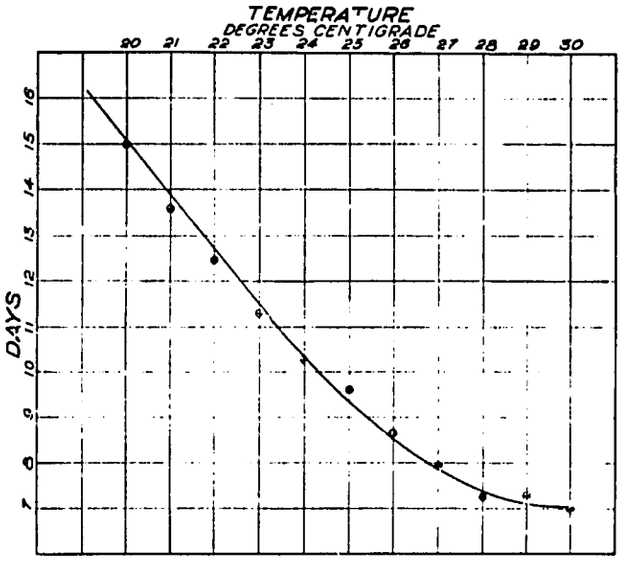

Figure 7. Curve illustrating the relationship between temperature and the duration of the egg stage.

Larval Feeding Period

The feeding period of 1,531 larvae which were reared at daily mean temperatures ranging from 21° to 32° C., and fed

Table 2. *Cerotoma trifurcata*. Duration of larval feeding period, 1928 and 1929.

Temperature		Duration of larval feeding period (days)			Number of larvae
°C.	°F.	Average	Minimum	Maximum	
21	69.8	16.60	15	19	80
22	71.6	16.15	14	18	46
23	73.4	13.40	12	18	188
24	75.2	13.51	10	17	291
25	77.0	11.92	10	16	35
26	78.8	10.51	8	14	193
27	80.6	10.78	7	14	152
28	82.4	9.91	8	12	109
29	84.2	9.20	8	13	285
30	86.0	8.80	8	10	55
31	87.8	8.60	8	9	20
32	89.6	8.52	7	11	77
Total					1,531

on the radicles of sprouted cowpeas, varied from 7 to 19 days. A summary of these data is given in Table 2 and the effect of the increase of temperature upon the rate of development is graphically illustrated in Figure 8. The index of correlation between temperature and the rate of development is .854.

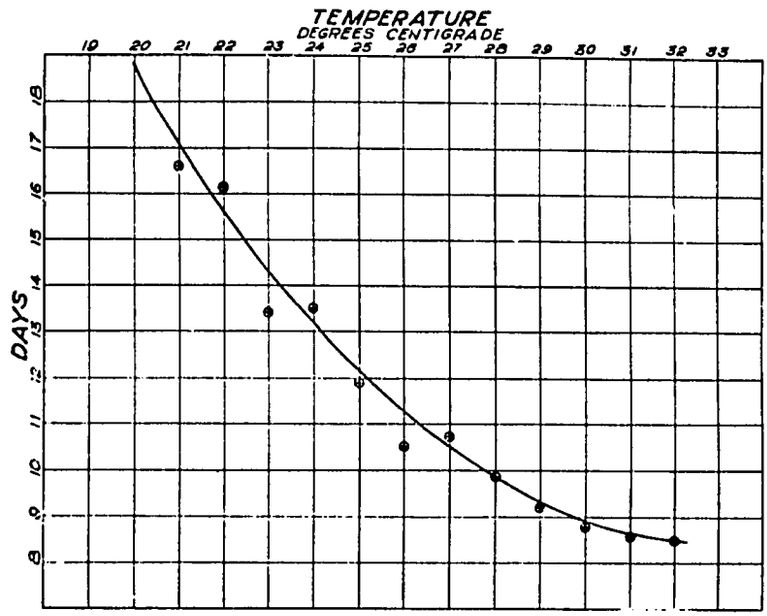

Figure 8. Curve illustrating the relationship between temperature and the larval feeding period.

The larval feeding period of individuals given food other than sprouted cowpeas was somewhat more prolonged. The variation in rate of development of individuals in the same lot was also greater. One larva fed on sprouted beans at 21° C. required 29 days for passing through its feeding period, and then developed normally to the adult stage. This is 10 days more than the maximum feeding period of larvae reared at the same temperature and fed on sprouted cowpeas. Some larvae in this same lot formed their pupal cells in 20 days. The rate of development of larvae fed soybeans, lima beans, and cowpea radicles broken from the cotyledons was also slower. The number reared on these hosts was too small, however, to tabulate or to justify definite comparisons.

The Prepupal Period

The prepupal period of 864 individuals reared at temperatures from 19° to 32° C. varied from 3 to 11 days. The average

TABLE 3. *Cerotoma trifurcata*. DURATION OF PREPUPAL PERIOD. 1928 AND 1929.

Temperature		Duration of prepupal period (days)			Number of prepupae
°C.	°F.	Average	Minimum	Maximum	
19	66.2	9.90	8	11	20
20	68.0	9.00	7	11	2
21	69.8	7.33	7	8	3
22	71.6	7.16	6	8	37
23	73.4	6.02	5	7	45
24	75.2	5.79	5	9	254
25	77.0	5.73	4	7	92
26	78.8	5.10	4	7	60
27	80.6	4.86	3	7	58
28	82.4	4.65	4	6	60
29	84.2	4.40	3	5	99
30	86.0	3.96	3	5	50
31	87.8	4.00	3	6	35
32	89.6	4.12	3	5	49
Total					864

time spent in this stage and the extremes of variation are shown in Table 3, and the relation between temperature and the rate of development is shown in Figure 9. The index of correlation between temperature and development is .823.

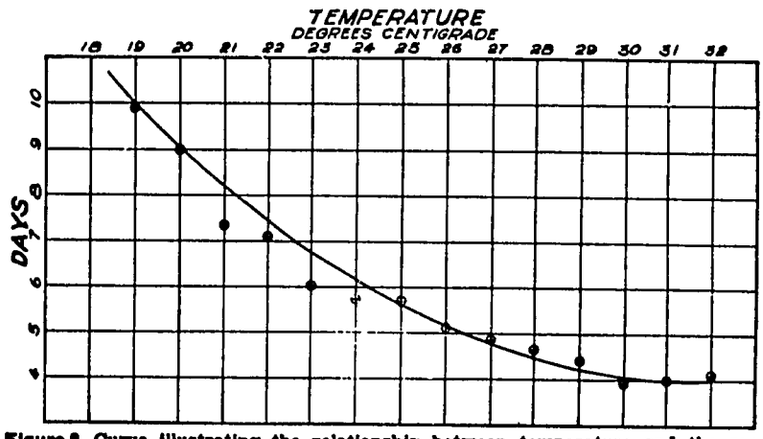

Figure 9. Curve illustrating the relationship between temperature and the prepupal period.

The mortality of prepupae when exposed to excessive heat was greater than that of any of the other stages.

THE PUPAL PERIOD

The duration of the pupal period of 457 individuals reared at temperatures ranging from 20° to 32° C. varied from 4 to 10 days. The data relating to the duration of the pupal stage is summarized in Table 4, and its relation to temperature is graphically illustrated in Figure 10. The index of correlation is .879.

TABLE 4. *Cerotoma trifurcata*. DURATION OF PUPAL PERIOD. 1928 AND 1929.

Temperature		Duration of pupal stage (days)			Number of pupae
°C.	°F.	Average	Minimum	Maximum	
20	68.0	10.00	10	10	7
21	69.8	10.00	10	10	2
22	71.6	9.00	8	10	19
23	73.4	8.67	7	10	12
24	75.2	7.52	7	9	83
25	77.0	7.06	6	9	97
26	78.8	6.60	6	8	58
27	80.6	6.20	5	7	49
28	82.4	5.77	4	7	73
29	84.2	5.22	5	6	27
30	86.0	5.00	5	5	6
31	87.8	4.82	4	6	17
32	89.6	4.43	4	5	7
Total					457

THE ADULT

The callow adult remains in its pupal cell after transforming from the pupal stage, until it hardens. The duration of this callow period may be only a few hours in midsummer, and may extend over several days in the cooler part of the year.

The adult beetle, after coming above ground, feeds voraciously for several days before it begins depositing eggs. The preoviposition period of 18 mated females for which records were secured varied from 5 to 22 days with an average of 8.92 days. Only two of these females required more than 13 days. These records were based on 12 female beetles of the first generation and six of the second generation.

The duration of the preoviposition period was found to be dependent upon the availability of host seedlings as food for

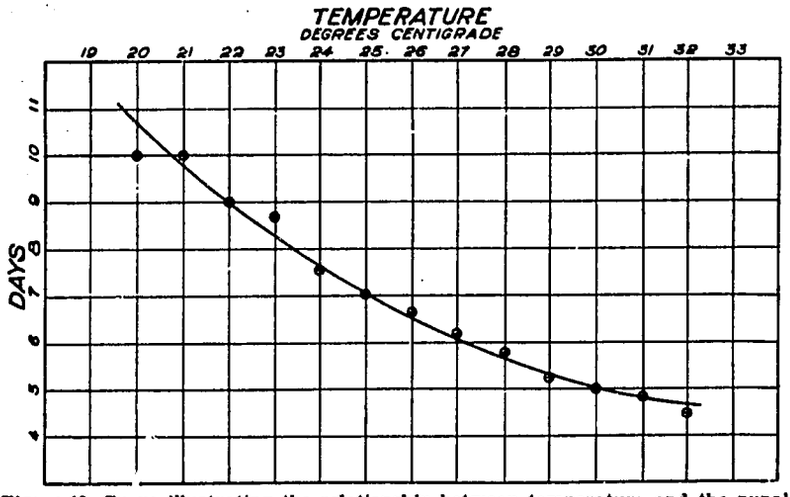

Figure 10. Curve illustrating the relationship between temperature and the pupal period.

beetles when they first transformed to the adult stage. Eleven pairs isolated from lots of beetles which transformed between June 18 and June 24 were fed foliage of cowpea plants which were three weeks old or older. No eggs were secured from these beetles. After July 10, 26 pairs of beetles were isolated and were fed the foliage of seedling cowpeas from two to five days old. Oviposition was secured from 18 of the 26 pairs. The 11 pairs of beetles which had been fed foliage of older plants for a period of three weeks were changed to a diet of seedlings after July 10. No eggs were secured. However, by the time the change in food was made the beetles fed only sparingly. The period of voracious feeding had passed.

The oviposition period of 11 females for which complete records were secured varied from 1 to 67 days, with an average of 16.9 days. Only one female deposited eggs over a longer period than 29 days. Probably some of the very short periods were abnormally terminated because of unfavorable conditions. When oviposition was once begun it continued with fair regularity every day until near the end of the period.

The number of eggs deposited by each of these 11 females varied from 2 to 904 with an average of 257.7. The maximum number of eggs secured from a single female by Eddy and Clarke *(2)* was 1386.

The longevity of the females which deposited eggs was much shorter than that of those which did not oviposit. Of the 11 mated pairs previously referred to, which became adult between June 18 and 24, and from which no oviposition was secured, only two females and four males had died by October 1.

The average longevity of those that had died by that time was 82 days for the females and 61 days for the males. The longevity of the remaining beetles at that time was 112 days. These beetles went into hibernation. Feeding by these beetles after the first ten days following emergence was very light and after the first month was almost negligible.

From the 11 pairs from which complete oviposition records had been secured, two females and two males were living by October 1, an average longevity at that time of 79 days. The average longevity of the females that had died was 51.5 days, and of the males 43.8 days.

No positive explanation can be offered for the apparently stimulating effect of seedling host plants upon oviposition. However, it may be due to their high nitrogen content. The following comparative analysis of the foliage of seedling cowpeas and the foliage of older cowpeas, made by George Janssen of the department of agronomy, was as follows:

Foliage of cowpea seedlings	
Dry weight	16.0 per cent
Nitrogen	6.83 per cent
Foliage of cowpeas six weeks old	
Dry weight	20.2 per cent
Nitrogen	3.89 per cent

TOTAL DURATION OF IMMATURE STAGES

Under optimum conditions, of which a temperature around 28 to 30 degrees is the most obvious, it would be possible for the bean leaf-beetle to develop from the egg stage to a sexually mature adult in 26 days, allowing 6 days for incubation; 8 days for the larval feeding period; 3 days for the prepupal period; 4 days for the pupal stage; and 5 days for the development of the sexually mature adult. This would be minimum time. However, optimum conditions both in food and temperature are unusual and seldom continue for any extended period. In addition, the preoviposition period is exceedingly variable. The shortest life history of individuals actually carried through all the stages was a lot of second brood beetles which developed from eggs deposited on July 11 and which began oviposition on August 16, a total of 36 days. In the cooler parts of the year the duration of stages is much prolonged and the immature stages alone may require nearly two months.

SEASONAL HISTORY

The bean leaf-beetle passes winter in the adult stage in trash or clumps of grass growing at a slight elevation, permitting the hibernating beetles to avoid standing water. In the

vicinity of Fayetteville, the beetles emerge from hibernation in April and early May. Oviposition by beetles of the overwintered brood may begin in late April and extend into the month of May. In cages, overwintered females have continued ovipositing after July 1. However, in the field there are relatively few overwintered beetles in evidence after the beginning of June. Larvae of the first brood may be found attacking the roots of their host plants in the latter part of May and throughout June.

The earliest record of emergence of adults of the first brood from the soil at Fayetteville was June 16 in 1928 and June 24 in 1929. These beetles did not appear in large numbers, however, during either season, until after July 1, and the break between the overwintered brood and the first brood of beetles was distinct. Weed *(9)* in Mississippi noted two periods of abundance of these beetles, April and July. Herrick *(3)*, working in the same state, also noted a break between two periods of occurrence of these beetles in Mississippi, in April and in July.

The earliest record of emergence of beetles of the second generation was August 11. This was doubtless later than the emergence of the second generation in the field, since no oviposition was secured from the earliest part of the first generation. The earliest record of adults of the third generation was September 22.

McConnell states that there are three generations at Greenwood, Mississippi, and perhaps more along the Gulf Coast. As already indicated, individuals of three generations were reared at Fayetteville. Most of the injury in Arkansas, however, is caused by beetles of the overwintered brood and the first generation, and by larvae of the first and second generations.

Beetles of the first, second, and third generations went into hibernation at Fayetteville in the fall of 1929. Most of the females of the first generation which had been fed host seedlings and which deposited eggs had died before cool weather set in. On the other hand, most of those first generation beetles, which were not fed seedlings soon after emergence and which apparently failed to become sexually mature, went into hibernation with beetles of the later generations.

FACTORS AFFECTING ABUNDANCE

While the bean leaf-beetle may be found in all seasons and in all parts of the state, its fluctuations in numbers are very marked. Probably the factor most favorable to it is an abundance of its wild hosts, or a sequence of hosts planted so that seedling plants are available for food early in the season and again when the first generation of adults matures.

Relatively dry weather is apparently favorable to the bean leaf-beetle. The abundance of the beetles on light soils may be

associated with the abundance of its wild host, the quail pea. However, the beetle is tolerant of unfavorable conditions and occurs in some numbers every season and in a wide range of conditions.

The bean leaf-beetle is quite tolerant of high temperatures. While the duration of the immature stages at temperatures from 20° to 27° C. is about the same as those of the 12-spotted cucumber beetle, at higher temperatures which appear to be unfavorable to the cucumber beetle, the development of the bean leaf-beetle continues to be accelerated. High mortality does not occur until the mean temperature approaches 32° C.

A single parasite, *Celatoria diabroticae* Shimer, has been reared in small numbers from the bean leaf-beetle. It is not numerous enough to affect the relative abundance of the pest.

RECOMMENDATIONS FOR CONTROL

Injury to beans in the seedling stage, grown in gardens or on truck farms, may be prevented or reduced by dusting with arsenicals. Two applications of calcium arsenate diluted with hydrated lime at the rate of 1 part to 10 of the diluent have given fair protection to beans. The applications should be made on seedling plants when the first feeding injury appears. Calcium arsenate does not appear to kill many of the beetles, but is effective largely as a repellent. Injury to beans by calcium arsenate in southeastern United States has been reported by other entomologists *(2)*, but none has been observed in Arkansas.

Insecticides cannot be depended on for the control of the bean leaf-beetle on field crops. Serious injury may be avoided by timing the planting of the host plants so that they come up between broods of adults and will have passed the seedling stage before the second brood appears. This recommendation has previously been made by McConnell *(7)*. In the vicinity of Fayetteville, Arkansas, planting cowpeas in the latter part of May and early June would most nearly avoid injury. In the more southern parts of the state, the most favorable time for planting would be earlier.

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BIOLOGY AND CONTROL OF STINK BUGS ON SOYBEANS

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Stink bug damage to soybeans was first recognized as a problem in Arkansas in the fall of 1959. At about that time the United States was beginning to export large quantities of soybeans to the Orient, and buyers for export began basing their prices on soybeans with no more than 2 percent "damage" of all kinds. Stink bug damage was included in this category, and soybeans with more than 2 percent damage were subject to a discount.

Stink bug damage is caused when the insect inserts its piercing-sucking mouthparts through the pod and into the soybean. Presumably the bug injects enzymes into the bean to partially liquefy the tissues, so they can be withdrawn through the long, slender beak. The result is a discolored and often sunken spot on the soybean, due to interior damage (Fig. 1).

Considerable turmoil in the soybean trade resulted when buyers first began discounting, largely because so little was known about the problem and no one knew what to expect. Some buyers were afraid to store soybeans because of the possibility of an increase in detectable damage and a consequent monetary loss. Growers often were incensed at the discounts, due to what seemed to them a triviality. Some growers refused to sell to exporters when a discount was assessed, and rerouted the soybeans to crushing establishments, which were not discounting.

A research project was initiated by the Arkansas Agricultural Experiment Station covering a number of the varied aspects of the problem. After several years of work, many questions naturally remain unanswered; sufficient information is at hand, however, to deal in an acceptable manner with the practical aspects of detection and control of stink bugs.

REVIEW OF LITERATURE

Most of the literature on green stink bug, the principal species to be discussed, concerns damage to peaches and other fruits. However, the biological data in these publications assist in understanding the problem on soybeans.

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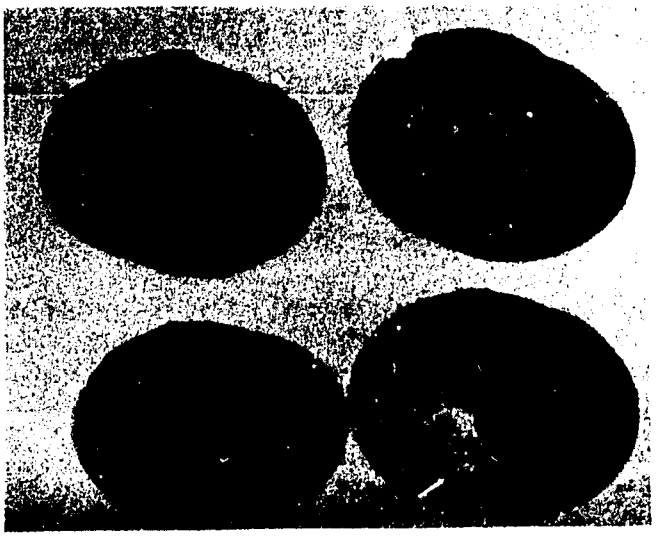

Figure 1. At top, damaged soybeans showing appearance of seed coat; bottom left, seed coat peeled away; bottom right, part of cotyledon cut away.

Whitmarsh, in 1917, reported on an extensive study of this species in Ohio, particularly as it affected peaches (8). Detailed descriptions and illustrations of the various life stages were presented. Data on the life cycle and seasonal history indicated one generation per year. Preferred wild hosts were listed as silver maple, box elder, Norway maple, dogwood, European linden (basswood), American linden, wild cherry, elderberry, black-haw, peach, apple, and catalpa.

Schoene and Underhill (5), in 1933, emphasized the relationship of green stink bug populations in Virginia to suitable wild hosts, and especially to a succession of these so that food was available throughout the season. They believed that wild hosts were preferred to cultivated ones, the latter becoming infested only when wild hosts failed.

Underhill (7) discussed the dependence of populations in Virginia on suitable wild hosts, and gave an extensive list of these. He stated that the problem on cultivated plants tended to recur year after year in the same places, due to fortuitous combinations of wild hosts. Preferred wild species included black locust, elderberry, honey locust, linden, wild cherry, mimosa, redbud, dogwood, and box elder. Fruiting parts were preferred. The most common cultivated hosts were lima beans, peaches, and cotton. One generation a year was observed. The insect hibernated under leaves, brush, and rubbish on the soil, although specimens

were difficult to find in winter. Underhill recommended that garden beans be planted at least 100 yards from known wild hosts.

Sorenson and Anthon (6) were mainly concerned with damage to various tree fruits in Utah. They presented seasonal history data and concluded that probably only one generation a year was completed. Over-wintering adults were found under oak leaves 50 to 80 yards from an orchard.

Woodside (10) attributed most dimpling of peaches in Virginia to green stink bug. The insect was found to hibernate in the adult stage among leaves and brush. Infestations in peach orchards were due to proximity of wild hosts, including black locust, honey locust, linden, maple, and black-haw. Migration to peaches occurred when these foods failed.

Sailer (4) reared green stink bugs in confinement, and suspected (as a result of variation in duration of the nymphal period) that racial differences existed between various populations. Specimens from Illinois and Maryland were used. Sailer speculated that more than one generation could occur in a season, contrary to previous information, since no diapause was encountered.

Miner (3) outlined the problem on soybeans in Arkansas in 1961, and described the appearance of damage caused by southern green stink bug, brown stink bug, and rice stink bug. Reduction in oil content of soybeans due to stink bug damage was found to be of a low order. The irregular distribution of populations was mentioned.

Blickenstaff and Huggans (1) demonstrated the destructive capacity of stink bugs in Missouri by confining heavy infestations in cages over growing soybeans.

Daugherty *et al.* (2) showed by cage experiments in Missouri that heavy infestations of brown stink bug reduced oil content of soybeans, reduced size of the beans, reduced germination, increased protein, and increased fat acidity (or fatty acid content). It was also shown that green stink bug caused more damage when the period between bloom and maturity became longer.

Wingard (9) reported in 1925 that infection of lima beans by a yeast, *Nematospora phaseoli,* was apparently due entirely to feeding activity of green stink bug. Schoene and Underhill (5) stated that the micro-organism greatly increased the severity of stink bug damage to lima beans.

SPECIES AND TYPE OF DAMAGE

In the southeastern counties of Arkansas a mixture of southern green stink bug, *Nezara viridula* (L.), and green stink bug, *Acrosternum hilare* (Say), was found to cause virtually all the stink bug damage. Proportions of the two species varied from field to field. Some fields had nearly all one species or the other, and during early stages of the work it was believed that only southern green stink bug was involved.

Farther north, and including the majority of the state, green stink bug was found to be responsible for nearly all the damage. This is the species referred to in the present publication unless otherwise noted.

Brown stink bug, *Euschistus servus* (Say), was occasionally found in soybeans, and is known to cause damage. Its numbers and importance were negligible, however, in comparison with the previous two.

Rice stink bug, *Oebalus pugnax* (Fabr.), was frequently found in soybeans, but evidently preferred to feed on grasses present as weeds, and probably was not responsible for damage to soybeans.

Small cage experiments were conducted from mid-September to mid-October of 1960 to determine the nature of damage caused by the various species. The insects were placed in a cylindrical screen cage, six inches long and three inches in diameter, and the cage was then slipped over part of a raceme of soybean pods in the field. No food was present except stems and pods.

Four southern green stink bugs (two adults and two fifth instar nymphs) were caged on a raceme for 19 days. All were adult and alive when removed. Sixteen soybeans removed from the cage were all damaged severely. One was greatly shriveled. In general, the seed coat was sunken and wrinkled in the punctured area, with a slight "wart" marking the site where the stylets entered. The flesh of the cotyledons was sunken and deformed beneath the seed coat, showing an irregular whitish splotch and numerous slender branches of white tissue which sometimes ran completely through the bean. A dark color often replaced some of the white discoloration. Frequently the inner membrane of the seed coat was fused to the cotyledons, rather than being free as is normal.

Cage work in 1961 with green stink bug showed that the type and severity of damage were identical with damage by southern green stink bug as just described.

Three fifth instar nymphs of brown stink bug were similarly caged over a raceme for 19 days. All were live adults when removed. Of 32 soybeans removed, 7 were undamaged. The remaining 25 were damaged, but much less severely than those in the southern green stink bug cage. Many had to be inspected closely to detect damage. The type of damage otherwise resembled that of southern green stink bug. The number of bugs and the number of soybeans were not the same in the two tests, but the great difference in results suggested that brown stink bug did not cause such violent effects as southern green stink bug.

Rice stink bug was so common in soybean fields that a series of six tests were conducted as above. The number of bugs per cage ran from two to six. Three cages were left in place for four days, while the other three were left for 17 days. Of a total of 51 soybeans in the shorter exposure, 42 were undamaged. The other 9 had, in general, no more than a superficial dark speck on the seed coat. Rarely was there slight internal damage. All 10 bugs used were alive at the end of the experiment.

Of 106 soybeans removed from the cage with the longer exposure, 93 were undamaged. The remaining 13 had superficial specks, and, rarely, a slight amount of internal damage. Six bugs out of 12 were alive at the end of the experiment.

Rice stink bug is known to feed freely on seeds of grasses. Since in these experiments no food other than soybeans was offered, it was concluded from the insignificant damage inflicted that in the field this species would not be a problem on soybeans. It was often noted that where many rice stink bugs were present in a soybean field, generally a great deal of Johnsongrass [*Sorghum halepense* (L.) Pers.], barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], or other grass also was present.

A similar cage experiment was conducted with three-cornered alfalfa hopper, *Spissistilus festinus* (Say), which commonly feeds on stems and petioles of soybeans. Four adults were caged on a raceme for 19 days. Twenty-three soybeans were then removed, of which 15 were undamaged. The remaining eight were damaged in a manner very like southern green stink bug, although to varying degrees. In general, dimpling or wrinkling of the seed coat was worse than in the case of stink bugs, and internal damage was somewhat less.

Since a normal feeding site (petioles) was available, the results suggested that this insect might damage soybeans in the field, and in a manner nearly indistinguishable from stink bug damage. Other piercing-sucking insects might do the same. Field

data are lacking, except for circumstantial evidence from two experiments. During 1962 and 1963, 50 sweeps with an insect net were made weekly throughout the summer in a field not expected to be infested with stink bugs. No stink bugs were ever taken in 1962. In 1963, out of 16 sets of weekly sweeps two stink bugs were taken (one on July 18 and one on September 21). Soybean samples for each year graded 2 percent "stink bug damage", despite the virtual absence of stink bugs.

Blickenstaff and Huggans (1) reported no damage in cage tests from the tarnished plant bug, *Lygus lineolaris* (P. de B.), or from the rapid plant bug, *Adelphocoris rapidus* (Say).

The only problem in identification of the various species of stink bugs found on soybeans lies in separating green stink bug from southern green stink bug. Their appearance is similar upon casual observation. Green stink bug has the sternum of the first abdominal segment prolonged into a point between the hind coxae. Southern green stink bug has this protruberance rounded rather than pointed. The antennal segments of green stink bug are blackish on the distal portion, whereas they are reddish on southern green stink bug. The osteolar canal running dorsally from the scent gland on green stink bug is long and tapering. On southern green stink bug, it is short and obtuse. (The scent gland is located above the posterior edge of the middle coxae.) Some of these characters are shown in Figure 2.

LIFE CYCLE

Two generations of green stink bug were reared in the laboratory in 1963. Temperature in the rearing room was held at 72°F. plus or minus 2°, humidity was kept at 60 percent plus or minus 3 percent, and a day-length of 15 hours was provided by artificial light. Rearing containers were half-pint cardboard ice cream cartons, with the lids replaced by sheer nylon mesh. Egg masses and early instars were provided with high humidity by means of a cheesecloth wick which ran from a water reservoir to the bottom of the rearing container. Food consisted of string beans from a grocery store. About half of a pod was placed in each cage every other day. All nymphs from one egg mass were kept in one cage until their life cycles diverged, at which time they were separated by molting dates. When adults were obtained, they were caged in pairs for oviposition records.

The rearing temperature of 72°F. was considerably lower than the mean outdoor summer temperature, so the duration of the various stages was doubtless greater than in the field. It was suspected that other conditions were not ideal for the bugs,

Figure 2. Ventral view of green stink bug, showing abdominal spine projecting into space between hind coxae, and the elongated scent gland. (Enlarged 4½ diameters.)

but the described system of rearing was the best that could be devised.

Egg Stage

Eggs were deposited in masses averaging 32 eggs each and at first were a light pastel green in color (Fig. 3). In four or five days they changed to a dull yellow, then to a pale pink after two or three more days, and finally to a bright pink a day or two before hatching.

The mean incubation period for 379 eggs was 12.7 days, as shown in Table 1. The range was from 9 to 19 days. This much spread seems excessive, but there is no explanation.

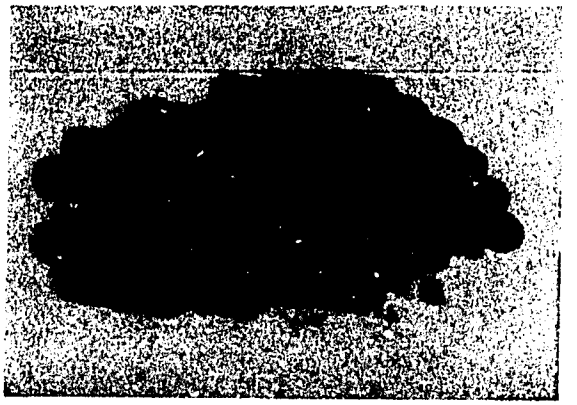

Figure 3. Egg mass of green stink bug, showing hatched and unhatched eggs. (Enlarged 4½ diameters.)

Table 1. Duration of Various Stages in the Life Cycle of Green Stink Bug, Fayetteville, 1963

Stage or period	No. of individuals	Mean duration, days	Range, days
Egg	379	12.7	9 to 19
First instar	265	7.0	5 to 10
Second instar	80	8.9	6 to 14
Third instar	68	7.9	6 to 11
Fourth instar	59	8.9	6 to 11
Fifth instar	55	12.8	8 to 20
Longevity, adult male	25	67.6	7 to 185
Longevity, adult female	23	59.0	28 to 120
Longevity, ovipositing female	10	73.3	35 to 175
Longevity, non-ovipositing female	13	48.1	28 to 120
Pre-copulation, female	11	22.3	11 to 30
Pre-oviposition, female	9	43.0	30 to 66
Oviposition period	4	31.3	12 to 44
Mean life cycle	....	101.2	.....

Nymphal Stages

First instars remained crowded together on or near the remnants of the egg mass. They were never observed feeding, either in the field or laboratory. Their color ordinarily left a gross impression of brownish red, although the actual color pattern as seen under a microscope was quite complex and included several other colors as spots or borders. [See Whitmarsh (8) for full color descriptions of all stages.]

This instar evidently required a higher humidity than later ones. In several instances nymphs were observed to move to moist situations.

The mean period spent as a first instar was 7.0 days, based on 265 records (Table 1). The range was from 5 to 10 days. All bugs from one egg mass generally molted on the same day.

Second instars made a gross impression of black, although again the actual color pattern was more complex. The bugs began feeding in this stage, although not as frequently nor for such long periods as in later stages. The mean duration of the second stadium was 8.9 days, ranging from 6 to 14 days, on the basis of 80 records.

Third instars were usually green with some yellow and black. This stage required a mean of 7.9 days for completion, ranging from 6 to 11 days.

Fourth instars usually were predominantly green with a little black, but starting with this instar some marked variation began to appear. Frequently the head and thorax, and occasionally the abdomen, approached black. Different egg masses produced different proportions of the dark forms. Coloration was not associated with sex. The dark forms also were found in the

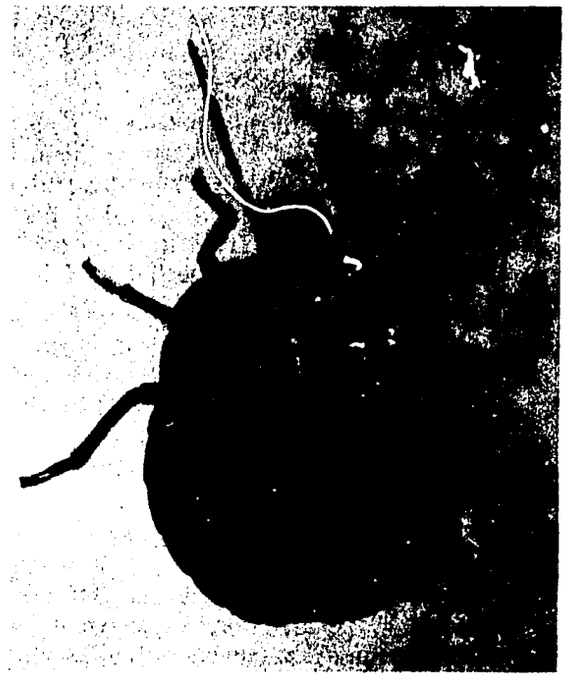

Figure 4. Dorsal view of fifth instar nymph. (Enlarged 4 diameters.)

field. At one location in Phillips County in 1962, the majority were green. In 1963, nearly all were dark.

Fourth instars required 8.9 days for completion of this stage, ranging from 6 to 11 days. Fifty-nine individuals were observed.

Fifth instars (Fig. 4) were colored much like the previous stage, and the same variation between green and black was found. Feeding became more frequent and more prolonged in this stage than previously. When fresh string beans were placed in the cage, only a minute or two elapsed before the bugs found them and commenced feeding. Fifth instars also were observed to feed on freshly-molted companions. The beak was inserted into the top of the thorax, and blood was withdrawn. Nymphs that had been thus fed upon became sluggish and eventually died.

Fifth instars required a mean of 12.8 days for completion of the stage, which is distinctly longer than previous stages. Fifty-five individuals required from 8 to 20 days for this stage.

Adult Stage

Adults (Fig. 5) began feeding avidly within a few hours of molting. After about two weeks, the bugs' interest in fresh string bean pods declined markedly. Feeding on a reduced level continued until the bugs' death, however.

It has been stated in the literature that the male matures before the female. In the present work no confirmation of this was obtained. On the basis of records on 26 males and 25 females, the males averaged .04 day less in the nymphal period, which obviously is not significant. Bugs from a given egg mass generally matured a few at a time over a period of 7 to 10 days.

There was an average lapse of 22.3 days before young adult females were observed to copulate for the first time (Table 1). Pairs were observed to copulate repeatedly over periods of up to five weeks. The preoviposition period averaged 43 days, ranging from 30 to 66 days. Only four females deposited eggs more than once, but on the basis of these the reproductive period averaged 31.3 days.

Thirty-three egg masses deposited in captivity averaged 32 eggs each, and ranged from 3 to 56. There was a tendency for eggs to be deposited in multiples of seven. Of the 33 masses observed, 19 were either in multiples of seven or were within one egg of it. (The female has seven ovarioles on each side.) The mean number of total eggs deposited per female was 59.4 for 11 individuals, ranging from 9 to 169.

Figure 5. Dorsal view of adult green stink bug. (Enlarged 4 diameters.)

The mean longevity of 25 males was 67.6 days, with a maximum of 135. The mean longevity of 23 females was distinctly less, at 59.0 days. The maximum was 120 days. Females that deposited eggs lived considerably longer than those that did not, although it is not known which factor was cause and which effect. Ten ovipositing females lived an average of 73.3 days, while 13 non-ovipositing females lived an average of 48.1 days.

If the means of the various stages shown in Table 1 are added, a mean life cycle of 101.2 days is indicated.

After adults of the second reared generation were obtained, the stock was lost due to lack of oviposition. Only one second-generation female deposited eggs, and the nymphs from these died. Some adults lingered on for weeks, but eventually died without reproducing. Difficulties actually began with the second generation nymphs, as a much higher mortality rate was encountered than in the first generation.

Fifteen pairs of adults were collected from soybeans on October 10, 1963, and brought to the rearing room. All died over a period of from two weeks to two months, without ovipositing. Evidently diapause or other unknown factors prevented completely successful rearing work.

SEASONAL HISTORY

Field records on seasonal history were obtained over a period of three years, principally in Phillips County but also to some extent in Mississippi, Poinsett, and Conway Counties.

Season-long records were obtained on three fields of soybeans in Phillips County in 1961. Field A, Lee variety, was bordered on one side by woods. Virtually no infestation was discovered until on July 27 a population of eggs, nymphs, and adults was observed on wild dogwood, *Cornus drummondi* Ashm., on the border of woods next to the soybeans. These evidently represented overwintered adults and first-generation eggs and nymphs, and obviously had been there for several weeks. By August 24, the population on dogwood had greatly declined and a light infestation of adults and early instar nymphs appeared in the adjacent rows of soybeans on which pods were then setting. At this time most of the dogwood berries had matured and fallen to the soil. On September 22, the infestation in soybeans next to the woods was heavy. On September 28, counts showed an average of 54 adults and nymphs per 100 feet of row next to the woods. One hundred feet or more away from the woods, infestations averaged only 5 bugs per 100 feet. These counts were made by walking very slowly along a row, counting all visible stink bugs without actually disturbing the foliage.

It was concluded that a first generation had developed almost entirely on dogwood, and that those in the soybeans represented a second generation.

Field B, also of the Lee variety and about a mile from Field A, had a similar history but the infestation was very light. During July and August, a few adults and nymphs were found on dogwood and on elder (*Sambucus* sp.) on the field margin. No infestation appeared in the soybeans until October 12.

Field C, in a different part of the county, was of the Hill variety. An infestation of adults was found on June 22 in the soybeans in a small area (about 30 x 150 feet) next to woods. No connection with a wild host was established. Infestations could have been present in large trees, however, in which case they could easily have been missed. In ensuing weeks, this population evidently spread throughout the field, which reduced its

density to the point where individuals were very difficult to find. No reproduction was noted until August 24, when a moderate population of adults and early instar nymphs was found in the previously infested area next to the woods. Pods were present at this time. On September 15 the infestation was heavy, averaging 123 per 100 feet of row. Most were nymphs. Away from the woods, in the field as a whole, the count was only 1.5 per 100 feet.

Season-long counts were made in 1962 and 1963 in Field A, both on wild hosts on the border and in the soybeans. In 1962 ten dogwood trees from 10 to 15 feet tall were visually inspected once weekly for stink bugs. In 1963 the population was much lower than previously, so all dogwood trees on the border of the woods were searched. These totaled about 45 trees of various sizes and degrees of accessibility to the observer. Populations in soybeans were estimated by shaking the plants in three feet of row in 20 places. A muslin sheet (18 by 40 inches in size) placed beneath the plants prior to shaking made counting of dislodged bugs easier. Where the number of shakes was other than 20, the figures were converted for purposes of comparison.

As indicated in Table 2, the infestation on dogwood began in early June and continued through August in both years. The population peak came later in 1963, however. The movement to soybeans began several weeks later in 1963, although peak populations came only about a week later. The soybeans were somewhat slower in development in 1963, which might have influenced the seasonal history of the insects.

The data in Table 2 indicate two generations a year, the first on dogwood and the second on soybeans. Some of the first generation may have developed in the soybeans but probably in small numbers compared with those on dogwood. Prior to the first recorded shakes in soybeans, as much time was spent on visual search in soybeans as was spent searching dogwood. A few bugs could sometimes be found, but not enough to show up consistently in 20 shakes.

A different type of seasonal history was found in a field in Conway County in 1963, indicating that wild hosts at times play a lesser part in infestation of soybeans. In connection with a study of season-long distribution of stink bugs within a field, weekly shakes were made at 187 locations evenly distributed over the field. Waste land with considerable brush and trees was present on one side of the field, but there was no dogwood or other known favored host.

Table 2. Seasonal Abundance of Green Stink Bug, Phillips County, 1962 and 1963

	1962[1]					1963[1]			
	No. on dogwood (10 trees)		No. on soybeans (20 shakes)			No. on dogwood (45 trees)		No. on soybeans (20 shakes)	
Date	Adults	Nymphs	Adults	Nymphs	Date	Adults	Nymphs	Adults	Nymphs
					5-23	0	0	....	....
					5-30	0	0	....	....
					6-6	0	0	....	....
6-14	13	42	...	....	6-13	0	7	....	....
					6-20	1	17	....	....
6-27	5	136	....	....	6-27	0	8	....	....
7-5[2]	0	129	....	....	7-3	0	1	....	....
7-12	0	57	....	....	7-11[2]	0	18	....	....
7-19	2	11	....	....	7-18	1	16	....	....
7-26[4]	4	12	0	0	7-25	5	17	....	....
8-2	5	6	...		8-1[3]	14	11	...	....
8-9[5]	9	4	6	2	8-8[4]	19	0	0	0
8-17	2	0	2	0	8-15[5]	9	2	....	....
8-23[6]	5	0	1	0	8-22[6]	0	0	0	0
8-31	0	0	1	0	8-29	1	0	....	....
9-6	0	0	5	3	9-5	1	0	4	1
9-14	0	0	1	32	9-12	0	0	0	8
9-20	....	....	2	56	9-19	0	0	2	34
9-27	....	....	5	42	9-26	....	...	4	44
10-5	....	....	7	40	10-5	....	..	9	28
10-11	...	..	2	15	10-10	....	....	16	22
10-18	....	....	6	4	10-17	....	....	11	1
					10-23	....	....	3	3

[1] No counts were made where no entries are recorded.
[2] A few bugs seen in soybeans from this date on, but too few to justify formal shakes.
[3] First bloom.
[4] Full bloom.
[5] Pods setting on soybeans.
[6] Large pods; soybeans forming.

Records were started July 10. This should have been early enough to detect any feeding on wild hosts, but none was found. A moderate infestation (about 1 bug in 9 row feet) was distributed over the field at the time and was in a decline which suggested the end of a generation. The low point was reached on July 24 and 31, after which a fairly steady increase began. The peak population was reached on September 25, which compares closely with data in Table 2.

Pods began setting in this field on August 2, at which time an appreciable and increasing infestation already was present. Had the infestation been higher, this situation could have led to early pod damage and a reduction in yield. In previously discussed fields where wild hosts were more of a factor, infestations came after pods were large and presumably caused little reduction in yield.

Even though a distinct connection with wild hosts was not established in 1963 and distribution was field-wide, there was still a tendency for highest numbers to be found nearest the woods and field borders. At the time it was thought that favorable hibernation quarters might be the explanation. In July of

1964 a few adults were collected from ash trees in the woods, and also on a rose mallow, *Hibiscus lasiocarpos* Cav. In the following year, nymphs and adults commonly were found on black locust on the field border. Wild hosts therefore may have been somewhat more important than was originally believed.

In 1964 the infestation in the field was lower than in 1963, but distribution was similar. That is, it was field-wide but heavier near the margins. The peak infestation came on September 18, one week sooner than in the previous year.

Records from Mississippi County in 1963 indicated a seasonal history similar to that shown in Table 2, although first generation bugs were not found on wild hosts in sufficient numbers to account for later populations in soybeans. In two fields, first infestations in soybeans were found on August 28 and September 4. The previous year, however, one of these same fields had a season-long infestation. The first bugs were found July 16, the peak was July 31, and the infestation remained moderately high through the rest of the summer. In both fields populations were highest near bordering woods.

It appears from all these records that wild hosts usually are involved in the first generation and that later infestations in soybeans are higher near the wild hosts. It also is possible for wild hosts to be of less importance, and the problem in this case is of a different nature.

During these seasonal history studies the most common wild host was wild dogwood, *Cornus drummondi* Ashm. This species is common in damp, wooded areas in eastern Arkansas. The second most favored wild host was elder, *Sambucus* sp. All other hosts were of minor or only occasional importance. These included, in addition to those already mentioned, pepper-vine (*Ampelopsis arborea* L.), sumac (*Rhus glabra* L.), wild grape (*Vitis* sp.), black locust (*Robinia Pseudo-Acacia* L.), and pecan (*Carya illinoensis* Wang.).

Little was added to previous information on overwintering habits. Green stink bugs several times were observed crawling among leaves in woods during warm days in mid-winter, or even taking flight. They were collected in winter from beneath bark of fallen trees, and from behind the sheaths of corn stalks. Numbers were so low, however, that conclusions on preferred hibernation sites were not possible. No bugs survived the winter in an outdoor hibernation cage in 1963-64.

INCIDENCE OF INFESTED FIELDS

In any given area it was usual to find only a relatively few fields with infestations on an economic level. It was considered that 5 bugs in 50 sweeps represented an economic infestation. In Phillips County, for instance, 33 fields were checked from one to three times each during August, 1960. Twenty-five sweeps with a 15-inch net were made in each of eight locations in each field at each visit. The most heavily infested field had a high of four stink bugs in 50 sweeps. Six of the fields yielded no bugs at all.

Forty-six fields distributed from the northeastern to the southeastern corners of the state were checked three times each during September, 1960. Fifty sweeps were made in one marked location in each field at each visit. In only two fields did 50 sweeps ever yield as many as five bugs. These two had a high of six bugs each. Another two fields each had a high of four; one field had a high of three, and two had highs of two. The other 39 had one or zero.

In 1961 an intensive survey of 14 fields in Phillips County was conducted in late September, when soybeans in most fields were nearing maturity. The method was to walk very slowly for 50 feet of row, counting all visible stink bugs on two adjacent rows. Between 10 and 31 such counts were made in each field, depending on size of the field. All counts were made on the edge of fields, where infestations were most likely to occur. Fields were checked once.

Only one field of the 14 had an average count believed to represent an economic infestation. In this field an average of 7.1 bugs were found per 50-foot count. Eight of the fields had averages of one or fewer bugs per 50 feet.

In Lonoke County, also in 1961, 17 fields were checked throughout the summer by making 200 sweeps, well distributed, in each field once each week. No economic infestations developed. The weekly average per 50 sweeps never reached one bug.

The following year (1962) 45 fields in seven southeastern counties were checked from one to eight times by W. P. Boyer, survey entomologist. One hundred sweeps were made in each field at each visit. Infestations were very light up to mid-September. During the last week in September, however, when 16 of the fields were checked for the last time, six had economic infestations of five bugs or higher per 50 sweeps.

In mid-August of 1963 a series of 30 fields distributed from the northeastern to the southeastern corners of the state were

checked once. At this time bugs were expected to be present both on wild hosts and in some numbers in soybeans, so visual examinations and sweeps were made in both situations. Only two fields were found with appreciable infestations in the field or on adjacent wild hosts.

Despite the low order of success in locating infestations by random sampling of fields, it has been noted that once an infested field or location is found, the infestation can be expected to be present to some degree year after year. This assumes no major environmental change such as lack of soybeans or clearing of woodland.

DISTRIBUTION WITHIN FIELDS

Local distribution of a population has a strong tendency toward the margins of fields, especially if woods are nearby and include favored wild hosts. In Field A, previously referred to, population counts were made in 1961 completely across the field, from next to the woods to the other side which adjoined cotton. The method used was to count all visible bugs in 50 feet of row. Results appear in Table 3. As shown, the highest infestation was found on the 20 rows nearest the woods, which had dogwood present, although a few bugs were found through the 240th row. These counts were made on September 28, and represented the presumed second generation. Adults and nymphs were not distinguished; at this time the vast majority were nymphs.

Counts also were made across the same field in 1962, as shown in Table 4. The method used was to shake the plants in 3 feet of row and count the dislodged bugs. This time the tapering off with distance from the woods was less sharp than in the previous year, possibly due to a later pod-set of soybeans. It is believed that this led to a prolonged movement of bugs across the field, in search of pods. A downward trend away from the woods was plainly evident, nevertheless.

In the 20-acre field in Conway County previously described, counts were made weekly throughout the field. Every 10th row was walked and one shake was made every 100 feet. Twenty counts per row resulted over most of the field; at one end they gradually dropped off to 16, due to narrowing of the field. The data from these rows were converted to a basis of 20 counts for purposes of this analysis. Results appear in Table 5.

This field had the most nearly uniform field-wide infestation of any studied, especially early in the season, and evidently was most independent of wild hosts. In Field A in 1961 and 1962, for instance, bugs were present only in trace numbers before early

Table 3. Distribution of Green Stink Bugs within a Field, Showing Relation to Woods, Phillips County, 1961

Row no.[1]	No. bugs observed[2]
1 to 10	51
11 to 20	65
21 to 30	21
31 to 40	29
41 to 50	12
51 to 60	6
61 to 70	7
71 to 80	2
81 to 90	5
91 to 100	5
101 to 110	8
111 to 120	3
121 to 130	1
131 to 140	7
141 to 150	18
151 to 160	4
161 to 170	1
171 to 180	3
181 to 190	6
191 to 200	5
201 to 210	3
211 to 220	3
221 to 230	2
231 to 240	2
241 to 250	0
251 to 260	0
261 to 270	0
271 to 280	0

[1] Rows 1 to 10 were nearest woods; rows 271 to 280 were farthest from woods.
[2] Counts were made on Sept. 28 and represent bugs observed on 50 feet of row.

Table 4. Distribution of Green Stink Bugs within a Field, Showing Relation to Woods, Phillips County, 1962

Row no.[1]	No. bugs per shake[2]
5	5.0
15	2.8
25	2.5
35	4.0
45	2.5
55	4.3
65	3.0
75	2.5
85	1.5
95	1.8
105	2.0
115	3.0
125	1.5
135	.5
145	1.3
155	.8
165	1.3
175	1.0
185	1.0
195	.3
205	.8
215	.3
225	.1
235	.0
245	.3
255	.8
265	.3
275	.8
285	.3
295	.0
305	.3
315	.0

[1] Row 5 was nearest woods; row 315 was farthest from woods.
[2] Average of 4 counts, one on Sept. 6, two on Sept. 20, one on Sept. 27. Counts represent bugs shaken from 3 row feet.

August and early September, respectively. In the Conway County field, however, a moderate, fairly well distributed infestation was present when first counts were made July 10. Even so, it was again evident that wild hosts or some other marginal factor was operating. The same field was surveyed weekly during 1964, with much the same results but at a lower population level.

In addition to these formal data, many casual observations made by several cooperators indicated that infestations generally were higher near woods. There have been exceptions to the rule, but unfortunately such exceptions have not been well documented. It may be that where no soybeans or other favorable second-generation host are present near the first-generation site, a general flight occurs which results in infestation of soybeans at almost any point. On the other hand marginal infestations also

Table 5. Distribution of Green Stink Bugs in Soybean Field, Showing Relation of Population to Woods, Conway County, 1963

Date	Row number[1]										
	5	15	25	35	45	55	65	75	85	95	Av.
	Number bugs per 20 shakes										
July 10	1	49	5	1	3	0	3	2	5	4	7.3
July 17	3	5	3	54	8	2	0	0	1	0	7.6
July 24	2	3	1	0	2	0	1	1	0	0	1.0
July 31	4	4	1	0	2	1	1	1	0	0	1.4
August 7	13	2	5	2	2	2	3	3	1	2	3.4
August 14	11	68	2	5	2	2	1	1	1	2	9.5
August 21	25	1	11	6	3	7	2	3	1	2	6.1
August 28	16	3	10	7	12	5	0	2	5	2	6.2
Sept. 4	34	13	9	5	4	5	1	3	2	2	7.8
Sept. 11	45	13	7	12	8	3	1	8	1	4	10.2
Sept. 17	80	23	13	14	9	16	3	1	1	2	16.2
Sept. 25	52	29	17	10	12	13	14	8	6	19	18.0
Oct. 3	26	19	9	5	7	8	10	2	4	6	9.6
Oct. 11	9	1	1	2	0	0	3	1	0	2	1.9
Season average	22.9	16.6	6.7	8.8	5.3	4.6	3.1	2.6	2.0	3.4	....

[1] Row 5 was nearest woods; row 95 was farthest from woods.

have been found well removed from woods, evidently the result of earlier harvest of nearby infested soybeans, and consequent migration.

DAMAGE TO SOYBEANS

Histology

Histological aspects of damage by green stink bugs were studied by means of microscopic section. Stink bug adults were allowed to feed on undamaged soybeans in the laboratory, after which the beans were dehydrated in alcohol and embedded in high melting-point paraffin. Sections including the damaged areas were then cut by microtome.

In undamaged areas, cell walls and cell contents were intact. In damaged areas, cell walls frequently were ruptured or missing, and cell contents were partially or wholly absent (Fig. 6).

Through the feeding stylets the bug presumably injects histolytic agents which liquefy the solid and semi-solid portions of the cells, thus enabling the bug to draw them up through the food canal of the stylets. The chalky appearance of damaged spots probably is due to air spaces produced when the cell contents are drawn out. Dissections in the laboratory showed that these whitish areas were present immediately after a bug had fed. Since there was not time for growth of a micro-organism, it is indicated that the spot is produced by feeding operations and is

Figure 6. Top, Microscopic section through damaged spot in soybean cotyledon showing empty cells with cell walls intact, vacant areas where entire groups of cells including both walls and contents have disappeared, and relatively undamaged (dark) areas. (Enlarged 100 diameters.) Center, Undamaged cells near a damaged spot on a soybean; cells evidently shrunken due either to natural drying or to treatment incident to sectioning. (Enlarged 1,000 diameters.) Bottom, Cells of soybean cotyledon in a spot damaged by stink bug; although cell contents are wholly or partially absent most cell walls remain. (Enlarged 1,000 diameters.)

not dependent on presence of pathogenic organisms. Such organisms, if present, presumably could alter or add to the damage.

Volume of Damaged Tissue

Since the volume of damaged tissue in a damaged soybean doubtless is related to oil loss and other chemical changes, dissections were made to indicate the relative volume of a damaged spot.

Using a soybean sample graded at 5½ percent damage, which is of the order commonly reported, the seed coats of 25 damaged soybeans were peeled away, the cotyledons were separated, and each cotyledon was split. The volume of this lot of bean quarters then was determined by water displacement. Then the damaged portions of each quarter were dug out as accurately as possible by means of fine chisels made from sewing needles. The volume of the essentially undamaged remainder then was determined by water displacement. Damaged tissue, represented by the difference, was calculated at 8.7 percent of the original volume of the damaged soybeans. On the basis of the original sample of damaged and undamaged beans, and ignoring seed coats, it was calculated that 0.48 percent by volume of the original sample was damaged.

An extreme sample obtained from Florida, graded at 64 percent damage, was treated in the same manner. The damaged tissue was found to comprise 22.8 percent of the damaged soybeans, and the original unsorted sample was calculated to have had 14.6 percent by volume of its tissue damaged by stink bugs. These soybeans had evidently been subjected to a very heavy infestation, and each bean had numerous punctures.

The 5½ percent sample comes much nearer to representing the usual problem than the 64 percent sample, so it is supposed that stink bug damage seldom comprises more than 1 or 2 percent of the volume of soybeans in a representative sample. The damaged portion doubtless contains some oil, so even this is not a total loss.

One small-scale experiment was conducted in 1960-61 to determine if the volume of visibly damaged tissue in a soybean increased in storage. From a heavily damaged sample, 50 damaged soybeans were taken at random and cut into eighths (occasionally sixteenths) and the volume of affected tissue was estimated by inspection under a microscope. The mean was 28.3 percent. Duplicate lots of 50 un-cut soybeans each then were stored in capped shell vials for 13 months, one lot at 8.7 percent initial moisture content and the other at 15 percent. No effort was

made to maintain the moisture content other than to keep the vials closed. At the end of the storage period each lot was cut up as previously described and the amount of damage estimated, by the same individual. The mean was 25.3 percent for the low moisture sample, and 24.1 percent for the high, indicating that no increase in volume of damaged tissue had occurred.

Another experiment was conducted in 1960-61 to determine if the number of soybeans with detectable damage increased in storage. A lot of Hood beans from Fayetteville and a lot of Hill beans from Marianna were used. On the basis of a 200-bean sample, the percent stink bug damage was determined to be 6½ percent and 8 percent, respectively. The method of rating was to inspect whole soybeans under a microscope, and to cut into any suspicious spots. One-quart samples of each variety then were stored for seven months in capped glass fruit jars at moisture contents of 10 percent, 12½ percent, and 15 percent as determined by a Steinlite moisture tester. At intervals of two weeks the samples were opened and stirred by pouring, and the moisture content was determined. Any deficiency from the prescribed moisture content was made up by stirring tap water into the samples. After the seven-month storage period the samples were opened and the percent stink bug damage determined on the basis of a 200-bean sample, as before. Results are shown in Table 6. In four cases the percent damage was lower than originally, and in two cases it was higher. It is believed that sample variation was responsible for changes in the figures.

The original 200-bean samples had been stored in capped shell vials with the damaged soybeans marked. Upon inspection, no additional damaged soybeans were found. The spots on the damaged beans were thought to be darker in color than originally, however.

An experiment was conducted to determine if damaged spots darkened with age sufficiently to be more readily seen through the seed coat. Fifty soybeans were selected that were believed

Table 6. Percent Stink Bug Damage as Affected by Storage at Various Moisture Levels, Fayetteville, 1960-61

Variety and percent moisture	Original percent damage	Final percent damage
Hill		
10.0	8.0	9.0
12.5	8.0	10.5
15.0	8.0	7.5
Hood		
10.0	6.5	3.5
12.5	6.5	4.5
15.0	6.5	3.5

to be undamaged on the basis of inspection under a microscope. No suspicious spots were cut into, however. (All seed coats were left intact.) Twenty-five of these soybeans were stored at an initial moisture content of 8.7 percent, and 25 were stored at 15 percent. After 12 months all beans were inspected and cut. No damaged soybeans were found in the lot stored at 15 percent. In the lot stored at 8.7 percent three damaged beans were found and in two cases the damage was easily discernible through the seed coat. It was concluded that damaged spots can darken and become more easily visible with age.

It is not known whether the brownish or blackish discoloration that often accompanies the chalky appearance is due to infection by micro-organisms or is due to chemical disintegration of damaged cells.

Oil and Protein Content

The effect of stink bug damage on oil and protein content of soybeans was studied during 1960 and 1961. Samples were collected by the author, and were analyzed by the U.S. Regional Soybean Laboratory at Urbana, Illinois.

In 1960, seven samples of soybeans were each sorted into damaged and undamaged lots. Soybeans were not split or cut in any way during sorting, because of the possibility of affecting chemical composition of the soybeans by excessive exposure to air and light. They were inspected on all sides through a microscope, looking for discoloration or warts resulting from feeding. Previous experience and checking with this method showed a high degree of dependability, so long as doubtful cases were not used.

The seven samples were those with the highest percent of stink bug damage available at the time, in order to reduce the time-consuming task of sorting into damaged and undamaged lots. This doubtless biased the results toward increased oil loss, since the damaged beans can be assumed to have had a relatively high incidence of multiple punctures.

Soybeans damaged 100 percent (every bean with some amount of detectable damage) averaged 0.8 percent more protein, and 0.8 percent less oil, than undamaged soybeans (Table 7). Assuming that test-weights of damaged and undamaged beans were not greatly different, and making a direct transformation of the above figures into terms of a sample with 10 percent damage (which would typify a heavily-damaged sample) it is indicated that such a sample would have an approximate loss of 0.08 percent in oil and a gain of .08 percent in protein.

Table 7. Effect of Stink Bug Damage on Oil and Protein Content of Soybeans, 1960

Sample no.	Variety	% damage, original sample	Protein content (%)		Oil content (%)	
			Undamaged	100% damaged	Undamaged	100% damaged
1	Hood	6.5	38.9	39.9	21.0	21.3
2	Mixed	15.0	38.2	38.5	21.0	21.3
3	Unknown	13.0	41.1	41.1	20.9	20.6
4	Jackson	22.0	38.9	41.0	20.9	18.5
5	Unknown	19.0	41.9	43.8	19.0	18.1
6	Hood	13.0	39.2	39.1	21.8	21.1
7	Jackson	64.0	40.3	40.6	22.8	21.1
Mean	.....	21.8	39.8	40.6	21.1	20.3
Difference	.....	.....	.....	+0.8[1]	.....	−0.8[2]

[1] Difference significant at 6 percent level of probability.
[2] Difference significant at 10 percent level of probability.

It is known that oil and protein contents may vary from place to place in a single field, and with the height of pods on the plants. A different approach was therefore used in 1961 in order to nullify any possible effects from these factors. A single field of Lee soybeans was used. At each of 10 locations well distributed over the heavily-infested part of the field, five whole plants were pulled. These were then threshed by hand, and the soybeans were well mixed and sampled for determining stink bug damage. Each sample then was sorted into undamaged and damaged lots and these were analyzed as before by the same laboratory (Table 8).

Samples with 100 percent damage averaged 1.0 percent more protein and 1.1 percent less oil than undamaged samples. If the assumption again is made that these data can be converted directly to terms of a sample with 10 percent damage, an oil loss of about 0.11 percent would be expected, or 0.03 percent more than in 1960.

Table 8. Effect of Green Stink Bug Damage on Oil and Protein Content of Soybeans; Samples Taken at Various Points in One Field of Lee Variety, Phillips County, 1961

Sample no.	% damage, original sample	Protein content (%)		Oil content (%)	
		Undamaged	100% damaged	Undamaged	100% damaged
1	48	43.0	43.0	21.8	20.7
2	32	43.1	44.8	23.6	20.5
3	12	42.4	42.4	21.8	21.1
4	16	41.8	42.4	21.1	20.9
5	34	42.7	43.5	20.9	20.2
6	42	42.6	44.3	20.4	20.2
7	18	42.2	43.6	20.8	19.4
8	28	41.5	43.1	21.1	19.3
9	4	42.3	43.8	21.0	20.7
10	12	40.9	41.9	22.0	21.2
Mean	24.6	42.3	43.3	21.5	20.4
Difference	.....	.....	+1.0[1]	.....	−1.1[1]

[1] Differences are significant at 1 percent level of probability.

Table 9. Effect of Green Stink Bug Damage on Oil and Protein Content of Soybeans, Phillips County, 1961

Sample no.	Variety	% damage, field-run	Protein content (%)		Oil content (%)	
			Undamaged	Field-run	Undamaged	Field-run
1	Hill	6	36.8	37.0	23.3	23.7
2	Hill	6	36.0	35.5	23.4	23.4
3	Lee	4	42.7	41.8	21.3	21.6
4	Lee	4	41.3	41.0	21.2	21.7
5	Lee	4	40.4	41.1	21.2	21.4
6	Lee	6	41.4	41.8	21.9	21.7
7	Lee	6	40.9	41.0	22.2	22.3
8	Lee	8	42.1	42.5	21.6	21.2
9	Lee	16	42.0	43.1	21.7	21.5
Mean	.....	.....	40.4	40.5	22.0	22.1
Difference	.....	.....	.....	+0.1[1]	.....	+0.1[1]

[1] Differences are not statistically significant.

In order to relate degree of oil loss to common field conditions without the necessity of converting data from 100 percent damaged samples, other samples were analyzed just as they came from the field. Nine samples were chosen, with damage ranging from 4 to 16 percent. Part of each sample was set aside for field-run analysis, without any sorting. Another part had all damaged soybeans removed, including all doubtful cases. The field-run and undamaged portions then were analyzed as pairs.

As is shown in Table 9, damaged field-run samples had an average of 0.1 percent more protein than undamaged samples. More surprising, they also had 0.1 percent more oil. This is not taken to indicate a real increase due to stink bug damage, but rather to indicate the small amount of loss in oil when ordinary field-run samples are used. Variation was doubtless responsible for the reversal. The differences were not statistically significant.

These low levels of oil loss may possibly be explained by the fact that even in the damaged beans in a sample, only a relatively small part of the tissue generally is injured; furthermore, some oil probably remains even in the damaged spot. This is evidenced by undamaged cells within the damaged region, as shown in Figure 6.

Research on the effects of stink bug damage on protein, oil, and fat acidity during a period of several months of storage is in progress.

YIELD

Infestations in soybeans generally have not reached high levels until after pods and beans were nearly full size, and soybeans damaged at this time lose only a small amount in weight.

It is therefore believed that stink bugs to date have not influenced yields to any appreciable degree. It is conceivable that some combination of factors could result in heavy early infestations, or in late maturity of soybeans, in which case yield reduction could be expected.

An experiment was conducted in 1961 to determine the effects on soybeans when green stink bugs were confined on them at three dates ranging from early pod formation to near maturity. Single caged plants in a field of Hill soybeans (an early-maturing variety) were used, with four replicates per treatment. Infestations consisted of one and three adults, respectively, on the early, medium, and late dates. These represent extremely heavy infestations.

On the early date, many small pods were still being set, and the largest pods were only half grown. On the medium date, pods were mostly full size, with large but soft beans inside. On the late date, pods were beginning to mature and the soybeans were losing moisture.

The soybeans were shelled by hand when mature and each bean was inspected for recognizable stink bug damage (chalky spots, etc.) as well as for other suspicious abnormalities, including small size and deformities. Results are shown in Table 10.

Results from this type of cage work must be interpreted with caution because of the extremely high infestations, the relatively small number of plants and insects used, and possible abnormal reaction of the insects and plants when caged. It was shown, however, that the three-bug infestation resulted in a large number of small and deformed soybeans, especially on the early infestation. Many of these soybeans would not have been retained by a combine in a normal harvest. The heaviest degree of "typical" stink bug damage (chalky spots, sunken areas, raised warts) occurred in the medium-date infestation at both infestation levels. Reduced damage from the late infestations may have been due to maturity and unpalatability of the soybeans.

Table 10. Effect of Green Stink Bug Infestation on Caged Individual Soybean Plants, 1961

Date infested	No. insects per plant[1]	Deformed and small beans (%)	Typical stink bug damage (%)
Not infested	0	3.3	0
Sept. 8	1	3.0	14.2
Sept. 22	1	1.4	21.9
Oct. 6	1	2.9	1.0
Sept. 8	3	24.5	21.3
Sept. 22	3	8.1	34.0
Oct. 6	3	5.1	15.9

[1] Four single-plant replicates were used.

In 1965, soybeans were grown in two large plastic-screen, "walk-in" field cages, 12 by 24 feet in size. Soybeans in both cages received heavy applications of methyl parathion on July 30, to eliminate stink bugs and probably most other pod-feeders. On August 13, twenty-five adult stink bugs and fifth instar nymphs were collected elsewhere and introduced into one of the cages. Pods were just starting to form at this time. Later, 25 more bugs were introduced in the same cage. This heavy infestation starting at pod-set was expected to reduce the yield. The other cage was intended as a non-infested check. Unfortunately, a few stink bugs gained entrance into the check, probably through accidental rips in the screen. Observations by an agronomist indicated that the plants inside both cages grew and yielded at least as well as those outside.

At harvest time, soybeans from the check cage had 9 percent stink bug damage; those from the infested cage had 33 percent damage. Two percent of the beans from the check cage were extremely small, chaffy, or deformed, but lacked actual internal evidence of stink bug damage. Twelve percent of the beans in the infested cage fell into this category, indicating that much of this condition had been caused by stink bug injury so early that the typical symptoms had been outgrown or otherwise lost.

Yield in the check cage was 23.7 bushels per acre of soybeans; in the infested cage it was 21.7 bushels per acre. A reduction of 8.4 percent was indicated.

Evidence that factors other than stink bug damage may be responsible for stunting or shriveling of soybeans (and consequent loss in yield) was obtained in 1962 and 1963. This work has been referred to previously. Weekly sweeps were made during the two years in a field with no history of stink bug damage. No bugs were taken in 1962. Two stink bugs were taken in 1963, out of 16 weekly collections of 50 sweeps each. Yet in 1962, 9 percent of the harvested soybeans were either greatly stunted in size or nearly full size but shriveled. An additional 2 percent had typical "stink bug" damage. The next year 7 percent were small or shriveled, and 2 percent had "stink bug" damage.

The loss of weight of essentially full-size soybeans due to stink bug damage was studied in 1960. Samples were taken from 10 fields, and lots of 100 undamaged soybeans and 100 damaged soybeans were selected from each. The weights of the samples are shown in Table 11.

While the indicated reduction of about 9 percent in weight might be appreciable if damage occurred field-wide and the percent of soybeans damaged was high, in practice reduction in grade

is considered to be of more importance than loss in weight of full-size beans.

Table 11. Weights of Stink Bug-Damaged and Undamaged Soybeans, 1960

Sample no.	Weight in grams of 100 beans	
	Undamaged	100% damaged
1	16.00	14.00
2	16.64	14.97
3	15.60	14.60
4	16.02	14.65
5	14.17	12.60
6	16.03	13.27
7	15.29	14.52
8	15.07	14.14
9	14.81	14.63
10	16.50	14.80
Mean	15.61	14.22
Difference	+1.39[1]	.....

[1] Difference significant at 1% level.

SOYBEAN VARIETIES AND STINK BUG INFESTATION

No evidence was found of existing varietal resistance. The various data obtained on varieties tended rather to demonstrate the effect of date of pod-set or of planting on damage, although even in this respect the data were partially inconclusive. All work reported in this section was in cooperation with agronomists at the Arkansas Agricultural Experiment Station.

The effect of variety and date of planting on stink bug damage was studied at the Southeast Branch Experiment Station in 1960. Four common varieties ranging in maturity date from early to late were planted on five dates each, ranging from early to late. Each plot was 4 rows by 20 feet in size, and four randomized replicates were used. Data on stink bug damage are shown in Table 12.

Two fairly consistent trends were evident: the later-maturing varieties tended to have more damage than early varieties,

Table 12. Effect of Soybean Variety and Planting Date on Stink Bug Damage, Rohwer, 1960

Variety[1]	Mean percent damage when planted on[2]					Mean[3]
	April 14	May 2	May 23	June 13	July 1	
Hill	14.5	5.5	9.0	5.3	3.3	7.5b
Hood	15.8	12.5	13.8	6.3	4.3	10.5b
Lee	13.5	13.8	11.5	5.8	7.0	10.3b
Jackson	19.0	15.3	27.5	11.0	10.5	16.7a
Mean[3]	15.7a	11.8a	15.5a	7.1b	6.3b	.....

[1] Arranged from early (Hill) to late (Jackson).
[2] Data represent means of four replicates.
[3] Means that share a common letter are not significantly different at the 5 percent level.

and the earlier plantings tended to have more damage than late plantings. The additive effect of these factors is well shown in the table, where the earliest maturing variety (Hill) planted latest (July 1) had the least mean damage. The latest variety (Jackson) planted earliest (April 14) was exceeded in damage by but one other entry. These results correspond well with data obtained by Daugherty, *et al.* (2).

A tentative explanation of the results is that in these small plots with plants of variable size the insects preferred to inhabit the larger or earlier-planted beans. Also, the late maturing varieties had green pods present and vulnerable for a longer period in late fall, when numbers of bugs were highest.

An identical test was conducted the following year, with the added feature of stink bug counts throughout the season. These counts were made by walking slowly along the rows and counting all visible bugs without disturbing the foliage.

The results, shown in Table 13, seemed to confirm the 1960 results as to effect of maturity date (variety), although the differences were not statistically significant. The effect of planting date was not consistent and results cannot be explained. Total bugs seen in plots of different planting dates were, in order from early to late: 22, 8, 8, 3, and 0. Total bugs seen on the various varieties were: Hill 14, Hood 12, Lee 10, and Jackson 5.

Evidence was obtained in 1960 that seven commercial varieties with similar maturity dates planted on the same date did not differ in degree of stink bug damage. The seven varieties were selected as being representative of the "mid-season" group, which makes up at least 75 percent of all Arkansas soybean acreage. The plots, located on the Southeast Branch Experiment Station, were 4 rows by 20 feet in size, randomized, and replicated four times. Data appear in Table 14. There were no statistically significant differences between varieties.

Stink bug damage was assessed on 21 varieties and breeding lines at Fayetteville in 1960. Plots consisted of 1 row 15 feet

Table 13. Effect of Soybean Variety and Planting Date on Stink Bug Damage, Rohwer, 1961

	Mean percent damage when planted on[2]					
Variety[1]	April 18	May 12	May 28	June 21	June 30	Mean[3]
Hill	6.8	4.3	8.3	4.5	6.8	6.1
Hood	8.8	10.0	7.0	5.8	8.5	8.0
Lee	8.0	11.8	5.5	5.3	6.0	7.3
Jackson	8.0	9.3	7.8	7.5	13.3	9.2
Mean[3]	7.9	8.9	7.2	5.8	8.7	....

[1] Arranged from early (Hill) to late (Jackson).
[2] Data represent means of four replicates.
[3] No significant difference between means for varieties or dates of planting.

Table 14. Stink Bug Damage to Various Soybean Varieties Having Similar Maturity Dates, Rohwer, 1960

Variety	Mean % damage[1]	Variety	Mean % damage[1]
Ogden	10.0	Halesoy 321	4.8
Hale Ogden 2	14.8	Hood	9.8
Bobsoy	10.5	Lee	10.0
Dortchsoy 2a	6.5		

[1] Data represent means of four replicates. There were no significant differences between varieties.

long. While a wide range of damage was found and there was a trend toward more damage on late varieties, it was not possible to conclude from these single records that real differences existed. The data are presented in Table 15.

Table 15. Stink Bug Damage to Various Soybean Varieties and Strains, Fayetteville, 1960

Designation	Maturity date	Percent damage	Designation	Maturity date	Percent damage
R 58-81	10-13	0	R 57-176	10-23	8
R 56-25	10-13	1	R 54-168	10-23	8
Ogden	10-13	2	R 59-34	10-15	8
R 56-49	10-13	3	R 56-27	10-23	9
Halesoy 321	10-13	3	R 56-22	10-16	10
Hale Ogden 2	10-13	3	R 58-82	10-15	11
R 59-96	10-13	4	Dortchsoy 2A	10-20	12
Hood	10-13	4	R 54-157-1	10-15	18
R 58-80	10-13	4	R 59-200	10-22	23
Lee	10-20	5	R 57-102-1	10-15	24
Bobsoy	10-20	6			

INCIDENCE OF STINK BUG DAMAGE

In the 1960 survey previously referred to, soybeans from 32 fields in eastern Arkansas were sampled and counts of stink bug damage were made. All samples were taken on borders and therefore doubtless ran higher in damage than field-wide samples would have. (An example of this relationship is provided by a field in Phillips County, which had 22 percent damage on an infested border. When the beans were sold, the field as a whole was graded at 2½ percent damage.)

Eight of the 32 samples had between 7 and 15 percent damage. At these levels control measures are believed to be profitable. Six fields had 3 to 6 percent damage which could have resulted in dockage when the soybeans were marketed but which probably would not have justified insecticidal control. Six fields had from 1 to 2 percent damage, which would not have resulted in dockage. The remaining 12 fields had zero damage.

Another survey of damage was conducted in the fall of 1964 from the northeast corner of the state to the southeast corner.

Fifty fields were sampled. Due to the sampling method, results probably approximated determinations as made in commercial channels more closely than in the previous survey. Fields were selected by driving five miles beyond the last sample, then stopping at the next soybean field adjoining the road. Samples were taken beginning at the border nearest woods and walking toward the center of the field, pulling pods at random for a distance of about 150 yards. One hundred soybeans from each sample were later inspected for damage. Results appear in Table 16.

The average damage for the 50 fields was 2.98 percent. Three fields exceeded 10 percent. Fields with damage of 6 percent or less (86 percent of the fields sampled) probably would not have justified treatment, even in a year when discounts were being assessed.

An additional 277 determinations of damage are presented in Table 17, representing most of the remaining samples taken for various purposes in the course of this research. These are strongly biased toward heavy damage, since they represent plots deliberately placed in infested spots, inspections made in infested spots for correlation of populations with resultant damage, and miscellaneous inspections made in fields or spots known or expected to be damaged.

These samples peaked at the 5 to 6 percent category, and 75 percent of them were within the range of 0 to 10 percent damage.

An indication of the degree of damage encountered in regular marketing procedures is found in personal correspondence of the author with buyers and others involved in marketing. Quotations

Table 16. Stink Bug Damage to Soybeans in 50 Random Samples, 1964

Damage range, %	No. samples in category
0	22
1 to 2	10
3 to 4	5
5 to 6	6
7 to 8	2
9 to 10	2
11 to 12	1
13 to 14	0
15 to 16	0
17 to 18	0
19 to 20	2

Table 17. Stink Bug Damage to Soybeans in 277 Miscellaneous Samples

Damage range, %	% of samples in category
0	6.5
1 to 2	10.1
3 to 4	13.0
5 to 6	17.3
7 to 8	15.1
9 to 10	13.0
11 to 12	7.2
13 to 14	4.0
15 to 16	2.5
17 to 18	4.7
19 to 20	1.1
21 to 22	1.1
23 to 24	1.8
25 to 26	1.1
29	.7
33	.4
48	.4

from several of these follow, all referring to Arkansas soybeans. "The damage varied from 2 percent to as high as 6 percent." "We were forced to pass on market discounts ranging from 2¢ to 10¢ per bushel (3 percent to 7 percent damage)." ". . . the damage is not running over 4 percent to 6 percent in this area." "Damage percentage ran mostly between 2 percent and 4 percent, sometimes going as high as 5 percent." "Recently five barge loads of beans for export showed between 4 percent and 5 percent damage."

INFESTATION AS RELATED TO DAMAGE

During the course of this work, several methods of estimating populations were tried, such as sweeping with a net, shaking insects onto the soil or onto a muslin drop-sheet, walking slowly while looking for stink bugs, and completely examining plants in a certain length of row. The shaking method was finally settled on as the best, even though it had some disadvantages. This method consisted of vigorously shaking three feet of row with the forearms and counting the insects dislodged on the soil or preferably on a muslin cloth.

Once this method became standard, an attempt was made to correlate population counts with subsequent damage at harvest time. Over a period of three years, in four counties, a total of 139 locations were inspected for infestation and damage. From two to five counts in late season were made in each location a week or more apart. The successive counts were made in as nearly the same spot as possible but without actually using the same plants each time. At harvest time a sample of soybeans was taken from the same spot in which counts had been made, using soybeans from the top, bottom, and middle of the plants. The beans then were graded for stink bug damage. The mean number of bugs per shake for all dates was used as an index of the prevalent population.

The data shown in Table 18 indicate the degree of damage which can be expected to follow infestations as estimated by the above method. One bug per 3-foot shake evidently can cause a great deal of damage. Even with the precaution of counting and sampling in as nearly the same spot as possible, much variation was found. Perhaps this was to be expected since nymphs were definitely gregarious, and the infested and damaged spot often was very sharply delineated. Variation could also have been caused by nymphs becoming adult and migrating out, leaving the damage behind. Furthermore, the shaking method is only an index rather than a complete count. Some bugs resist being shaken off the plant.

Table 18. Relation between Stink Bug Infestation and Damage to Soybeans, 1962 through 1964

Average no. bugs per 3-foot shake (range)	No. locations	Percent stink bug damage	
		Range	Mean
0.0 to 1	71	0 to 38	11.6
1.1 to 2	28	0 to 46	17.3
2.1 to 3	17	6 to 70	29.7
3.1 to 4	11	8 to 84	37.2
4.1 to 5	3	36 to 74	49.7
5.1 to 6	2	28 to 36	32.0
6.1 to 7	2	58 to 90	74.0
7.1 to 8	3	12 to 56	30.0
8.1 to 9	0	....	.....
9.1 to 10	1	....	62.0
10.1 to 11	1	....	72.0

A different method of counting was used in Poinsett County in 1962 and 1963. This consisted of carefully examining each plant in 6 feet of row, turning the foliage carefully about in a determined effort to find every bug, but without injuring the plants unduly. Ten counting locations were used in 1962 and nine in 1963. Seven periodic counts were made in 1962, and three in 1963. Results are shown in Table 19, along with damage to the respective soybeans at harvest time. Much variation again is evident. The high degree of damage from infestations of one bug or less per 3 feet of row is again shown.

The previous counts (Tables 18 and 19) were made largely in fields known to be heavily infested. Under these conditions a spot with a low infestation count still had a high expectancy of damage, due to movement of bugs or to nymphs becoming adult and flying away. It therefore seems probable that an accurate measure of damage from light infestations can be had only in fields with light infestations throughout.

Counts were made in such a field in Conway County throughout the summer of 1964. The data have been included in Table 18, but are here mentioned separately. At 25 spots, the five weekly counts beginning three weeks after pod-set showed an average infestation of 0.38 bug per 3-foot shake. The highest weekly average was 0.5 bug, which was found on September 18 and 25. The damage at harvest time averaged 3.8 percent.

Table 19. Relation between Green Stink Bug Infestation and Damage to Soybeans, Poinsett County, 1962 and 1963

Average no. bugs per 3 feet of row	No. locations	Percent stink bug damage	
		Range	Mean
0.0 to 1	14	1 to 50	18.6
1.1 to 2	4	8 to 27	20.7
4	1	....	55.0

INSECTICIDE TESTS

Infestations sufficiently high, extensive, and uniform as to be usable for field plots were not found often. Size of plots, number of replications, and number of treatments therefore had to be kept at a minimum in the experiments that were conducted.

A test was conducted in Phillips County in 1961, next to woods. Plots were 0.01 acre in size and replicated three times. Insecticides were applied as sprays at 20 gallons per acre, by means of a knapsack sprayer. Infestation counts were made by visually inspecting the 132 row feet in each plot for stink bugs, either nymphs or adults. Most were nymphs at the time. These counts were made before spraying and 72 hours afterward. Soybeans were of the Lee variety. Applications were made October 6, 1961. Data shown in Table 20 indicate that methyl parathion, dimethoate, and carbaryl were satisfactory insecticides.

Table 20. Effectiveness of Various Insecticides against Green Stink Bug, Phillips County, 1961

Insecticide and lb./A[1]	No. bugs visible in 132 linear feet								Percent kill[3]
	Rep. I		Rep. II		Rep. III		Total bugs		
	Before	After[2]	Before	After[2]	Before	After[2]	Before	After[2]	
Methyl parathion ⅓	14	0	54	0	3	0	71	0	100.0
Dimethoate ½	25	0	7	0	17	1	49	1	99.0
Malathion 1	4	7	20	3	10	1	34	11	83.2
Carbaryl 1	7	0	13	0	2	0	22	0	100.0
Untreated	35	38	6	17	2	28	43	83	.....

[1] All materials were emulsifiable concentrate except carbaryl, which was 80% "sprayable" powder.
[2] Counts made 72 hours after treatment.
[3] Corrected by Abbott's formula.

Another test was conducted in nearly the same place in 1962. Plots were 0.02 acre in size and were replicated only twice, due to the limited area of heavy infestation. Insecticides were applied as sprays at the rate of 12½ gallons per acre by means of a knapsack sprayer. Infestation counts were made by vigorously shaking 3 feet of row at five points in each plot, and counting the nymphs and adults on the soil. Counts were made before spraying and 72 hours afterward. Applications were made on October 5, 1962. Soybeans were of the Lee variety. Dimethoate at both dosages was superior in the test (Table 21). Methyl parathion possibly was satisfactory but carbaryl was poor.

A test was conducted at the Main Station near Fayetteville in 1964. Plots were 0.01 acre in size, replicated three times, in Jackson soybeans. Applications were made by knapsack sprayer, using 21 gallons of liquid per acre. Two applications were made to each plot, spaced one week apart. Infestation counts were

Table 21. Effectiveness of Various Insecticides against Green Stink Bug, Phillips County, 1962

Insecticide and lb./A[1]	No. bugs in 5 shakes						Percent kill[3]
	Rep. I		Rep. II		Total bugs		
	Before	After[2]	Before	After[2]	Before	After[2]	
Methyl parathion ⅓	32	7	33	5	65	12	75.9
Dimethoate ½	24	1	32	2	56	3	93.0
Dimethoate 1	24	0	28	3	52	3	92.5
Carbaryl 1	21	16	31	6	[illegible]	22	44.7
Untreated	21	10	13	16	34	26	.....

[1] All materials were emulsifiable concentrates except carbaryl, which was 80% "sprayable" powder.
[2] 48 hours after second treatment.
[3] Corrected by Abbott's formula.

by the shaking method, and were made before the first treatment and 48 hours after the second. Applications were on October 5 and October 12, 1964. In this test methyl parathion was distinctly the best material, followed by dimethoate and carbaryl (Table 22).

An average of the results from the three experiments gives dimethoate (½ lb./acre) 93.8 percent kill, methyl parathion 92.0 percent, and carbaryl 73.9 percent. Methyl parathion and carbaryl have been judged to be satisfactory insecticides on the basis of field-scale usage. No field usage of dimethoate has been observed.

In 1965 in Phillips County methyl parathion at 1/3 pound per acre was applied seven times at weekly intervals to about one-half acre of soybeans, starting at pod-set. Harvested soybeans had 1.4 percent stink bug damage, compared with 32 percent damage in adjacent untreated soybeans.

Table 22. Effectiveness of Various Insecticides against Green Stink Bug, Washington County, 1964

Insecticide and lb./A[1]	Number bugs in 5 shakes								Percent kill[3]
	Rep. I		Rep. II		Rep. III		Total bugs		
	Before	After[2]	Before	After[2]	Before	After[2]	Before	After[2]	
Methyl parathion ⅓	20	0	10	0	15	0	45	0	100.0
Dimethoate ½	8	0	11	0	5	1	24	1	89.4
Carbaryl 1	22	1	14	3	8	0	44	4	76.9
Untreated	14	6	9	2	10	5	33	13	.....

[1] Emulsifiable concentrate except for carbaryl, which was 80% "sprayable" powder. Two applications were made of each insecticide.
[2] 48 hours after second treatment.
[3] Corrected by Abbott's formula.

DISCUSSION

One of the problems of the soybean grower is knowing how to check fields for stink bug infestations and how to determine whether a given field requires treatment. Information bearing on this subject is brought together here.

If a field is adjacent to known wild hosts, these plants should be inspected during June or July. The presence of first generation stink bugs will indicate the most likely location of future infestations in soybeans.

As soon as pods have set, soybeans on the borders of the field should be checked for stink bugs, giving special attention to areas closest to wild hosts. Border infestations are so typical that evidently the entire field need not be checked, unless an insecticidal application is planned. Shaking the plants vigorously over a muslin sheet placed on the ground is the best method of checking for presence of stink bugs. An appreciable infestation when pods are small, possibly one bug in six feet of row, is considered a threat to yield.

The usual time for damaging infestations to appear in soybeans is during the first half of September. A thorough check of borders should therefore be made at this time, again giving locations next to wild hosts special attention. One bug per three feet of row can cause sufficient damage to justify treatment if buyers are expected to discount for this damage.

About 6 percent of damage to harvested soybeans can be tolerated before it becomes economical to use control measures, on the basis of the discount formula used by buyers in 1960. This called for no discount for up to 2 percent damage. Above that, there was a two-cent per bushel discount for every additional percent of damage. Thus, beans with 6 percent damage were discounted eight cents per bushel. Assuming a yield of 25 bushels per acre, this would be $2.00 per acre, or about the cost of one application of insecticide. Since prevention of damage doubtless would not be complete, and since more than one application might be required, the 6 percent figure may be low.

Before treating, the entire field should be checked to learn the extent of the infestation. Often only a part of the field will be found infested, and only this part need be treated.

If the infestation is discovered too late to prevent damage and only one side of a field is infested, it may be possible to harvest the damaged beans separately and make special disposition of them.

SUMMARY

The green stink bug, *Acrosternum hilare* (Say), was found to be the principal stink bug species causing damage to soybeans in Arkansas. The southern green stink bug, *Nezara viridula* (L.), was partially responsible for damage in the southeastern counties. Damage was caused by insertion of the feeding stylets into the soybean, which resulted in a whitish blotch along with more or less shrinkage and distortion. Duration of the various life stages under laboratory conditions at 72°F. and 60 percent relative humidity indicated a total life cycle of 101.2 days mean duration.

Seasonal history records showed that the first generation generally was completed on wild hosts, especially dogwood. Migration to soybeans then occurred, where a second generation was completed. In several cases, however, infestation of soybeans had little or no obvious relation to wild hosts.

Only a small percentage of fields in any given area were found to have appreciable infestations. Distribution within fields also was spotty, with highest infestations generally near woods.

Microscopic section of damaged soybeans showed that cells in the damaged area were empty or nearly so. Many cell walls remained, however. Histolytic agents probably were injected by the bug, resulting in liquefaction of cell contents preparatory to withdrawal. It was indicated that damaged tissue in soybeans with moderate degrees of damage seldom exceeded 1 or 2 percent by volume. The volume of visibly damaged tissue did not increase in storage, nor did the percent of soybeans affected. Soybean samples with 10 percent damage were indicated to contain about 0.1 percent less oil and 0.1 percent more protein than undamaged samples.

Soybeans damaged but essentially full-size had a loss of about 9 percent in weight. Early infestation by large numbers of bugs resulted in severe reduction of soybean size. Late-maturing varieties were found to suffer the most damage. Early planting increased the damage in one experiment.

A survey of 50 fields selected at random showed an average of 2.98 percent stink bug damage. Fields with less than 6 percent damage (thus not requiring treatment) made up 86 percent of the fields sampled.

Infestation counts associated with damage at harvest time showed that infestations of one bug per three feet of row resulted in damage sufficient to justify insecticidal treatment. In small plots, dimethoate at one-half pound per acre averaged 93.8 per-

cent kill of stink bugs, methyl parathion at one-third pound averaged 92.0 percent kill, and carbaryl at one pound averaged 73.9 percent kill. Methyl parathion and carbaryl have been judged satisfactory materials on the basis of field-scale usage. They are registered for use on soybeans. No field usage of dimethoate has been observed and it is not registered for use on soybeans.

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HOST PLANT PREFERENCE OF THE SOYBEAN POD BORER, *GRAPHOLITHA GLICINIVORELLA* MATSUMURA (LEP., EUCOSMIDAE)

1. Oviposition site

BY

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The host plant preference of the soybean pod borer, an important factor in the resistance of the soybean plant, was studied in the field, using four varieties, two hairy and two glabrous. It was found that there was a considerable difference in the number of eggs laid on the hairy and glabrous varieties, and also in the place where eggs were laid. These differences were observed when the hairy varieties were planted alternately with the glabrous ones. However, the difference in the number of eggs laid was not found when all pods of the soybean plants were removed. This treatment of the hairy varieties caused a great decrease in the number of eggs laid, while on the glabrous varieties this was not the case. These observations suggest that two factors operate (a) varietal preference (b) site preference within plants, e.g. the hairy pod is the most attractive oviposition site.

PAINTER (1951) has stated that insect resistance in crop plants is due to three factors: preference, antibiosis and tolerance. This was confirmed in a previous paper (NISHIJIMA & KUROSAWA, 1953) dealing with the resistance of soybean varieties to the soybean pod borer, *Grapholitha glicinivorella* Matsumura, which is one of the most important pests of soybean in Japan. The experiment on the relative importance of these factors was conducted by the method of inoculation (NISHIJIMA, 1954). It demonstrated that the principal factor conferring resistance in soybeans was related to host plant preference as it concerned oviposition. Thus, an investigation was undertaken in order to investigate the problem.

The subject of host preference has occupied the special attention of many workers, particularly in relation to insect nutrition (DETHIER, 1953, 1954; FRAENKEL, 1953, 1958; HOUSE, 1958; KENNEDY & BOOTH, 1951; KENNEDY, 1953, 1958; LIPKE & FRAENKEL, 1956; PAINTER, 1953; THOMPSON, 1951; THORSTEINSON, 1953, 1955). In the case of the present species, however, it is difficult to consider any nutritional stimulus in the process of host plant preference, because the gravid female selects soybean plants which are not the proper food for herself and the larva enters into a given pod to feed. The nutritional aspect in host preference is beyond the scope of this investigation. Therefore, attention will be directed mainly towards the relationship between the plant characters, a principal element of token stimuli, and oviposition behaviour relating to sensory physiology. The present paper deals with the results of field observations prior to the experimental analysis of the problem.

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OVIPOSITION IN THE RANDOMIZED BLOCK FIELD

Material and method. In the years of 1952 and 1953, the randomized block field as shown in Figure 1 was placed in the field of Hokkaido University at Sapporo. In each of three rows within a plot, ten plants were grown at intervals of 25 cm. Two hairy varieties (Tokachi-Nagaha and Chusei-Hikarikuro) and two glabrous ones (Chusei-Hadaka and Nagaha-Hadaka No. 1) were chosen. On the 15th, 22nd and 30th of August and the 8th of September, three plants per variety were examined in detail for the number of eggs and the sites of eggs laid.

Result. In the varieties tested, the period of pod growing stage, extending from the end of July to the end of August, showed no difference among the varieties, and it coincided with that of the occurrence of the moth. This indicates that all

TABLE I

Percentage of eggs laid on various sites of the hairy and glabrous soybean varieties

Egg-laying sites	Variety A	B	C	D
Leaf	< 1	< 1	0	0
Petiole	3	1	0	0
Stem	2	2	0	0
Stipule	7	5	70	76
Calyx	6	8	25	21
Pod stalk	4	4	0	0
Pod	77	80	5	3

the plants provide the same chance for oviposition. Consequently, assuming that each variety has an equal attractiveness to the gravid female, nearly identical numbers of eggs should be laid on all varieties. But the result shown in Figure 1 is adverse to this assumption. It showed clearly that much more eggs were laid on the hairy varieties (A, B) than in the glabrous ones (C, D), showing no remarkable differences both between the years and among the blocks. The number of eggs laid was 638 (A), 536 (B), 146 (C) and 123 (D) in the total of 1952 and 1953.

In the number of eggs found at various sites of soybean plant given in Table I and Figure 1, there was a marked difference between the hairy varieties and the glabrous ones. In the hairy varieties, most of the eggs (i.e. 77—80 per cent) were found on the hairy pod. The next vegetative sites in order of preference for oviposition were the calyx and stipule. The eggs found on the stipule were always located on the outer surface. Very few eggs were also found on the leaf, petiole, stem and pod stalk. On the other hand, in the glabrous varieties the sites at which eggs were laid were restricted only to the stipule, calyx and pod. The eggs were found mostly on the inner surface of the stipule (70 per cent), though substantial numbers were found on the calyx (20 per cent). Moreover, the pod was the least attractive site for oviposition, contrasting with the hairy varieties.

The above observations suggest that the gravid moth shows some particular host plant preferences when ovipositing. This raises two problems which will be considered: (1) the preference between hairy and glabrous varieties, as shown by differences in egg numbers and sites (2) the preference for attractive sites for

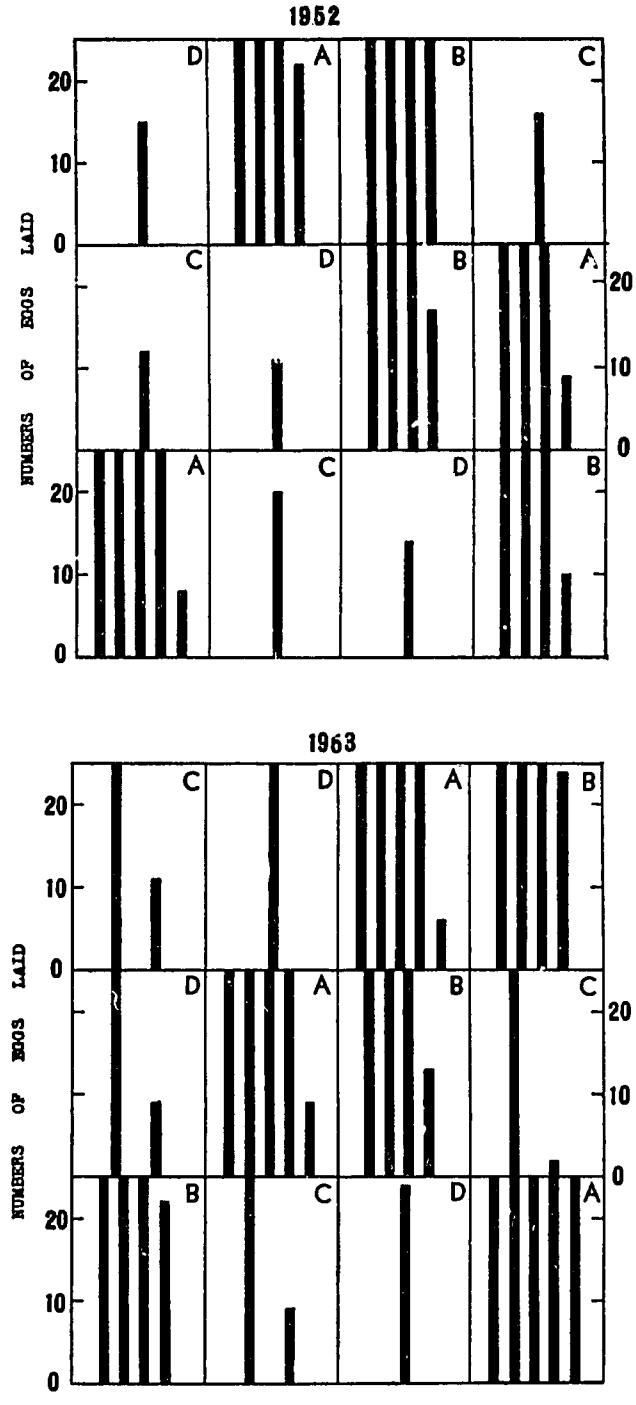


Figure 1. Numbers of eggs laid on the four soybean varieties (hairy A, B and glabrous C, D) in the randomized block field. The area of a plot was 4.125 m^2 (1.65 $\times$ 2.5 m)

egg-laying in soybean varieties. In field observations it may be difficult to determine the basis of these preferences.

OVIPOSITION IN AN ALTERNATELY PLANTED FIELD

Material and method. In 1954, two hairy soybean varieties, Tokachi-Nagaha (A) and Chusei-Hikarikuro (B), were sown alternately with two glabrous ones, Chusei-Hadaka (C) and Nagaha-Hadaka No. 1 (D), at intervals of 25 cm, in the layout shown below.

A	C	A	C	A	C	A	C	A	C
D	A	D	A	D	A	D	A	D	A
B	C	B	C	B	C	B	C	B	C
D	B	D	B	D	B	D	B	D	B

Four plots containing four varieties as shown above were provided in order to obtain more adequate data by replication. On the 15th of May, three seeds of each variety were sown close together at each position to avoid gaps if some seeds did not germinate. On the 20th of June the plants were thinned to leave one vigorous plant at each spot. The plants grew normally, the beginning of the flowering period being recorded on the last week of July. The first appearance of the moths was on the 29th of July. The main period of egg-laying activity was from the 15th of August to the 10th of September. During this period, the eggs laid on three plants per variety, which were marked at random from each plot, were counted at intervals of five days.

Result. The results are expressed by giving the totals for twelve plants per variety (3 plants × 4 plots) on each date of observation.

TABLE II

Number of eggs laid on the hairy and glabrous soybean varieties in the alternately planted field

Variety	Date of observation						Total
	15 Aug.	20 Aug.	25 Aug.	30 Aug.	5 Sept.	10 Sept.	
A	38	57	84	102	44	29	354
B	32	49	93	75	47	21	317
C	5	14	38	56	20	7	140
D	3	10	31	53	16	9	122

As shown in Table II, the number of eggs laid was clearly different between the two varietal groups. The eggs found on the hairy varieties (A, B) were more than twice as numerous as those found on the glabrous ones (C, D). In the former the favourite site for oviposition was the pod; no eggs were found on the glabrous pods. These results agree with the finding in the foregoing section. It is therefore concluded that the oviposition pattern of the species is not affected by the alternate plantation of the varieties of soybean which might cause disturbance of some factors attractive or repellent to the moth. In the hairy varieties, it is suggested that a greater egg-laying may be caused by the presence of hairy pods, because a large number of eggs are laid on the pod (see Table I). Then, a simple

question arises: "Do hairy pods serve as an attractive site for oviposition?" To answer this question, the following experiment was conducted.

OVIPOSITION ON BEANS FROM WHICH THE PODS WERE REMOVED

Material and method. The soybean varieties used were Tokachi-Nagaha (A) and Nagaha-Hadaka No. 1 (D). The seeds were sown on the 15th of May, 1954, under the same plot-design as that illustrated in Figure 1. A block was divided into four plots in order to compare plants of A and D from which pods were removed with normally podded A and D. The podless soybean plants were obtained by plucking all the flower stalks throughout the flowering period, extending from the middle part of July to the end of August. On the 26th and 31st of August and the 6th of September, the eggs were counted on three plants per plot.

Result. The results are expressed by the total number of eggs per twelve plants (3 plants × 4 plots) on each date of observation.

TABLE III

Numbers of eggs laid on podded and podless soybean plants of the hairy and glabrous varieties

Variety	Treatment	Date of observation			Total
		26 Aug.	31 Aug.	6 Sept.	
A	Podded plot	97	114	31	242
A	Podless plot	20	28	12	60
D	Podded plot	36	49	7	92
D	Podless plot	42	55	10	107

As shown in Table III, the difference in the number of eggs laid in podded and podless plants was very gre ' in the hairy variety, contrasting with the small difference in the glabrous one. The podless plants of the hairy variety (A) had far fewer eggs than the others. On the other hand, no considerable differences could be found between the two treatments in the glabrous variety (D). These results demonstrate clearly that the amount of oviposition is influenced considerably by the presence or absense of hairy pods, while it is not affected by glabrous pods at all. Thus the experiment suggests that the "hairy pod" provides an attractive or favourable site for oviposition.

A COMPARISON OF THE MICRO-CLIMATIC CONDITIONS IN THE HAIRY AND GLABROUS SOYBEAN FIELDS

A brief description of the microclimate may be useful for the consideration of the results mentioned in the preceding sections. In the hairy and glabrous soybean fields, the temperature and humidity at the level of the topmost pods between the rows were recorded from the 16th to the 31st of August in 1956, during the period that the moths were actively ovipositing. At the same time, the light intensity at various heights of a plant was measured by a luxmeter both under fine and cloudy weather conditions (see Fig. 2).

The mean temperatures in the hairy and glabrous soybean fields were 21.4° C

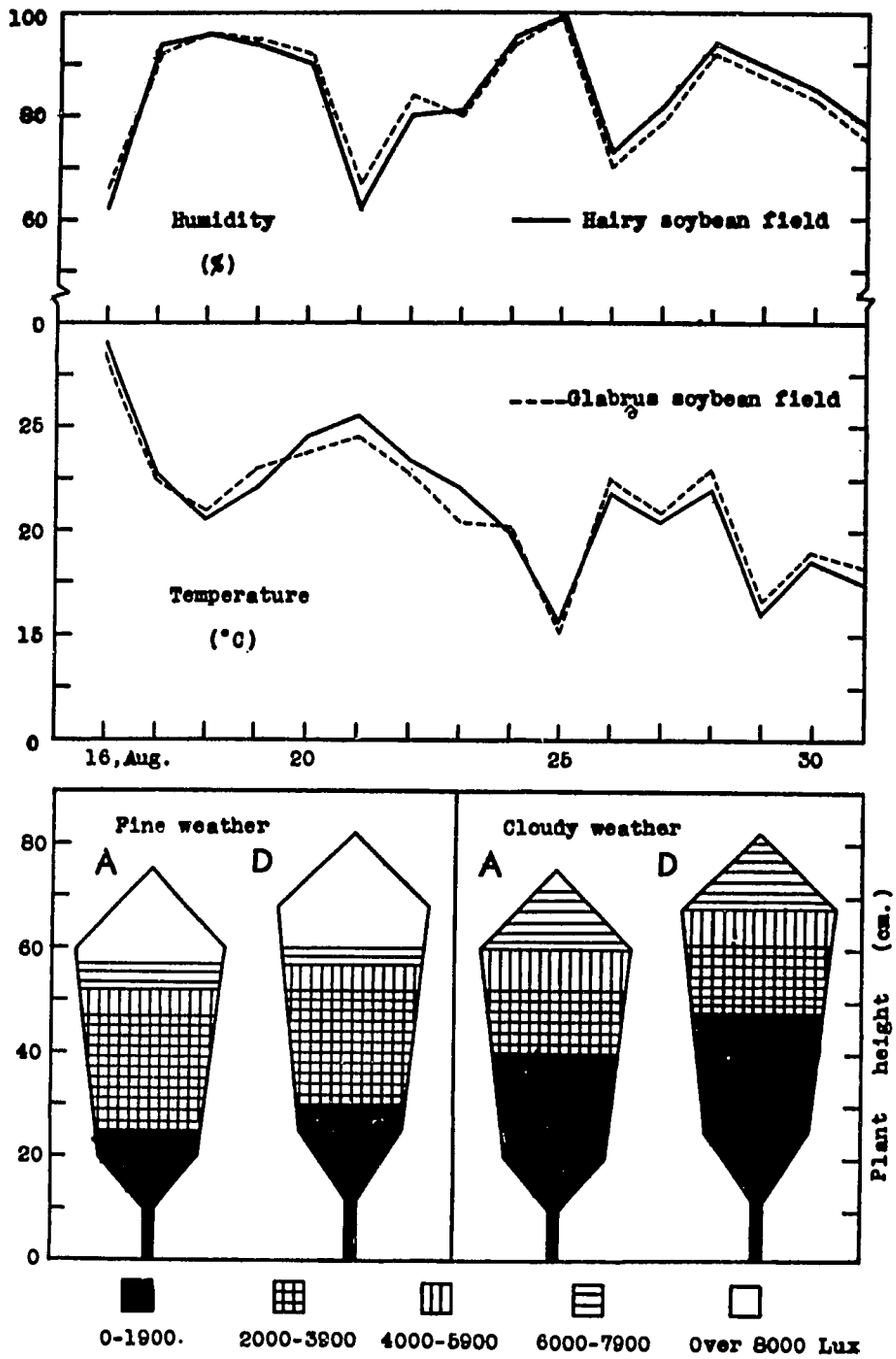


Figure 2. Comparison of the temperature, humidity and light intensity between the hairy and glabrous soybean fields.

and 21.3° C, with a range of 15.8—29.0° C and of 15.5—28.6° C respectively. The mean relative humidity in these fields was 83.8% and 84.8%, with a similar fluctuation as illustrated in Figure 2. These results indicate that, so far as temperature and humidity are concerned, no remarkable differences can be found between the hairy and glabrous soybean fields.

The light intensity near the soybean plant, which may cause a different pattern of oviposition by leading the moths to a different photo-stimulus, is of course changeable with weather, such as sunny or shady conditions, and also with the site of measurement. These differences are clear in Figure 2. For instance, the light intensity in fine weather was over 8000 lux above the topmost pods, while it decreased downwards on the plant. However, no *relative* difference between the hairy and glabrous plants could be found.

DISCUSSION

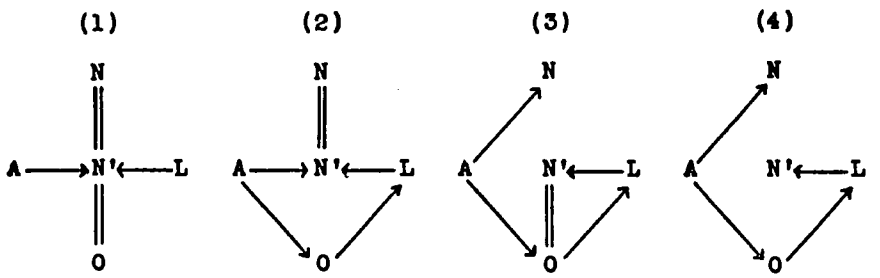
The subject of "host selection" or "food preference" being an important problem of entomology and the theme of the present investigation, some reference to general theory is called for. There are two main schools of thought on the subject. KENNEDY & BOOTH (1951), KENNEDY (1953, 1958) and FENNAH (1953) have claimed that host selection is a dual discrimination reaction that involves nutrition, particularly as it applies to tissue preference found in some species of Homoptera. This has been strongly disputed by DETHIER (1953, 1954) who has demonstrated that nutritionally unimportant token stimuli, such as attractants and repellents, are predominantly responsible for regulating feeding preference. He stated: "we should not expect *a priori* a close correlation between nutrition and plant preferences". This idea has also been supported by FRAENKEL (1953, 1958) and LIPKE & FRAENKEL (1956).

Apart from the validity of these theories, the present author considers that such conflicting opinions have been held, depending on whether attention has been directed towards "a dynamic process" or "a static analysis" and partly on the specific differences of the insects used. KENNEDY's work (1951—1958) on the food plant preference of aphids gives a dynamic rather than a static approach. This work is important, but at the same time work with phytophagous insects other than aphids must not be overlooked.

Aphids are insects in which adults and larvae are able to feed on the same kind of plants. Since their fecundity is strongly influenced by the food ingested, it may be possible to explain the relation between nutrition and host plant preferences. However, this is very difficult to invoke in the ovipositing female of some holometabolous insects, as has been pointed out by DETHIER (1954). For instance, most butterflies and moths are attracted to water, sugar or other sweet substances, probably for their feeding requirements, while they are also attracted to very different places for oviposition, usually a certain species or group of plants. Is there any connection between such preferences for feeding and oviposition? In this case, the meaning of "host plant preference" is, in the strict sense, not applied to "food preference", but merely to "oviposition site preference". When we consider the foregoing facts, it is apparent that the process of host

plant preference is varied with the group of insects, and in order to avoid some confusion on the subject it is desirable to inquire first into the pattern of host plant preference.

Assuming that host plant preference in insects is concerned with adult (A) and its food for nutrition (N), oviposition site (O), larva (L) and its food for nutrition (N'), the following patterns will be considered.



The patterns are represented, for example, by most aphids and the Colorado beetle (*Leptinotarsa decemlineata* Say) in (1), most locusts in (2), boring or mining species of Lepidoptera in (3) and by the gypsy moth (*Lymantria dispar* L.) in (4) respectively. In the second and fourth patterns, the larvae are endowed with the abilities to migrate a good distance and to recognize suitable food, since their eggs are laid under the ground or in the vicinity of their food. In the third pattern, on the contrary, the larvae are never granted the opportunity to select their own food, since they are restricted by spatial factors to the food selected by the gravid female. The host plant preference for her progeny is largely determined by the abilities of the adult, and it should not be confused with the preference for her own food. The soybean pod borer belongs to the third pattern, since the oviposition is restricted on the host plant, *Glycine max* Merrill (soybean), and the larvae do not as a rule migrate from a given plant to a neighbouring plant (KUWAYAMA, 1938; NISHIJIMA, 1954a). It is therefore obvious that the principal aspects of the host plant preference of the species are not related to nutrition, but to that of oviposition site preference, as discussed below.

It is well known that there is a considerable difference between hairy and glabrous soybean varieties in the egg number laid by the borer moth (KUWAYAMA, 1928; UCHIDA & OKADA, 1937; OKADA, 1948; NISHIJIMA & KUROSAWA, 1953; NISHIJIMA, 1954a). This was also confirmed in this paper. Such a difference may raise the question whether this results from a different population of the moth crowding between the two groups of the varieties or a different micro-climatic condition in the fields. Indirect evidence on this question was given by the fact that such a difference was observed in the alternately planted field as well as in the randomized block field. Furthermore, the experimental fields, each representing a hairy variety and a glabrous one, showed similar climatic conditions (e.g. temperature, humidity and light). These facts indicate that the marked difference in number of eggs laid between the hairy and glabrous varieties is not a phenomenon caused by differences either of field climatic conditions or of moth population.

In the site of eggs laid on the soybean plant, there was a considerable difference between the hairy and glabrous varieties. In the hairy varieties the favourite site for oviposition was the pod while in the glabrous varieties it was not the pod (which showed the lowest percentage), but the inner surface of the stipule. This tendency was found in each field experiment. It is therefore certain that such a clear difference in the site of eggs laid *between* the two groups of the varieties is unchangeable. On the other hand, *within* a variety, the rate of eggs found on various parts of soybean plant seems to be variable to some extent. As has been stated by KUWAYAMA (1928), the rate of eggs laid on the pod is, of course, to be changed or decreased when the pod bearing stage of plant does not coincide fully with the period of oviposition. In the case of the podless experiment, however, the number of eggs laid itself was greatly decreased by the complete removal of hairy pods. Thus a marked difference in the number of eggs laid between the hairy and glabrous varieties disappeared when the pods of the hairy variety were removed artificially. This suggests that the "hairy pod" is the most attractive site for oviposition, while the glabrous pod does not serve as such.

In conclusion, it is demonstrated that the host plant preference of the soybean pod borer shows two interesting aspects, namely, inter- and intra-varietal preferences. The experimental analysis of these aspects will be given in succeeding papers.

I wish to express my special thanks to Dr. T. UCHIDA and Dr. C. WATANABE of the Entomological Institute of Hokkaido University for reading this manuscript. I am deeply grateful to Dr. T. INUKAI of the Institute of Applied Zoology of the same University for his kind suggestions.

ZUSAMMENFASSUNG

DIE WIRTSPFLANZENPRÄFERENZ DES SOJABOHNENBOHRERS, GRAPHOLITHA GLICINIVORELLA *MATSUMURA. 1. DIE EIABLAGE*

Die Wirtspflanzenpräferenz des Sojabohnenbohrers, eine wichtige Erscheinung hinsichtlich der Resistenz der Sojabohnenpflanze, wurde im Freiland unter Benutzung von je zwei Varietäten behaarter und unbehaarter Sojabohnen untersucht. Es zeigte sich, daß sowohl hinsichtlich der Anzahl als auch der Lokalisation der abgelegten Eier zwischen den haarigen und unbehaarten Varietäten der Bohnen ein beträchtlicher Unterschied besteht. Diese beiden Unterschiede wurden auch dann festgestellt, wenn die haarigen Varietäten im Wechsel mit den haarlosen gepflanzt worden waren. Als jedoch sämtliche Schoten aller Sojabohnenpflanzen künstlich entfernt wurden, konnte kein Unterschied in der Anzahl der abgelegten Eier mehr gefunden werden. Diese Behandlung verursachte bei den haarigen Varietäten eine übermäßige Verminderung der Eizahl, während dies bei den haarlosen nicht der Fall was.

Diese Beobachtungen zeigen offenbar, daß es hinsichtlich dieses Gegenstandes zwei Haupterscheinungen gibt, nähmlich Inter- und Intravarietätenpräferenz, und daß die erstere stark von der Anwesenheit der „haarigen Hülse" beeinflußt wird, die als die anziehendste Eiablagestelle zu gelten hat.

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Biological Synopsis of the Green Cloverworm[1] in Central Iowa[2]

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ABSTRACT

Observations of *Plathypena scabra* (F.) were made in central Iowa from 1968 to 1972. Data were gathered from laboratory, greenhouse, cage, and open-field environments. Additional United States distributional records since 1925 indicated that the species now extends to about 103° W longitude, and larvae reportedly feed on 34 plant species. In Iowa the primary hosts are soybean, alfalfa, and clover. Adult longevity was 22.4 days, with females living significantly longer than males. Flight activity was pronounced at <1 foot candle, and most adults were caught in light traps between 8:00 PM and 12:00 midnight CDT. Light-trap catches were highly biased toward males. The sex ratio from 288 field-collected larvae did not differ significantly from 1:1. Oviposition began with 4- to 5-day-old adults and continued for 2.5 weeks. Peak oviposition occurred 12–16 days after emergence. Eggs were laid on upper or lower leaf surfaces and were subject to mortalities by predators and heavy rainstorms. Young larvae showed no preference for plant stratum, and significantly more older larvae were found in the upper third of the soybean canopy. Important larval mortality was caused by predators (*Orius insidiosus* (Say) and *Nabis* sp.), parasites (primarily *Rogas nolophanae* Ashmed and *Winthemia* sp.), and pathogens (a granulosis virus, *Beauvaria bassiana* (Balsamo), and *Metarrhizium* sp.). Most larvae pupated in the soil, but 10.4% pupated in the soybean-plant canopy. Adults were active in May, and oviposition began in alfalfa about May 15. Oviposition in soybean was usually delayed until the 1st week of June, and all stages were present until the middle of September. Latest fall activity was on November 16. A long ovipositional period with a relatively long life cycle produced great overlapping of generations. Prominent generations were therefore considered, with 3 occurring in alfalfa and 1 in soybean. The overwintering stage in Iowa remains an unresolved question.

The green cloverworm, *Plathypena scabra* (F.), is a Nearctic species that can be categorized an "occasional" pest of soybean (Pedigo 1972) and other economic legumes (Stirrett 1931). Particularly in recent years, the species has attracted more attention because of increased acreages and market values of soybean in the United States. Primarily a defoliator, *P. scabra* is one of the most widespread of known soybean insect pests. Outbreak history of this species was reviewed by Pedigo et al. (1972a).

Considering its wide distribution, not many studies have been conducted with the green cloverworm, and basic information regarding life history, behavior, and population dynamics is lacking (Stone and Pedigo 1972a). Probably the most comprehensive biological studies were conducted by Hill (1925) and Smith and Franklin (1961). Both studies referred primarily to the species in alfalfa agroecosystems. Burbutis et al. (1965) and Burbutis and Kelsey (1970) discussed seasonal distribution and abundance of green cloverworms on lima beans in Delaware.

Less biological information is available concerning *P. scabra* in soybean agroecosystems. Most early studies refer to observations made during widespread outbreaks (Smith 1919, Sherman 1920, Sherman and Leiby 1920). Some information regarding phenology and abundance in soybean is given also in faunal studies of soybean insects (Balduf 1923, Kretzschmar 1948, Ratcliffe et al. 1960, Blickenstaff and Huggans 1962).

More recently, biological studies relating to *P. scabra* in soybean have been made in Iowa. Pedigo (1971) discussed oviposition on soybean leaflets and emphasized the influence of leaf pubescence. Stone and Pedigo (1972b) reported on feeding and development in controlled laboratory environments. Population trends and mortality by biological agencies were discussed by Pedigo et al. (1972a,b).

In many of the Iowa studies, observations of *P. scabra* have been made that were not appropriate for inclusion in previous reports. Most of these observations relate to species biology, and an accumulation of facts during 5 years of study has prompted the following summary of this information.

METHODS AND MATERIALS.—Data in this summary consist of observations made of green cloverworms in the laboratory, greenhouse, and field. Some information was gathered during the course of: (1) maintaining colonies of *P. scabra*, (2) general collecting of soybean insects, and (3) studying certain individual and population processes (oviposition, feeding, survivorship, parasitism, etc.). Other information was gathered from field studies designed to produce an understanding of the life history of the species in Iowa.

Observations of a greenhouse colony on caged soybean were made under the conditions outlined by Pedigo (1971). Laboratory observations were made in Percival® environmental cabinets under the following conditions: photophase 14–15 hr; temperature, day 27–29°C, night 18–21°C; RH max 96%, min 55%. Holding procedures in environmental cabinets were those of Pedigo (1971) for adults and of Stone and Pedigo (1972b) for immatures.

Field observations from studies of experimental populations in open-field- and screenhouse-grown soybean (Pedigo et al. 1972b) are included, as are those of natural populations. Natural populations of larvae were sampled in alfalfa from June 4 to Oct. 26, 1971, and in soybean from June 22 to Sept. 8, 1971, to detect seasonal occurrence of generations. Soybean samples were taken by insect-net sweeping in the manner described by Pedigo et al. (1972a) in 4 fields (4 samples/field, 100 sweeps/sample). Alfalfa fields (including varying mixtures of red clover) were sampled by sweeping along 1500 ft transects. Usually, 20 samples/field per date were taken (50 sweeps/sample) until late season, when declining larval numbers necessitated increasing the number of samples. When an alfalfa field was cut, an alternative alfalfa field was sampled within the same general location.

Green cloverworm adults were collected from July 16

[1] Lepidoptera: Noctuidae.

[2] Journal Paper no. J-7423 of the Iowa Agriculture and Home Economics Experiment Station, Ames. Project no. 1956. Received for publication Nov. 10, 1972.

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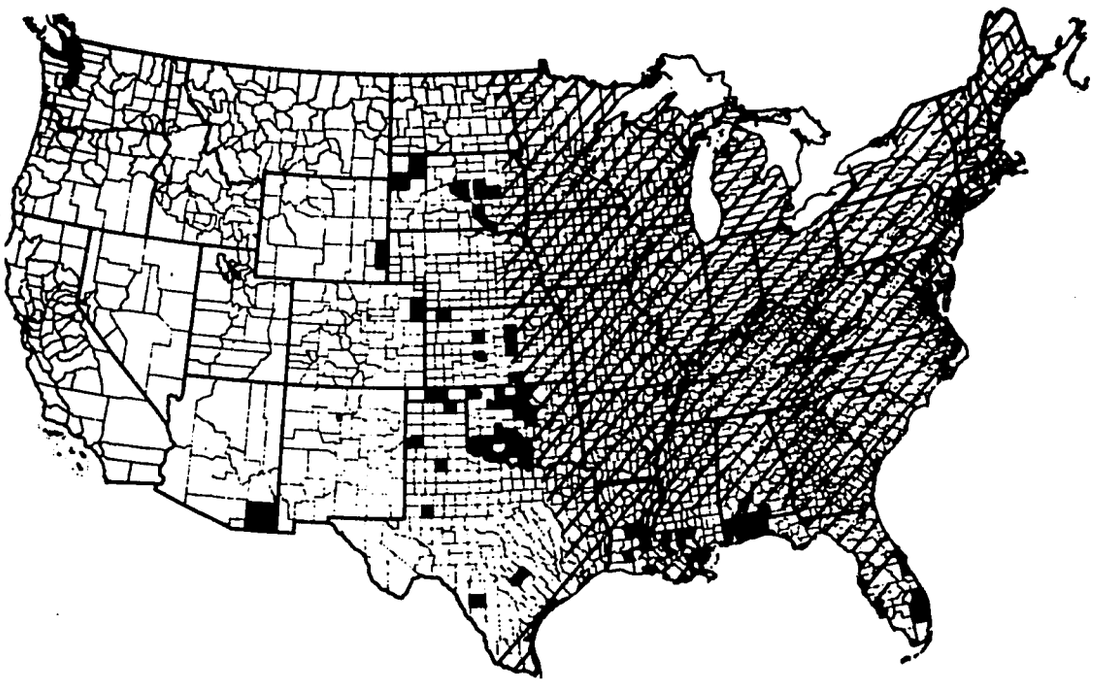

FIG. 1.—Distribution of the green cloverworm in the United States. Cross-hatched area indicates distribution reported by Hill (1925). Blackened areas are new county records that lay along or outside Hill's distribution records.

to Oct. 3, 1970, with a BL trap near a farmstead 4 miles SW of Ames. Red clover, alfalfa, and soybean fields were within 300 yd of the light trap.

RESULTS AND DISCUSSION.—*Geographical Distribution and Food Plants.*—The most recent detailed summary of geographical distribution of *P. scabra* in the United States was given by Hill (1925). Hill's distribution record was updated by examining the Cooperative Economic Insect Report (Anonymous 1952–71) and considering other sources (C. C. Burkhardt, Laramie, Wyo., Goshen Co. record; Fla. Dept. Agric. survey, Santa Rosa, Okaloosa, Brevard, Broward, Martin, and Palm Beach Co. records; Kimball (1965), Escambia and Gadsden Co., Fla., records; Smith and Franklin (1961), Ellis Co., Kans., record; G. L. Godfrey, Urbana, Ill., Spink and Brown Co., S. Dak., records; personal collecting, Rawlins Co., Kans., Yuma Co., Colo., records) and mapping county records that lay along or outside previous *P. scabra* boundaries.

The updated distribution (Fig. 1) includes all major soybean-growing areas of the United States but not all areas where substantial acreages of alfalfa, alfalfa mixtures, and clover are grown, viz., Montana, Idaho, and California (Anonymous 1970). The main distribution shows a western advance since 1925 from ca. 98° to ca. 103° W. longitude, indicating that the species can survive in areas with an annual precipitation of 15 in. and less (although much of the alfalfa in these areas is irrigated). An extended distribution is shown also in the Gulf States, thereby eliminating most areas of previously reported absenteeism in the eastern United States. These advances could be real, i.e., actual movement of populations into new areas, or they could be the result of more collecting and better reporting, or both. The isolated report in eastern Arizona and the availability of host plants (particularly in New Mexico, Colorado, North Dakota, Wyoming, and Montana) makes us believe that the western distribution of *P. scabra* is more extensive than shown.

Outside the United States, the species has been an occasional pest of beans in southwestern Ontario, Canada (Beirne 1971), and a single male adult was collected at Lee, Kent, England, Aug. 31, 1956 (Bradley 1960). We know of no records from Mexico, although we believe the species occurs there because of its reported presence along the southern Texas border.

During 1967–71 the most commonly reported food plants of *P. scabra* were soybean, alfalfa, clovers, field bean, lima bean, and pea (Anonymous 1952–71), in that order. The larvae, however, probably feed on leguminous crops in general (Hill 1925). Hill (1925) compiled a list of host plants and discussed species on which *P. scabra* was known to feed. Hill's report was updated by reviewing the literature and adding food-plant records (Table 1). Thirty-four plant species have been reported (other than corn and crabgrass which will not sustain development), 11 of which are additions to Hill's report.

Iowa grows 5,618,268 acres of soybean and 2,358,644 acres of alfalfa, clover, and legume mixtures (Sutherland 1970). These plants are, therefore, the primary hosts of *P. scabra* larvae in Iowa.

Adults have been observed feeding on nectar of host-plant blossoms (Hill 1925). In our greenhouse colony, adults drank copiously of water droplets on soybean leaves when water or 1% sugar solution was sprayed into the holding cages.

Adult.—The adult emerged from the pupal exuvium by splitting 2 sutures that extend from the vertex of the head to the posterior metasternum. It escaped from this anteroventral opening and usually moved to a vertical surface to expand and dry its wings. We observed that wing deformity and accidental death of

Table 1.—Plants on which green cloverworm larvae have been reported to feed.[a]

Scientific name	Common name	Reference[b]
Ambrosia trifida	giant ragweed	Hawley 1922
Arachis hypogaea	peanut	CEIR 1965
Daucus carota	wild carrot	Hill 1925
Fragaria virginiana	Virginia strawberry	
Glycine max	soybean	
Ipomoea purpurea	morning glory	
Lactuca sativa	lettuce	CEIR 1961
Lespedeza procumbens	lespedeza	Hill 1925
Lotus corniculatus	birdsfoot trefoil	Neunzig and Gyrisco 1955
Lupinus angustifolius	blue lupine	CEIR 1966
Lycopersicum esculentum	tomato	CEIR 1957
Medicago polymorpha	California bur clover	CEIR 1968
M. sativa	alfalfa	Hill 1925
Desmodium sp.	tick trefoil	
Melilotus alba	white sweet clover	
Polygonum pennsylvanicum	smartweed	
Phaseolus lunatus	lima bean	
P. vulgaris	(most varieties)	CEIR 1971
Pisum sativum	common pea	Hill 1925
Potentilla canadensis	common cinquefoil	
Pyrus malis	apple	Frost 1955
Robinia sp.	locust	Hill 1925
Rubus sp.	blackberry	
Salix sp.	willow	
Solidago sp.	goldenrod	Riley 1885
Spinacia oleracea	spinach	CEIR 1967
Stizolobium sp.	velvet bean	Hill 1925
Trifolium hybridum	alsike clover	
T. incarnatum	crimson clover	
T. pratense	red clover	
T. repens	white clover	
Vigna sinensis	cowpea	
Vicia faba	broadbean	
V. sativa	common vetch	

[a] Except corn and crabgrass which Hill (1925) has shown will not sustain development.
[b] CEIR = Cooperative Economic Insect Report, most recent report to 1971 is given.

noneclosed adults was much more prevalent among those emerging from pupal exuviae that we had removed from the cocoon. This fact indicates that a stationary pupal exuvium (as found under natural conditions) allows more efficient adult eclosion. In rearing programs, where normal adults are required, pupae should not be removed from the cocoon.

The adult was a mottled gray-brown deltoid moth with various black and silver markings. Sexual dimorphism existed between the male and the female (Fig. 2, 3). The front wing of the male was usually more unicolorous than that of the female, having irregular, transverse, black lines on its posterior half. The female generally had more contrasting areas of color, with a rust area along the anterior ½ of the wing's trailing edge and an irregular, silver, transverse band on the posterior ½ of the wing.

Color variants from these descriptions sometimes made difficult sexual separation based on color. More precise separation of sexes was made by observing the relationship between eye diameter and distance between the eyes on the frons (interocular distance). In dividing the eye diameter by the interocular distance for 29 adults, we found a mean value of 2.51 (range 2.11–3.09) for males and 1.25 (range 0.95–1.45) for females. Because the mean male value was twice as large as that of the female, with no overlapping values, this characteristic was reliably diagnostic. Other obvious dimorphic characteristics were the frenulum (male 1 strong spine, female 2 weak diverging spines) and length of setae on the underside of the thorax (male long, hairy appearance; female short, naked appearance).

Sex ratios of green cloverworm populations were determined during the summer of 1971 when 614 randomly collected larvae (collected from June 22 to Sept. 22) were held for adult emergence from soybean, and 288 larvae were held from alfalfa collections over the same period. Results were: soybean 316 ♂, 298 ♀; alfalfa 149 ♂, 139 ♀. Using an expected ratio of 1:1, χ^2 values calculated for these data were: soybean 0.53, $P_{\chi^2} > 0.05$; alfalfa 0.36, $P_{\chi^2} > 0.05$. These ratios agree approximately with the findings of Smith and Franklin (1961) from moths reared on alfalfa in Kansas. We therefore believe that, generally, the sex ratio of green cloverworm populations is 1:1. Mean longevity of the adult stage has been reported as 7.3 days (Hill 1925), 9.0 days (Smith and Franklin 1961), and 7.9–11.1 days (Stone and Pedigo 1972b). The Stone and Pedigo report was from moths held in environmental cabinets. Mean adult longevity in our greenhouse colony was usually much greater than any of the foregoing values. From observations of 50 newly emerged adults (25 ♂, 25 ♀) in the greenhouse, we calculated a mean longevity of 22.4±10.5 days, with a range of 3.5–49.5 days. According to sex, the means were: males 20.2±10.3 days, and females 24.6±10.5 days. In a *t*-test, $t = 2.16$, $P < 0.05$, indicating that the 4.4-day difference is significant, and therefore, females lived significantly longer than males under our greenhouse conditions. The reason for shorter lifespans in our environmental cabinets is unknown.

Like other noctuids, most flight and biological activities began at dusk and continued into the night. Observations of flight activity in a screened enclosure showed that evening flight began at ca. 3 ft-c of light and increased 3-fold (15–52 moths flying) at <1 ft-c, during a 10-min period. A battery-operated BL trap in soybean on Aug. 17, 1971, caught adults only between 8:00 PM and 2:00 AM CDT. On a 2-hr collection schedule beginning at 6:00 PM, counts were 0, 9, 7, 3, 0, 0, 0.

Adult activity as measured by light-trap catch has not been commonly reported in the literature. Knutson (1944) collected noctuids from April to Sept. 1938–40 at St. Paul, Minn., with 10 light traps of different colors (5 incandescent, 5 fluorescent). In this study, he recorded moth flights as early as the 1st week of May, with heaviest flights occurring the last 3 weeks of July. Knutson's total catch with light traps was 335 adults; sex ratio 1.3 ♂:1 ♀.

In our 1970 light-trap studies we captured 643 moths, with greatest numbers occurring in July and dropping substantially on Sept. 11 (last moth caught Oct. 9). Numbers collected were erratic, showing no clear generation or seasonal patterns. Unlike Knutson's collections (Knutson 1944), ours were very biased toward males (558 ♂ and 85 ♀). Because natural larval populations showed a 1:1 sex ratio, we believe that it was the BL trap that produced this sexual bias, i.e., BL were much more attractive to males than to females. Because Knutson (Knutson 1944) reported ca. a 1:1 sex ratio from his light traps, further studies, considering design,

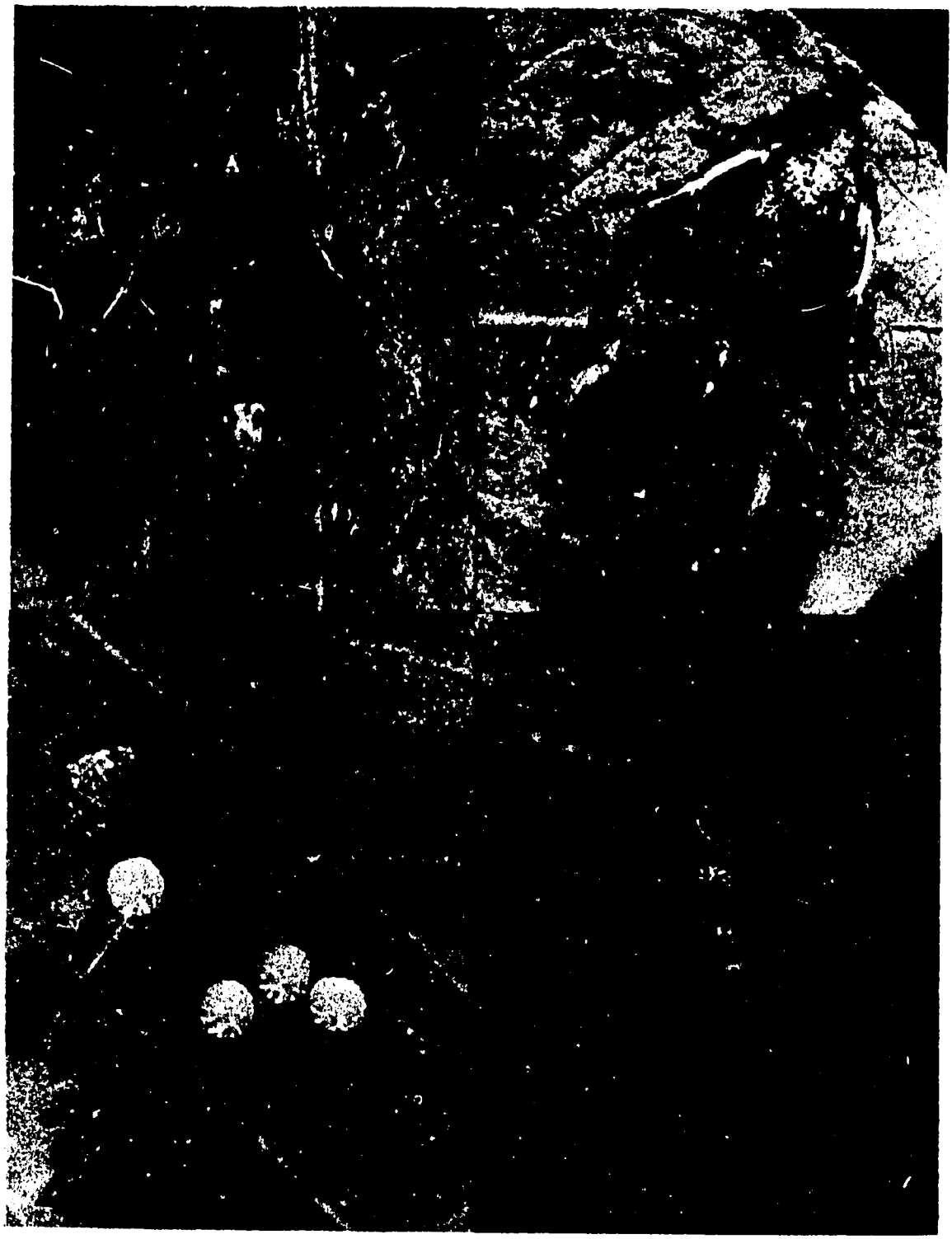

FIG. 2–5.—Green cloverworm. 2, Male; 3, female; 4, eggs newly laid; and 5, eggs 3 days after deposition.

light source, and color, should be conducted to determine light-trap methods of obtaining less biased catches of the sexes.

Adult mating usually occurred after dark, but we observed at least 4 pairs copulating during daylight hours. Copulation of partners occurred with abdominal tips opposed, when the male inserted a bulbous spermatophore into the female bursa copulatrix. In female dissections, 1 spermatophore was most frequently observed, with 2 the maximum.

Table 2. Numbers and percentages of green cloverworms observed in strata of a soybean-plant canopy.

		Stratum (thirds)					
		Lower		Middle		Upper	
Stage[a]	Σ observed	No.	% of Σ	No.	% of Σ	No.	% of Σ
Egg[b]	120	26	21.6	59	49.2	35	29.2
Small larvae	101	35	34.7	44	43.6	22	21.8
Medium larvae	95	25	33.3	24	32.0	26	34.7
Large larvae	41	8	19.5	10	24.4	23	56.1

[a] Larval stages: small, 1+2; medium, 3+4; large, 5+6 (+7, if present).
[b] Observations of 1080 field-collected soybean leaflets; counts include empty chorla.

Oviposition by females usually occurred on upper or lower leaf surfaces and was strongly influenced by leaf pubescence (Pedigo 1971). We counted 1087 eggs from 28 ♀ (reared on soybean) laid on soybean leaves in the greenhouse from July 13 to Aug. 4, 1970. Oviposition began 4–5 days after emergence, continuing for a 2.5-week period. This preoviposition period was much shorter than the 10-day period reported by Smith and Franklin (1961). Peak oviposition occurred 12–16 days after emergence.

The mean number of eggs per female (38.8) in our oviposition study seems exceptionally low. From data collected by Hill (1925) and Smith and Franklin (1961) with alfalfa-collected moths, we calculated means of 201.2 and 230.0 eggs/female, respectively. Differences in host plant cannot adequately explain our low mean. In another observation where Stage 1–3 larvae were collected from greenhouse cages with 22 ♀, we counted 2119 larvae, giving a mean realized fertility of 96.3 larvae/female. These discrepancies indicate need for controlled studies of adults reared on soybean to establish a precise potential fecundity.

Egg.—Green cloverworm eggs (Fig. 4, 5) were laid singly, and significantly more were laid on lower leaf surfaces of alfalfa and clover than upper because of greater leaf pubescence on the underside. There was no preference for leaf surface on soybean leaves (Pedigo 1971). Table 2 gives egg stratification in the soybean-plant canopy.

Eggs were translucent green and were ca. 0.5 mm diam, with 14–19 longitudinal ridges extending from the equator to the pole. Stone and Pedigo (1972b) reported a mean egg stadium of 4.8 days, comparing closely with the findings of Hill (1925), Sherman (1920), and Smith and Franklin (1961). About 48 hr before hatching, eggs turned a light brown, and pale orange spots and small dark streaks appeared just under the chorion. At 18 hr before hatching, these spots appeared as very distinct red-to-rust areas (Fig. 5), and at 4 hr before, black larval eyespots were distinct.

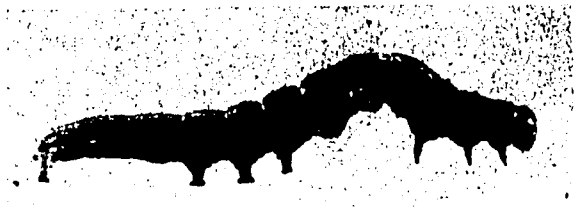

FIG. 6.—Stage-6 green cloverworm larva.

At hatching, the larva began to break the chorion at the midpoint between the apex and base. The larva then chewed a slit ca. 190° of the egg circumference, pushed the top-flap back, and crawled out. The empty chorion was fully formed, transparent, and iridescent. The larva did not eat the chorion.

Eggs were particularly subject to high mortalities by predators (Pedigo et al. 1972b) and probably also by severe summer rainstorms. On July 7, 1971, we placed leaves with 120 eggs in 3 small soybean plots for egg-mortality studies. A wind-rain-hail storm occurred at 2:00 AM CDT July 8, with winds up to 80 mph, 1.5 in. of rain, and some hail. Forty eggs remained on the leaves, giving a mortality of 66.7% caused by the storm.

Larva.—The green cloverworm larva (Fig. 6) is very frequently referred to as a semilooper because it moves in a looping motion as a true looper but possesses 3 pairs of ventral prolegs rather than 1 or 2. The prolegs, dark-green body color, and 3 pairs of longitudinal white stripes were most frequently used for field identification and provided for little confusion with other noctuid species. Hill (1925) gave a very complete larval description by stage.

Most authors (Hill 1925, Smith and Franklin 1961) report that there are 6 larval stages, with 7 occurring occasionally. Stone and Pedigo (1972b) found that 7 stages occurred in 24% of the larvae studied. Table 3 shows the head capsule widths from larvae reared on soybean. These means are slightly smaller (0.005–0.250 mm smaller) than those reported by Hill (1925). Differences were probably caused by the smaller number of larvae measured by Hill. Some overlap of measurement existed between head-capsule widths of different stages, but in most cases these widths can be used for stage identification.

Table 3.—Head-capsule widths (mm) of green cloverworm larvae reared on soybean leaflets.

Stage	No. larvae measured	Max	Min	Mean±SD
1	28	0.283	0.133	0.226±.040
2	30	.430	.320	.352±.024
3	43	.700	.480	.570±.060
4	39	1.000	.660	.886±.090
5	44	1.500	.700	1.242±.180
6	40	2.000	1.350	1.690±.196
7	10	2.300	1.730	1.879±.104

Stone and Pedigo (1972b) tabulated stadial lengths of 3 groups of larvae. Mean stadia were 19.9, 19.0, and 18.0 days with soybean-fed larvae. These stadia were ca. 3–5 days shorter than that of Hill (1925) and ca. 1.5–2.5 days shorter than that of Smith and Franklin (1961) with larvae reared on alfalfa.

Ecdysis of the green cloverworm has not been described previously in the literature. In our observations of several molting larvae, we found that the process began when the larva spun a silken web for attachment with the crochets. After attachment, a 2-hr sluggish period began, with the larva emptying the gut, causing the body to turn pale green. When the gut was cleared, the larva pulled its head into the exuvial thorax (in ca. 2 hr), causing the prothoracic segment to bulge. The larva remained quiescent in this position for 10–15 hr (longest 35 hr), during which time the only observable change was darkening of the new mandibles.

To shed the old cuticle, the larva forced a gathering of the cuticula immediately in front of the ventral prolegs. Continued pulsations and contortions caused a split in the dorsal thorax. This split allowed the larva to exit with the old head capsule still attached. In 10 min, the larva was free, and the old head capsule had been removed. Following a short period of inactivity, a 1-hr period of thoracic leg flexure and another 30-min period of quiescence occurred. The 1st activity of the newly molted larva was consumption of the exuvium (except the head capsule), then it began feeding on leaf tissue. Total time required for the molting process was usually 16–21 hr.

Larvae fed mainly on leaf tissue between the main veins of soybean leaflets, and this behavior compared closely with descriptions of feeding on alfalfa (Hill 1925). Infrequently we observed larvae feeding on soybean pods, flowers, cotyledons, and stems but only under conditions of stress, viz., after all available leaf tissue was eaten and then only after several hours of starvation.

Feeding behavior differed between young and older larvae. We have observed that all stages were more frequently found on the lower leaflet surface, but only younger larvae, stages 1–3, fed and hung on silken threads beneath the leaflets. Because of this hanging, younger larvae were the more difficult to dislodge from the plant. Usually, Stages 1 and 2 ate all but the upper leaf epidermis giving a parchmentlike appearance to areas of feeding. Older larvae ate completely through the leaflet. In feeding trials under mean Iowa July conditions, green cloverworm larvae had a mean consumption of 16.31 in^2. of soybean leaf tissue, with over 90% consumed during Stages 5–7 (Stone and Pedigo 1972b). This soybean consumption was much greater than the alfalfa consumption (3.78 in^2.) measured by Hill (1925).

Larval behavior was greatly antisocial, with larvae being antagonistic to one another. Upon coming in contact with one another, larvae flipped violently, sometimes falling onto other leaves or completely off the plant. This behavior served as a mechanism of dispersal to other feeding sites on the plant and also as a means of escape from insect predators.

When taking in situ counts of larvae on soybean plants, we found all ages of larvae throughout the canopy, but large larvae were observed much more frequently in the upper ⅓ than in the middle or lower ⅓ (Table 2). χ^2 was used as a test of independence between plant stratum and larval age (as indicated by size). The null hypothesis was that the proportions of larvae in each age class are the same for the 3 plant strata. A table of expected values, when compared with the observed values, gave a χ^2 of 16.37, and $P_{\chi^2} < 0.01$, indicating that plant stratum occupied was not independent of age structure. Further χ^2 tests were run between small and medium-sized larvae, where $\chi^2 = 4.10$, and $P_{\chi^2} > 0.05$, showing no dependence on plant stratum. Data from these groups were subsequently combined and compared with data on large larvae, resulting in a χ^2 of 12.56, and $P_{\chi^2} < 0.01$. These statistics therefore show that, in general, Stages 1–4 have no preference for plant stratum but that large larvae are found most frequently on the upper ⅓ of the plant.

Larval mortality by both biotic and abiotic factors has been reported in the literature. Pedigo et al. (1972b) found that substantial mortality of small larvae in soybean is caused by the predators *Nabis* sp. and *Orius insidiosus* (Say). Parasitism by tachinid flies, *Winthemia* sp. and others, and braconid wasps, *Rogas nolophanae* Ashmead and others, totaled 30.5% in 1971 near Ames (Lentz and Pedigo 1972), with *R. nolophanae* parasitism being greatest. In our observations, a granulosis virus, *Beauvaria bassiana* Balsamo, and a *Metarrhizium* sp. have been the primary pathogens of larvae, with *B. bassiana* an important factor in the collapse of outbreak populations in 1968. High soil temperatures can also cause larval mortality when larvae fall to the soil surface. Smith (1956) found in Kansas that Stage-4 larvae died in ca. 0.5–2.5 min. when dropped on a soil surface of 55–56°C (ambient temp 38–40°C) and that usually the soil in hot, dry weather is hot enough to kill active larvae in a short time.

Prepupa and Pupa.—When preparing to enter the prepupal stage, the larva cleared the gut as in typical larval ecdysis, but usually produced 2–3 fecal pellets

FIG. 7.—Green cloverworm prepupa (left) and pupa (right).

that ranged from orange to gold (before this time they were green) in a drop of amber fluid. The composition of the fluid and cause of discoloration of the pellets is unknown and has not been reported. In our studies, the presence of these pellets was used as an indication of larvae entering the prepupal stage.

After clearing the gut, the prepupa spun a loose web and shortened the body, assuming a slightly curved position. The prepupal mesothorax was greatly expanded, and the body tapered caudally, with the exuvium on the abdomen becoming wrinkled (Fig. 7). In our observations the mean prepupal stadium was 1.2–1.4 days (Stone and Pedigo 1972b), comparing closely with that of prepupae from alfalfa (Hill 1925, Smith and Franklin 1961).

In alfalfa, Hill (1925) reported that pupation occurs on or just beneath the soil surface and that soil particles and bits of plant material are incorporated into the cocoon. This situation occurs also in soybean, but in addition, we observed pupation in the plant canopy. In the canopy, the prepupa usually webbed a leaflet together and pupated in the fold created by webbing. With 104 adults emerging in a screenhouse, we found that 10.4% had pupated in the plant canopy and about equal numbers were found in the 3 plant strata.

The pupal molt required ca. 10–15 min, beginning with the ecdysal split in the prepupal prothorax. The exuvium was shed with the aid of abdominal undulations, and the newly freed pupa was pale green. Within 10 min of pupal egression, abdominal segments begin to turn brown, and within 1.5 hr the pupa was a unicolorous brown (Fig. 7). Some individuals turned almost black before adult emergence. The mean pupal stadium was 9.1–10.0 days in our observations (Stone and Pedigo 1972b), as compared with 12.1 days (Hill 1925) and 11.0 days (Smith and Franklin 1961) for pupae reared on alfalfa.

Seasonal Phenomena.—A consideration of the phenological observations made in central Iowa between 1968 and 1972 (Table 4) gave a general viewing of seasonal disposition of green cloverworms. Adults were active in May, being ca. 2–6 weeks later than those in Tennessee (Hill 1925) and Kansas (Smith and Franklin 1961). Knutson (1944) collected adults in light traps as early as the 1st week of May in Minnesota. Based on observations of stage 4 larvae in late May, we estimated that early moths began laying eggs in alfalfa ca. May 15, thereby beginning Generation 1 in alfalfa. At this time, few soybeans had emerged. Therefore, oviposition in soybean was generally delayed until the 1st week of June. From the last of June until the middle of September, all stages were present in soybean fields, with age structure being greatly variable because of variability in cutting date in alfalfa fields.

In soybean, the last larvae of the season (usually Stages 5 and 6) were found about the middle of September when leaves began to turn yellow and drop from the plants. Oviposition continued in available alfalfa fields until about the last of September, with small larval numbers (ca. 1/3000 sweeps) present the last week of October. The latest fall activity was noted Nov. 16 (Table 4).

Several authors (Coquillett 1881, Chittenden 1901, Sherman and Leiby 1920, Hill 1925) reported the presence of "well-defined" generations, ranging from 2 to 4/yr. Smith and Franklin (1961) and Dean and Smith (1935) stated that generations were difficult to define, owing to time and frequency of cutting alfalfa. We found the latter situation true in central Iowa, with ill-defined generations in both alfalfa and soybean. The probable cause of ill-defined generations is alfalfa cutting (variation in time and frequency) and a long ovipositional period (ca. 2 weeks) with a relatively long life cycle (ca. 39 days). These factors cause a considerable overlapping of generations (Clark et al. 1967). The consequences of this overlapping are 2-fold: (1) referal to true "generations" is not very meaningful in explaining the seasonal cycle, and (2) conventional techniques of population analysis, viz., life-tables with key-factor analysis, are inapplicable (Varley and Gradwell 1970).

Instead of generations, sensu stricto, we found it more advantageous to consider seasonal cycle in relative-number peaks in selected age groups, with the peaks serving to indicate a prominent generation. Relative numbers were calculated for large larvae (Stages 5+6) in alfalfa and soybean near Ames as:

$$X_i' = \frac{X_i}{\sum_{i=1}^{n} X_i}$$

where X' = relative no. larvae/100 sweeps, X = no. larvae/100 sweeps, i = sample period no., and N = no. sample periods. By plotting these relative numbers with time of sampling (Fig. 8), we were able to detect 3 prominent generations in alfalfa and 1 in soybean. It was interesting to note that the highest peaks in both crops occurred concurrently, additional peaks in alfalfa being allowed by its longer seasonal availability as a host. Although we believe numbers of prominent generations to be stable, time of occurrence could vary as much as 2 weeks or more either earlier or later.

Overwintering of green cloverworms in central Iowa remains an unresolved question. Riley (1880) stated that the adult overwinters over its entire range, and others have reported the species to overwinter as a pupa and adult as far north as Ohio (Balduf 1923) and

Table 4.—Seasonal events of the green cloverworm from observations in central Iowa, 1968–72.

Date	Event	Stage(s) observed	Collection site
May 12, 1970	first spring activity	adult	alfalfa
May 31, 1972	first immature	larva; stages 2–4	alfalfa
June 6, 1970	first immature	larva; stage 3	soybean
Sept. 12, 1968	last immature	larva; stages 5, 6	soybean
Oct. 1, 1971	latest small larva	larva; stage 2	alfalfa
Oct. 26, 1971	last immature[a]	larva; stage 6	alfalfa
Nov. 16, 1969	last fall activity[a,b]	adult	window screen

[a] After 1st hard freeze.
[b] Adult actively flying; collected in evening; daylight temperatures ca. 5–10°C.

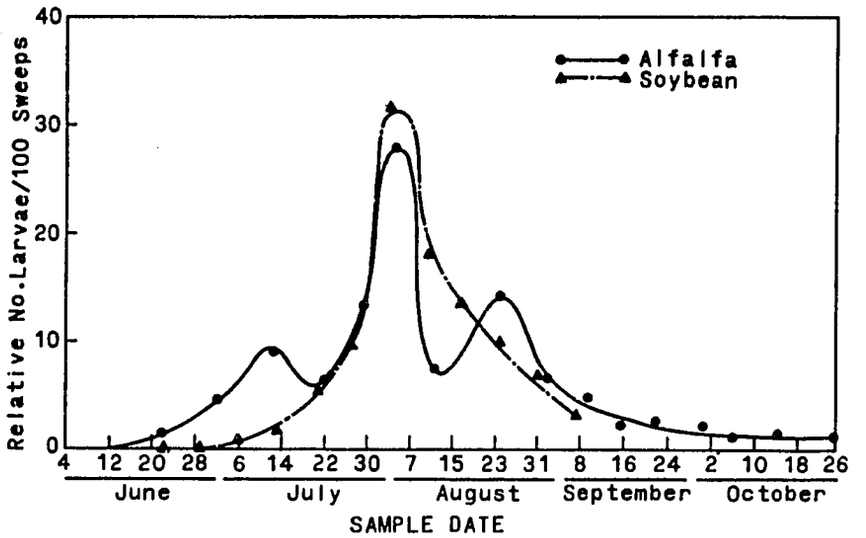

FIG. 8.—Relative number of large larvae per 100 sweeps collected in Iowa alfalfa and soybean fields during 1971.

Pennsylvania (Frost 1955). In 3 Iowa winters (1968–69, 1970–71, and 1971–72) of holding adults in outdoor cages supplied with soybean litter, none has survived. Likewise, pupae held in small plastic boxes and placed in litter did not survive the winter of 1970–71. Laboratory investigations of pupae and adults in environmental cabinets are presently being conducted to define lower lethal temperatures and to determine overwintering potentials.

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Mites on Soybeans: Moisture and Temperature Relations[1]

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ABSTRACT

Computer analysis of population data for mites, predominantly *Tetranychus turkestani* Ugarov & Nikolski, in 8 soybean fields during a 7-year period showed a significant correlation with both rainfall and maximum temperature. Rainfall accounted for 51.3% and average maximum temperature for 25.3% of the population variation. Climatological conditions during August appeared to be the most important. Correlation of rainfall totals with mite population for each of the months June through September indicated that August rainfall was most influential. Moreover, of the monthly average maximum temperatures, only those of August were significantly related to peaks of mite abundance. Measurement of soybean leaf temperatures for 2 weeks with electrical monitoring equipment showed that *T. turkestani* lives under temperature conditions that can fluctuate widely within short periods.

In recent years there has been a great increase in acreage of soybeans planted in Delaware. Soybeans are now one of Delaware's major agricultural crops, and we are concerned with improving yields. One of the factors contributing to low yields is injury caused by spider mites. Baker and Connell (1961) reported that the strawberry spider mite, *T. turkestani* Ugarov & Nikolski, constitutes 95% of such mites on this crop in Delaware.

Many soybean growers believe that mites are more likely to be injurious during dry summers rather than when rainfall is abundant. In an earlier study insufficient evidence was uncovered to support this belief (Baker and Connell 1961). We now have accumulated sufficient data to allow further consideration. Logically, the moisture conditions having the greatest influence are those in the actual habitat of the mites, i.e., the lower surface of the leaf, but this is an elusive factor to measure. Atmospheric moisture and temperature are closely interrelated, and both may be subject to considerable change within variable periods in this microhabitat. Both are influenced by temperature of the surrounding air, as well as by amount of available water in the soil, air currents, type of leaf, angle and intensity of light to which the leaf is exposed, and other factors (Miller and Saunders 1923). Two of these other factors are the exchange of infrared radiation between the leaf and other materials and the amount of water present in the atmosphere (Curtis 1936). Gates et al. (1968) reported that leaf temperature frequently exceeded air temperature by as much as 10°C.

Atmospheric moisture is commonly expressed in terms of relative humidity, the percentage saturation of the air at any given temperature. Cloudsley-Thompson (1962) listed reasons that several of the methods that have been used to measure relative humidity are unsuitable for microenvironments. The most promising method for measurement of moisture in small spaces uses a lithium chloride-coated rhodium or platinum wire. As the relative humidity changes, so does the resistance of the wire, and this can be measured with a galvanometer. However, there are limitations in this method that must be overcome before it can be used under field conditions (Rodgers 1965). At present, therefore, there appears to be no satisfactory method for measuring humidity at exposed leaf surfaces.

The effects of high or low atmospheric moisture on mites in the genus *Tetranychus* have been reported by 3 investigators. The differences in results from one species to another and the contradictory results reported in some instances for a single species indicate that the information on the subject is not sufficient to allow any generalizations to be drawn.

Boudreaux (1958) considered the influence of different moisture conditions on 6 species of *Tetranychus* in relation to fecundity, as well as to longevity, of adult females. Of the species studied, *T. telarius* (L.), *T. urticae* Koch, *T. yusti* McGregor, and *T. desertorum* Banks produced more eggs and lived longer in the drier (0–35% RH) than in the wetter (95–100% RH) atmosphere. The opposite was found for *T. gloveri* Banks and *T. tumidus* Banks, which produced more eggs and lived longer in the wetter atmosphere.

Nickel (1960) reported observations that supported Boudreaux's findings with *T. urticae* and *T. desertorum*, except that in the case of *T. desertorum* the wetter environment favored longer life. The moisture conditions used by Nickel (1960), dry (25–30% RH) and wet (85–90% RH), are thought to be not sufficiently different from Boudreaux's to be of importance. The temperature range, 15–36°C, was also close to Boudreaux's 10–35°C range.

Nickel also reported on developmental rate and percentage survival of immatures. He found that, in the case of *T. desertorum*, in the moist as compared with the dry environment, the mites reached the adult stage more rapidly, but a greater percentage died before reaching adulthood. The opposite was the case

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Table 1.—Peak populations of *T. turkestani* on 10 leaves in 8 Delaware soybean fields sampled weekly in the years 1961 through 1967. The numbers in parentheses indicate the periods during which the peaks were observed.[a]

Year	Newark	Middle-town	Dover	Milford	Lewes	Selby-ville	George-town	Bridge-ville
1961	131 (11)	431 (10)	46 (6)	3510 (7)	79 (11)	174 (8)	177 (9)	49 (7)
1962	256 (5)	1073 (12)	2868 (7)	3 (5)	401 (10)	2153 (10)	142 (11)	378 (12)
1963	64 (11)	9810 (11)	22508 (10)	610 (7)	111 (6)	805 (6)	99 (10)	3914 (7)
1964	17 (8)	201 (9)	2636 (10)	3657 (9)	3525 (9)	250 (9)	12 (2)	4500 (9)
1965	0	266 (6)	6400 (8)	500 (9)	4 (6)	19 (12)	40 (5)	23 (6)
1966	51 (1)	82 (7)	7754 (10)	21626 (7)	593 (9)	397 (9)	556 (8)	309 (7)
1967	1 (3)	7 (11)	0	0	26 (11)	4 (6)	57 (4)	1 (11)

[a] (1) July 1–7; (2) July 8–13; (3) July 14–20; (4) July 21–27; (5) July 28–Aug. 3; (6) Aug. 4–10; (7) Aug. 11–17; (8) Aug. 18–24; (9) Aug. 25–31; (10) Sept. 1–7; (11) Sept. 8–14; (12) Sept. 15–21.

for *T. urticae*. The low-moisture conditions resulted in earlier maturity and a higher death rate of immatures of this species. McEnroe (1963), on the other hand, reported that in his experiments *T. urticae* reached maturity earlier at the higher (80%) as compared with the lower (15%) RH.

Rainfall is another important form of environmental moisture. Some of the factors which influence its local character are topography, wind, light, temperature, vegetation, soil surface, and soil moisture (Mech 1965). Linke (1953) reported that the beating force of rainfall on plant leaves does not entirely explain the decrease in numbers of *Tetranychus altheae* Hanstein on hops in Germany during rainy periods. In his experiments, rainfall was simulated by immersing infested leaves in water for 2–4 hr daily. However, such a technique seemingly does not simulate characteristics of rainfall that would cause dislodgement from impact.

Rainfall and Mite Infestations

To obtain data relevant to precipitation and mite populations, leaves were collected from 8 soybean fields, each of which was situated within 1 mile of a United States Weather Service station. Proximity to such a weather station permitted use of the data from this agency's Climatological Records for Maryland and Delaware. Over a 7-year period (1961–67) from the last week of June until mid-October, 2 leaflets were collected each week from each of 5 randomly selected rows within the 1st 50 rows from the field margin. The leaves were placed in polyethlene bags and brought to the laboratory, where mites on them were counted with a steremicroscope. The peak infestation recorded for each field each year, i.e., the greatest number of mites per 10 leaflets on any one of the 12 sampling dates, was used as an index of infestation severity for that year. These values were tested for correlation with average maximum temperature, average minimum temperature, and total rainfall for June, July, August, and September of each corresponding year with the aid of an IBM 1620 computer using a universal function program. We rarely found this mite on soybeans during June, but we were interested in June weather conditions, since they could influence the size of populations migrating to this crop from other hosts.

The data were organized also in another manner. The results of the weekly surveys were divided into 4 groups according to the number of mites found, and these values were compared with the precipitation for the week immediately preceding the sampling. The groupings used were 1–50 mites, 51–300, 301–1000, and 1001–infinity. Weeks during which no mites were found were not included, since, in such a case, the presence or absence of rainfall could have no influence.

We are aware that many factors may influence populations of *T. turkestani* on this crop. A few of these are variety, plant vigor, plant nutrition, proximity of other hosts, predation, and disease. In this paper we are attempting only an analysis of the influence of rainfall and temperature.

Table 1 lists the periods each year in which the greatest numbers of mites were observed at each location, together with the total present at those times on a 10-leaf sample. These peak values were used in the rainfall and temperature correlation, the results of which appear in Table 2. The values in the F column of Table 2 indicate whether the independent variable did or did not have a significant effect on the dependent variable (peak mite populations). The R^2 value, when multiplied by 100, indicates the percentage of the variability in the dependent variable that is accounted for by the independent variable. Total rainfall plus average maximum temperature gave the best correlation with mite abundance. This means that the combined effect of rainfall and maximum temperature for each summer accounted for 58.1% of the variation in the peaks of mite abundance. Under natural conditions there are many variables that affect any animal population. These 2 factors accounted for more than half the variation, so we have an indication that these are important limiting factors.

Both total rainfall and combined average maximum temperature had significant effects on the variation, but rainfall was the more influential, accounting for 51.3% of the variation; the combined average maximum temperature accounted for only 25.3%.

The correlation of the different monthly rainfall totals with population indicated that August rainfall was most influential, followed closely by July, and not so closely by September. Of the average

Table 2. – Results of summer temperature and precipitation regression with peak mite populations for Delaware during the years 1961–67, inclusive.

Independent variable	df	Value of F for significance at .05 level	F for data	R^2 for data
Avg max June temp	1/49	4.04	0.12	0.003
Avg max July temp	1/49	4.04	1.59	.031
Avg max August temp	1/49	4.04	13.53[a]	.216
Avg max Sept. temp	1/49	4.04	.13	.003
Avg min June temp	1/49	4.04	10.32[a]	.174
Avg min July temp	1/49	4.04	.04	.001
Avg min August temp	1/49	4.04	1.25	.025
Avg min Sept. temp	1/49	4.04	1.20	.024
Total June rainfall	1/49	4.04	.00	.000
Total July rainfall	1/49	4.04	22.86[a]	.318
Total August rainfall	1/49	4.04	30.04[a]	.380
Total Sept. rainfall	1/49	4.04	4.22[a]	.079
Combined avg max temp	4/46	2.58	3.87[a]	.253
Total rainfall	4/46	2.58	12.12[a]	.513
Total rainfall & avg max temp	8/42	2.17	7.26[a]	.581

[a] Significant correlation with peak mite populations.

monthly maximum temperatures, only those of August were significantly related to peaks of mite abundance.

Of the 53 infestations recorded, more than half the peak populations occurred during August. It appears from this evidence that August climatological conditions are key factors in limiting densities of *T. turkestani* populations.

The only other independent variable which was significantly related to mite population peaks was average minimum June temperature. This may affect population increase by influencing the metabolic rate of individuals, and consequently such normal activities as reproduction and dispersal.

Table 3 lists the results of the grouping analysis. The periods of the low infestations were preceded by a substantial amount of rainfall, while the more severe infestations were preceded by less-than-normal rainfall.

The combination of the results just presented indicates that rainfall does have an adverse effect on *T. turkestani* populations and that the effect is amplified by high temperature. Three possible mechanisms are suggested through which these factors may produce this result: (1) the force of the rain could beat mites from the leaves, and/or hinder their dispersal (Linke 1953); (2) the rainfall may promote conditions of high relative humidity, which retard the metabolic processes of the mites (Boudreaux 1958); (3) the high relative humidity may provide optimal conditions for the spread and growth of fungal parasites of the mite (Selhime and Muma 1966).

Table 3.–Mean amount of rainfall in inches which occurred the week preceding mite population surveys from 1961 to 1967 inclusive.

Range of mites per sample	Rainfall during preceding 7 days (in.)
1–50	0.799
51–300	.619
301–1000	.477
1001–Infinity	.324

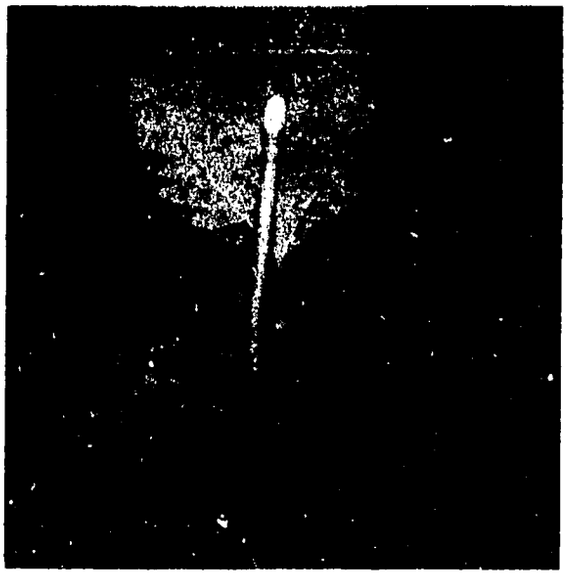

FIG. 1.—Probe fastened in position in contact with surface of underside of a leaf.

Leaf Surface Temperatures

To obtain data concerning the leaf-surface temperatures at certain levels in a soybean plant, a YSI Model 37 Telethermometer was operated with a YSI Dual Channel Recorder in a soybean field at Georgetown, Del., Sept. 13–24, 1967. The sensing elements were YSI 401 general-purpose probes, and these were attached to leaf surfaces in the following manner. A piece of 20-gauge wire was looped around the probe, approximately ⅛-in. from the sensing tip, then the ends of the wire were pushed through the leaf tissue on each side of the midrib and flattened against the leaf surface (Fig. 1). This attachment held the probe against the lower leaf surface at all times and was not thought to influence the measurements. The recording equipment was housed in a weather shelter, situated at the edge of the field. One probe was placed in this shelter at a position of 18 in. above the ground. Probes on plants were placed on the underside of leaves at the top and middle of a healthy uninfested soybean plant, as well as on the upper surface of a leaf at the top of such a plant. Also, 1 probe was placed on the underside of a leaf in the middle of a plant heavily infested with *T. turkestani*.

The shelter housing the recorder was situated approximately 20 yd from the United States Weather

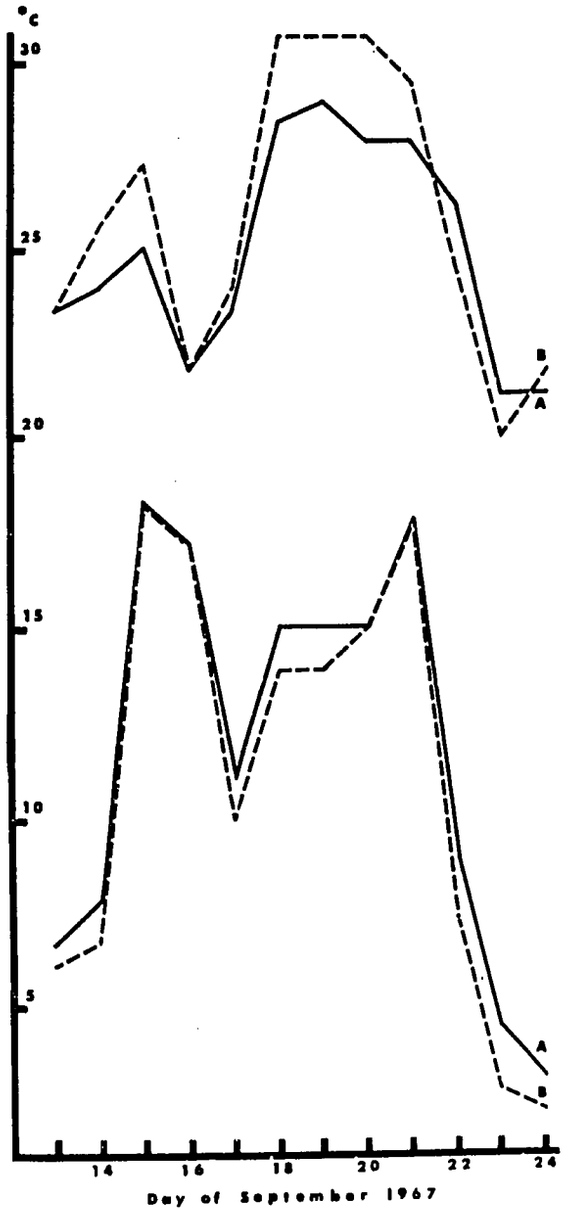

FIG. 2.—Maximum-minimum temperatures for a 2-week period at Georgetown, Del., at elevation above ground of (A) 48 in. (U. S. Weather Service instruments) and (B) 18 in. (recording telethermometer at margin of soybean field).

Service station at Georgetown, which includes a maximum-minimum thermometer placed 4 ft above ground. The recorded values from this instrument were used as a macroenvironmental check for the microclimatic measurements.

Fig. 2 and 3 show the maximum and minimum temperatures of this 12-day observation period in September 1967. Fig. 2 compares data from the sheltered probe with that from the United States Weather Service thermometer. For this period, the probe 18 in. above ground recorded maximum temperatures which were slightly higher and minimum temperatures that were slightly lower than those recorded at the 4-ft level. This probably resulted from the greater effect of soil radiation on the

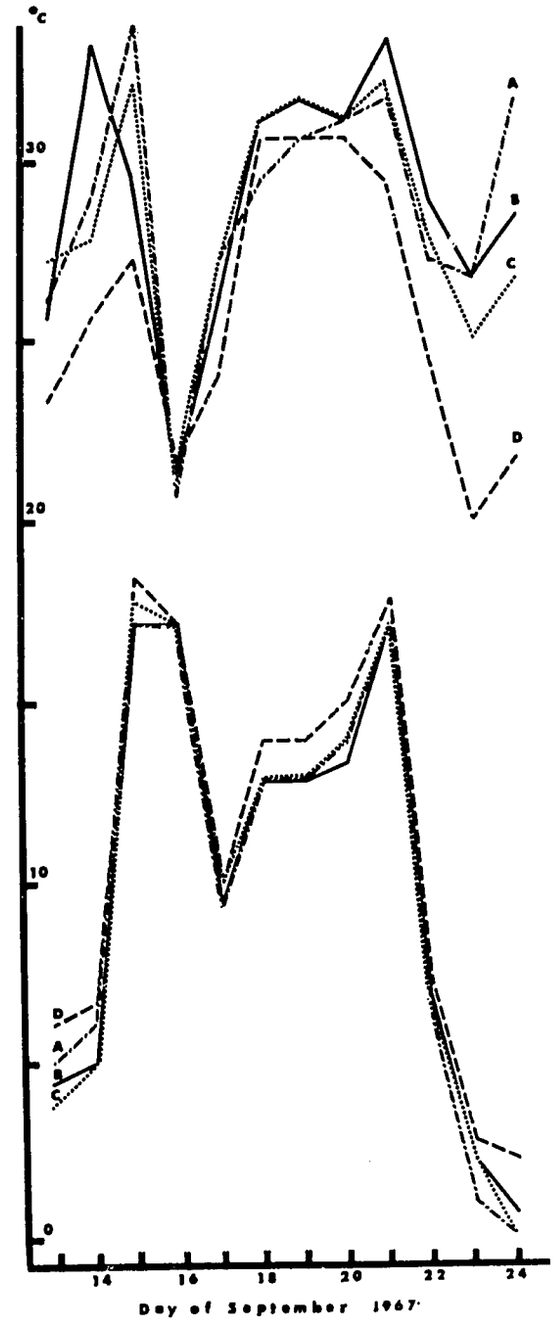

FIG. 3.—Comparison between maximum-minimum temperatures of under surface of leaves of mite-infested and uninfested soybean plants, with probes, (A) at middle of healthy plant, (B) at top of healthy plant, (C) at middle of mite-infested plant, (D) 18 in. above ground in weather shelter.

instrument in the lower position, as described by Geiger (1957), and differences at the 2 levels in day and night air currents parallel to the ground.

Fig. 3 presents the maximum-minimum values for leaf surface temperatures at 2 locations on a healthy soybean plant and one location on an infested plant in comparison with similar values for the sheltered probe. The sheltered probe is presumed to provide reference values for air temperatures in the field throughout the period. The results indicate that the daily temperatures of leaf surfaces are more extreme than those of the surrounding air. Daily leaf temperature maxima were usually, but not always, above those of air temperature. On one day this elevation was as much as 7°C above air temperature. Daily leaf temperature minima were usually slightly below air temperature minima, the greatest difference measured being 2.2°C.

Miller and Saunders (1923) reported differences in leaf temperatures of up to 5°C between turgid and wilted leaves in direct sunlight. It was thought that heavy infestations of *T. turkestani* may have removed enough fluids from the leaf tissue to cause wilting and as a consequence to lead to increased leaf surface temperatures as described by Miller and Saunders. Lines A and C in Fig. 3 are plots of maximum and minimum temperatures for 2 comparable leaf surfaces, one (A) on an uninfested plant and the other (C) on a heavily infested plant. Except for the last 2 days the differences between these values are slight, suggesting that the infested leaf was not hindered in its temperature-regulation processes by the heavy infestation of *T. turkestani*.

The data from continuous monitoring of leaf-surface temperatures deserve some comment. It has been pointed out that 5 sensing probes were used with 1 recorder. The recorder registered the temperature at each probe in turn for 5 min each half hour. In addition to showing the temperatures of the leaf surfaces being monitored, the recorder tape showed changes occurring during the 5-min periods that the instrument was recording for a particular surface. As might be expected, these changes were rather gradual at night, but during the day they ranged from gradual to quite pronounced. For example, on Sept. 16, with rain throughout the day, all leaf surface temperatures were close together with little change during any recording period and a maximal deviation from air temperature of 1.2°C. In contrast, on Sept. 23, with bright sunshine and occasional clouds, there were frequent and noticeable fluctuations. Air temperature changed as much as 3.9°C, leaf under-surface temperature 8.4°C, and leaf upper-surface temperature at the top of the plant an astonishing 16.2°C during one 5-min recording period.

From this information it may be concluded that *T. turkestani*, and presumably other phytophagous mites, live under temperature conditions which can vary widely within short periods. Also, it is apparent that their environment attains higher maximum and lower minimum temperatures than those of the surrounding air. Because temperature and relative humidity are interacting factors (Ludwig 1945), the quite variable microenvironmental temperatures may be responsible for relative humidity conditions with a greatly adverse impact on *T. turkestani* populations, and this feature deserves further study.

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Part 3

EFFECTS OF ARTHROPOD FEEDING AND PLANT RESISTANCE

Effects of Tarnished Plant Bug[1] Feeding on Soybean[2]

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ABSTRACT

Studies were made to determine the effect of *Lygus lineolaris* (Palisot de Beauvois) feeding on buds, blossoms, and pods of soybean by confining adult insects to the fruiting structures of the soybean plant. Adult feeding for 24 hours caused some deleterious effects on all fruiting structures. When 2 and 4 insects per node were allowed to feed for 2 weeks on buds or blossoms, the number of pods per node, the number of seeds per pod, and the weight per seed were reduced significantly.

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is a pest on a variety of crops (Taksdal 1963), but damage to soybeans by this insect has not been recorded in any detail in the literature. Blickenstaff and Huggans (1962) reported that essentially no damage was done to soybeans by the tarnished plant bug in a controlled experiment using 10 insects/plant.

Several surveys of insect populations on soybeans in the Midwest have consistently shown a high population of tarnished plant bugs on soybeans (Balduf 1923, Probst and Everly 1957, Kretzschmar 1948,

[1] Hemiptera: Miridae.

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FIG. 1.—Confining cage in position on soybean stem.

Blickenstaff and Huggans 1962). Studies in Illinois indicated that the number of tarnished plant bugs begins to increase at the time of soybean budding and blooming, and the population of adult bugs reaches a peak when the young pods are about ¼–½ in. long (Broersma 1968[8]). This study was undertaken to evaluate some of the effects of the tarnished plant bug on soybeans, as this insect is present in large numbers during flowering and pod and seed development.

MATERIALS AND METHODS.—Adult tarnished plant bugs used in these tests were collected from an alfalfa field on the Illinois Agricultural Experiment Station farms, Urbana. The test insects were starved for 24 hr prior to being caged over soybeans. Mature adults were used in all experiments. Small plastic cages were used to confine the bugs on the fruiting structures of the soybeans at various stages of pod development. The cages, measuring 1×1¾×2½ in. and 1×2½×3½ in. were made of a lightweight plastic. A pair of holes was made to allow the cages to fit around the soybean stem. Another pair of holes covered with a fine mesh allowed circulation of air to prevent the buildup of condensation. A 5th hole was used to insert the insects. A leaf had to be removed to enable the cages to be fitted properly around the node. The cages were held in place on the plant by a thin piece of foam rubber ½ in. wide and 6 in. long which was wrapped around the stem of the plant at the points of contact with the cage. Fig. 1 illustrates a cage in position on the plant. Zero, 1, 2, and 4 insects were confined per cage. As a comparison, 3 conditions were used to determine the effect of the cage and the removal of a leaf, namely, a cage with no insects, no cage with the leaf removed, and no cage with leaf intact.

The cages were placed on the fruiting structures of 'Wayne' variety soybeans at 4 stages of development—bud, blossom, developing pod, and filling pod. Insects were caged on the bud with petals not yet visible on July 17. Adults were caged on blossoms on July 23, when the blossoms had not yet begun to shed their petals. Developing pods, ½ in. or shorter, were caged and infested with adults Aug. 7. The filling pods had the seed positions visible in the pods when the insects were caged Aug. 21.

Tarnished plant bugs which had been starved for 24 hr were confined on the fruiting structures for 24 hr in 1 test and for 2 weeks in another. Caged insects were replaced with fresh insects on day 6 and day 10. Damage by the tarnished plant bugs was assessed 2 weeks after they were introduced and periodically thereafter until harvest. The number of seeds per pod, the number of pods per cage, and

[8] Unpublished annual report.

Table 1.—Effect of tarnished plant bug feeding on soybean buds.[a]

	Length of feeding period[b]					
	24 hr			2 weeks		
Insects/ cage	No. pods/ node	Avg seeds/ pods	Avg weight/ seed (g)	No. pods/ node	Avg seeds/ pods	Avg weight/ seed (g)
4	0.8	1.2	0.13	0.2 a	1.0	0.07
2	2.2 a	2.1 a	.12	.5 ab	1.9 a	.14
1	2.0 a	2.0 a	.12	.9 b	1.9 a	.10
0	2.0 a	2.2 a	.14	2.1 c	2.0 a	.11
(No cage)	2.4 a	2.3 a	.13	1.9 c	2.3 a	.13

[a] Data taken at harvest Sept. 25.
[b] Means followed by the same letter are not significantly different.

Table 2.—Effect of tarnished plant bug feeding on blossoms.[a]

	Length of feeding period[b]						
	24 hr				2 weeks		
Insects/ cage	No. pods/ node[c]	No. pods/ node	No. seeds/ pod	Avg weight/ seed (g)	No. pods/ node	No. seeds/ pod	Avg weight/ seed (g)
4	1.8	2.0	2	0.14	0.7 a	1.5 a	0.13
2	2.2 a	1.2	2	.13	.9 ab	1.8 a	.13
1	2.8 a	2.4	2.1	.11	1.1 b	1.9 a	.11
0	3.2 a	2.2	2	.12	2.0 c	2.5 b	.13
(No cage)	3.2 a	2.4	2.7	.14	2.5 c	2.5 b	.14

[a] Data taken at harvest Sept. 25 unless otherwise stated.
[b] Any 2 means followed by same letter are not significantly different.
[c] Observations made Aug. 6, two weeks following the 24-hr confinement.

Table 3.—Effect of tarnished plant bug feeding on developing pods.[a]

Insects/cage	Length of feeding period[b]					
	24 hrs			2 weeks		
	No. pods/ node	No. seeds/ pod	Avg weight/ seed (g)	No. pods/ node	No. seeds/ pod	Avg weight/ seed (g)
4	2 a	1.7 a	0.15	1.1 a	1.3	0.13 a
2	2.6 a	1.5 a	.15	0.9 a	1.6 a	.10
1	2.6 a	1.8 a	.14	1.3 a	1.7 a	.12 a
0	2.6 a	2.1 b	.15	3.0 b	2.6 b	.15 b
(No cage—leaf removed)	3.2	2.2 b	.17	2.9 b	2.4 b	.16 b
(No cage—leaf not removed)	2.8 a	2.6 b	.17	3.2 b	2.6 b	.15 b

[a] Data taken at harvest Sept. 25, 1968.
[b] Any 2 means followed by same letter are not significantly different.

the average weight of the seeds were used as criteria to assess damage. In tests on the developing pod stage the nodes were checked for the number of pods per node and the number of seeds per pod prior to the introduction of insects, rechecked 2 weeks later, and terminally at harvest. The data were compared by analysis of variance and Duncan's new multiple range test.

Results and Discussion.—When 4 plant bugs/cage were allowed to feed on the buds for 24 hr, the number of pods per cage (or node) and the number of seeds per pod were significantly reduced when compared with the other treatments (Table 1). The weight per seed was not affected at any of the treatment levels. After 2 weeks of feeding (Table 1) all treatments having tarnished plant bugs significantly reduced the number of pods per node. However, only the treatment with 4 insects/cage reduced the number of seeds per pod enough to be significant. This reduction is not surprising, as the major part of pod development took place after the insects were removed from the cages. The differences in average weight per seed were not significant, but the seeds were noticeably smaller in the cage containing 4 plant bugs.

When tarnished plant bugs were placed in cages with blooming soybeans for 24 hr, data collected at harvest indicated that none of the criteria for determining effects of feeding were significant (Table 2). However, the number of pods per node was significantly reduced with 4 insects/cage when counts were made of these same cages 2 weeks following the 24-hr confinement. Apparently secondary buds could mature and produce pods to replace those destroyed earlier.

In the tests where plant bugs were confined to blossoms for 2 weeks, the number of pods per node and the number of seeds per pod were significantly reduced at all levels of infestation (Table 2). The weight per seed was not affected.

Tarnished plant bugs confined on developing pods for 24 hr had a significant effect on the number of pods per node and also on the number of seeds per pod. The number of pods per node was significantly reduced (Table 3) only where 4 bugs were present per cage. However, the number of seeds per pod was reduced at levels of 1, 2, and 4 tarnished plant bugs/cage. Insect infestations of 1, 2, and 4/cage confined for 2 weeks significantly reduced the number of pods, the number of seeds per pod, and the average weight per seed.

Filling pods were adversely affected by 24 hr of feeding. The number of seeds per pod and the average weight per seed were reduced. The number of pods per node appeared to be affected, although not significantly. Adverse effects were produced at all levels of infestation in the 2-week feeding tests (Table 4).

The amount of damage caused by the tarnished plant bug to the fruiting structure of the soybean plant varied with the stage of development of the plant. The number of pods per node was reduced

Table 4.—Effect of tarnished plant bug feeding on filling pods.[a]

Insects/cage	Length of feeding period[b]							
	24 hr				2 weeks			
	No. pods reduced/ node	No. seeds reduced/ node	Avg weight/ seed (g)	% normal seed	No. pods reduced/ node	No. seeds reduced/ node	Avg weight/ seed (g)	% normal seed
4	0.6	0.48 a	0.11 a	38	0.64	0.59 a	0.11 a	52
2	.2	.54 a	.13 ab	39	.43 a	.61 a	.12 a	56 a
1	.4	.45 a	.14 bc	65	.43 a	.31 b	.12 a	62 a
0	.2	.17 b	.15 c	74	.36 a	.33 b	.14 b	82 a
(No cage—leaf removed)	0	.22 b	.15 c	[illegible]	.36 a	.43 b	.15 bc	59 a
(No cage—leaf not removed)							.16 c	66 a

[a] Data taken at harvest Sept. 25, 1968.
[b] Any 2 means followed by same letter are not significantly different.

more by feeding damage to buds and blossoms than to pods. For example, when 4 tarnished plant bugs were allowed to feed on buds for 24 hr the number of pods per node was reduced by 1.6 pods, whereas feeding on the filling pods caused a reduction of 0.6 pods. The number of seeds per pod and the average weight per seed were more drastically affected by feeding in the pod stages than in the bud and blossom stages. If the fruiting structure was not seriously damaged by the plant bugs, secondary growth and pod development could take place. In addition, when some of the soybean pods or seeds are destroyed, other pods tend to increase in size. As maturity of the plant increases, the ability to account for lost pods or seed decreases. According to Johnston (1968), the lower ⅓ of the soybean plant tends to have fewer pods per node as well as fewer seeds per pod than the center ⅓ of the plant. Thus the differences in the number of pods per cage, the number of seeds per pod, and the average weight per seed between the control cages can be explained on the basis of where the cages were placed on the plant. The cages for the buds and blossoms were placed on the lower ⅓ of the plant, while developing pods and filling pods were caged near the center of the plant.

Although all aspects of the economic importance of the tarnished plant bug have not been established, these data show that this insect can be a contributing factor in reducing yields of soybean seed.

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Some Effects of Soybean Pubescence on Populations of the Potato Leafhopper[1,2]

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ABSTRACT

Populations of *Empoasca fabae* (Harris) were compared on soybean varieties having different types and amounts of pubescence. The orientation of the hairs was more important in resistance to the leafhopper than the number of hairs. Glabrous strains of soybeans were damaged by leafhoppers more than other strains. Fewer pods were aborted, and the glabrous strains had a significant increase in yield, number of pods per node, pods per main stem, and weight per 100 seeds when the leafhoppers were controlled with an insecticide.

The potato leafhopper, *Empoasca fabae* (Harris), is one of the most abundant insects found on soybeans in mid-western United States (Balduf 1923, Blickenstaff and Huggans 1962, Kretzschmar 1948). The potential of this insect as a threat to soybeans has been often overlooked. Occasionally, when the leafhopper population surpasses the economic threshold on commercial plantings, chemical control is necessary. Soybean researchers in north-central United States have experienced difficulty with growing glabrous strains of soybeans because of leafhopper attack. This study compares the relationship of pubescence in soybeans with the numbers of potato leafhoppers present on the plants, and the effects of the leafhoppers on plant growth and seed yield.

Potato leafhopper damage to soybean leaves is similar to that described for potato by Ball and Fenton (1920) as tip burn or browning and curling of the leaf margin, and stunting. Smith and Poos (1931) found that the potato leafhopper fed by puncturing the phloem, causing tissue distortion and plugging of the xylem tubes in the midribs and stems, interfering with translocation within the plant. They reported that the degree of pubescence of soybeans was a primary factor in soybean resistance to the potato leafhopper. They stated also that the amount of pubescence was proportional to the number of nymphs which developed to adults on the host plants. The inheritance of pubescence type in soybeans was recently illustrated and described (Bernard and Singh 1969).

The potato leafhopper is sensitive to weather conditions. When rainfall is adequate or high (3–4 in./month) the population increases as the summer progresses (DeLong 1938). However, if the same area experiences about a week of dry weather and high temperatures, the population will be reduced dramatically. Decker and Cunningham (1967) pointed out that low as well as high temperatures will greatly reduce populations. They stated also that high humidity can reduce the effect of the high temperatures, but when the temperatures are near 32°C mortality is high and rapid in spite of humidity.

The maturity and condition of plants at the time of egg laying and nymphal feeding may influence the frequency and intensity of the potato leafhopper infestation. For example, it was noted that females oviposited much more extensively in young peanut plants than they did in older, more mature plants of the same size and vigor (Poos and Wheeler 1943).

Methods and Materials.—Two groups of near-isogenic strains of soybeans with different types of monogenically controlled pubescence were developed by backcrossing to the commercial varieties 'Clark' and 'Wayne.' These 2 varieties and the BC_5 strains listed in Table 1 were planted May 19, 1967, and June 4, 1968, on the Agronomy Farm near Urbana, Ill., in a randomized block design with 4 rows/plot. Ten trifoliate leaves from each of 2 rows/plot were examined biweekly in 1967 and weekly in 1968 for leafhopper nymphs, beginning the last week of June and continuing through the 3rd week of August. The plots were observed also for effects of leafhopper feeding and oviposition on the various types of plants. At maturity, the center 2 rows were harvested for yield of seed.

In 1968 the study was expanded to include the effects of the leafhopper on plant development and seed yield. To accomplish this, 1 row of each plot was sprayed on July 17, 1968, with dimethoate at a rate of ½ lb AI/acre. The 'Harosoy' variety was flowering, but Clark had not yet begun to flower. Beginning on July 24, 1968, counts were made of the pods dropped and the leafhopper nymphs/10 trifoliate leaves along ° linear feet of row selected at random from a sprayed and an unsprayed row from each plot. (A buffer row was situated between the sprayed and unsprayed rows.) These areas were prepared for easy detection of dropped blossoms or pods by raking and smoothing an area of 1 ft on either side of the row at the examination site. Counts were made and recorded July 24, 30, Aug. 8, and 22.

At harvest the treated and untreated plants of Harosoy and 2 related glabrous and curly pubescent strains were compared for the numbers of pods per node, nodes per main stem, branches per plant, and the average weight per 100 seeds and the average yield.

Results and Discussion.—The glabrous strains in both Harosoy and Clark genetic backgrounds showed visible effects of leafhopper infestation early in the growing season (Fig. 1). In 1967, for example, adverse effects could be detected in the seedling stage. The strains with curly pubescence soon developed significantly higher numbers of leafhoppers than the glabrous strains, but visual effects were not apparent until about midseason. The strains with curly pubescence averaged 16 more nymphs/10 trifoliate leaves than did the glabrous strains during the period of peak leafhopper populations in both 1967 and 1968.

[1] Homoptera: Cicadellidae.

[2] Cooperative investigation of Economic Entomology, Illinois Natural History Survey, and Agricultural Entomology, Ill. Agr. Exp. Sta.; and the Crops Research Division, Agr. Res. Serv., USDA, Urbana, Ill. 61801. Publication no. 661 of the U.S. Regional Soybean Laboratory. Received for publication Dec. 8, 1970.

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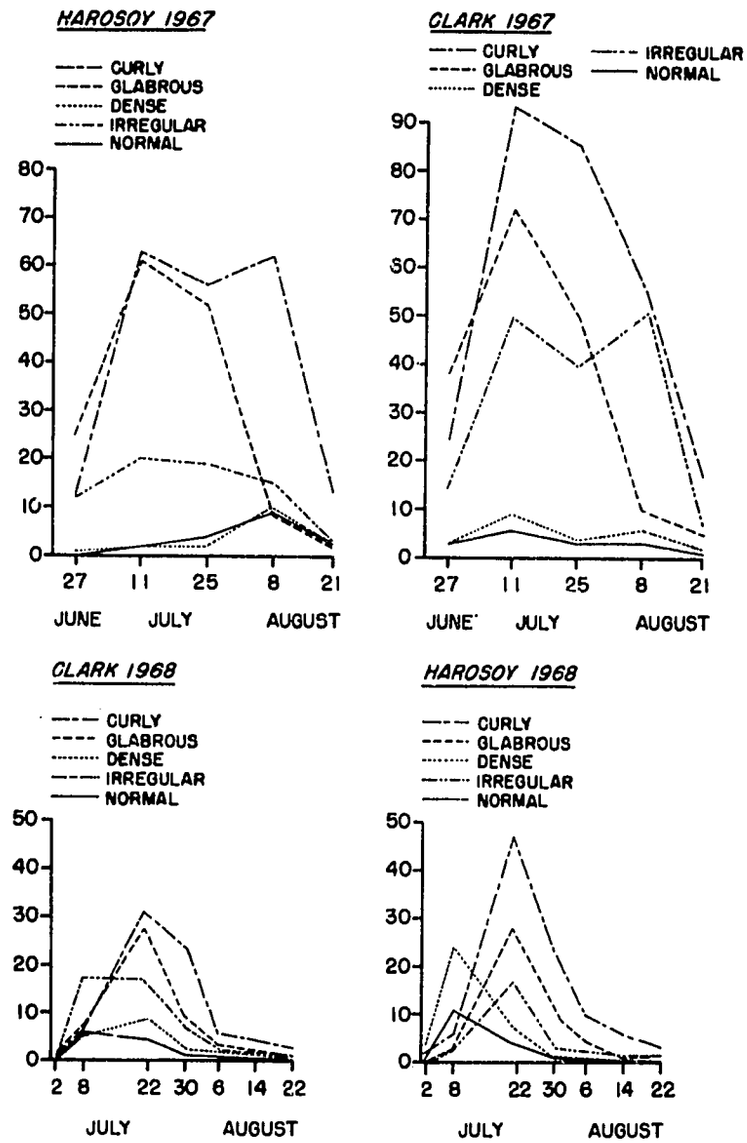

FIG. 1.—Potato leafhopper populations during the 1967 and 1968 growing seasons as found on Harosoy and Clark soybeans and related strains.

Both the curly pubescent and the glabrous strains had populations significantly in excess of the normal Harosoy and Clark (Table 1).

The dense pubescent strain (31.0 hairs/mm² for Harosoy and 29.7 for Clark) was hypothesized to have very low populations because of the density of hairs. However, the 1968 leafhopper population on this strain was significantly higher than on the normal strain which had considerably fewer hairs (8.1 hairs/mm² for Harosoy and 6.1 for Clark) (Table 1). The irregular pubescent strains possessed approximately the same number of hairs as the normal strains but had hair orientation intermediate between curly and normal. Its leafhopper populations were significantly greater than those on the normal strains. The slightly dense pubescent Clark strain also had populations significantly greater than normal Clark during the 1968 season. It was not included in the 1967 test.

The leafhopper populations on nearly all strains reached their peak earlier in 1967 than in 1968. In 1967 populations peaked July 11 and Aug. 7, while in 1968 they peaked about July 22 (Fig. 1). There are several factors which could tend to account for this difference. Differences in planting date for the 2 years may have had some influence, but weather conditions and the cutting of an adjacent field of alfalfa in 1967 had a more pronounced effect. Rainfall in June 1967 was light with only 1.55 in. reported for the month. In contrast, June 1968 was very wet, with nearly 7 in. of rain and no direct influence of adjacent fields of alfalfa being harvested. Even though the leafhopper population developed later in 1968 than in 1967, it diminished

Table 1.—Number of *E. fabae* recorded and average yields for soybeans with different types of pubescence during the 1967 and 1968 seasons.

Soybean strain	Pubescence type	No. hairs/ mm[a, a]	1967 Avg no. leafhoppers/ 10 trifoliate leaves[b]	1967 Avg yield bu/acre	1968 Avg no. leafhoppers/ 10 trifoliate leaves[b]	1968 Avg yield bu/acre
Harosoy and related BC_5 strains						
L63-1097	curly	7.9 (1)	44.1	29.8	13.0	36.6
L62-561	glabrous	0	31.2	8.8	6.9 d	10.2
L65-132	irregular	(2)	13.5 a	43.6	5.6 cd	47.1
L62-801	dense	31.0	3.6 a	47.4	5.7 cd	48.0
Harosoy	normal	8.1	2.8 a	47.7	3.4 ab	51.4
L62-880	sparse	2.6	9.5 a	44.9	2.7 a	48.8
L65-60	slightly dense	(3)			2.4 a	49.4
Clark and related BC_5 strains						
L63-2435	curly	5.8 (1)	61.8	26.0	11.0	43.6
L62-1385	glabrous	0	36.4 b	12.1	7.1 e	37.9
L65-187	irregular	(2)	31.8 b	32.3	6.7 e	46.0
L65-89	slightly dense	(3)			3.9 bcd	42.8
L62-1686	dense	29.7	4.4 a	29.4	3.2 bcd	45.8
L63-2999	sparse	1.7	7.4 a	33.7	2.6 abc	46.2
L65-90	slightly dense	(3)			2.3 abc	43.1
Clark	normal	6.1	3.3 a	33.2	0.5 a	43.5

[a] (1) Orientation of hair lying down; (2) no. hairs near normal orientation similar to curly; (3) combination of dense and sparse; data from Singh et al. (1971).
[b] Any 2 means followed by same letters are not significantly different. Duncan's multiple range test, 1%*P*.

earlier in 1968 in spite of the fact that the soybeans were still attractive, having been planted later.

As a result of this early reduction in the 1968 population, the late-maturing glabrous Clark isoline was able to regain much vigor previously lost because of feeding of the leafhoppers. This is very evident in the yield data (Table 1). In 1967, the average yield for the Clark glabrous strain was 12.1 bu/acre, while in 1968 it was 37.9 bu/acre. The earlier-maturing Harosoy glabrous strain was in the blooming stage when the leafhopper populations peaked in 1968 and it was able to recover only slightly from the damage. It therefore yielded poorly in both years. This same pattern held true for the curly pubescent strains, which yielded well below the normal varieties except for the curly pubescent Clark isoline in 1968, which yielded as high as Clark.

The drier soil and air conditions as well as higher leafhopper populations undoubtedly contributed to lower yields for all strains in 1967.

Leafhopper populations did not decrease as quickly on curly types as they did on the glabrous types. This decrease was probably due to the fact that initially heavy populations severely stunted the

Table 2.—Comparison of dimethoate-treated and untreated soybeans for the average number of pods dropped per 3 linear feet per week and the average number of leafhoppers counted per 10 trifoliate leaves.

Soybean strain	Pubescence type	Avg no. pods dropped/ 3 linear ft per week: Check	Avg no. pods dropped/ 3 linear ft per week: Sprayed	Avg no. leafhoppers/ 10 trifoliate leaves: Check	Avg no. leafhoppers/ 10 trifoliate leaves: Sprayed
Harosoy and related BC_5 strains					
L62-561	glabrous	31*	13	12*	2
L63-1097	curly	26*	16	24*	2
L62-801	dense	16	12	1	2
L62-880	sparse	16	16	4	0
L65-132	irregular	14	13	3	1
L65-60	slightly dense	13	11	3	0
Harosoy	normal	12	9	2	1
Clark and related BC_5 strains					
L62-1385	glabrous	15*	10	16*	1
L63-2435	curly	11*	8	18*	4
L65-89	slightly dense	8	4	3	0
L65-90	slightly dense	8	7	2	0
L65-187	irregular	7	7	7	1
Clark	normal	7	7	3	1
L63-2999	sparse	6	7	4	0
L62-1686	dense	4	4	3	0

Table 3.—Comparison of leafhopper effect on dimethoate-treated and untreated plants of Harosoy soybeans and 2 related strains.

Pubescence type	Avg yield (bu/acre)		No. pods/ node		No. nodes/ main stem		No. branches		Weight/ 100 seeds	
	Check	Treated	Check	Treated	Check	Treated	Check	Treated	Check	Treated
Glabrous	10.2	27.6*	0.9	1.2*	10.6	13.2*	2.1	1.6	13.7	19.2*
Curly	36.6	41.4	1.7	2.4	15.3	14.1	2.1	1.6	21.4	20.7
Normal	50.8	53.3	2.0	2.7	18.9	14.1	2.8	2.1	21.6	22.5

growth of the glabrous plants. The severe hopperburn and senescence of leaves of glabrous plants may have caused the rapid population decrease.

When the leafhopper populations were suppressed with use of dimethoate at 0.5 lb/acre, the number of pods and blossoms aborted was reduced on Harosoy glabrous and curly strains. The effect was noted also in the Clark strains, but to a lesser degree, because the leafhopper populations had diminished before heavy setting of pods. During the 5-week test period the average number of pods dropped in a 3-linear-foot area of Harosoy glabrous soybeans averaged 31/week for the untreated area and 13/week for the treated area. The leafhopper population averaged 12 nymphs/10 trifoliate leaves on the untreated plants and 2 nymphs/10 trifoliate leaves on the treated plants.

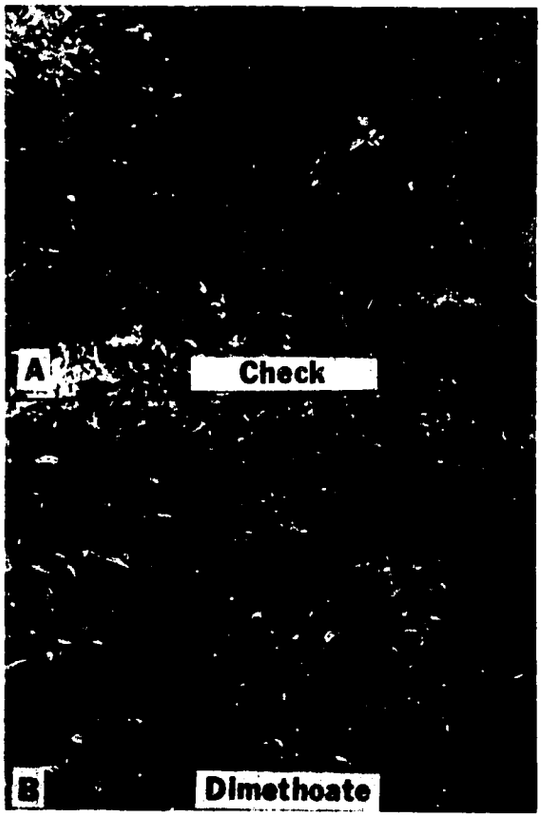

FIG. 2.—Harosoy glabrous soybeans treated (B) with dimethoate attained maturity later than untreated beans (A).

The peak population of leafhoppers occurred July 24, and the greatest numbers of pods and flowers were aborted between Aug. 8 and 22 and later. Therefore loss of pods seemed to be due more to loss of vigor in the plant than to direct feeding or oviposition by the leafhopper.

The populations of leafhoppers on Harosoy and Clark strains other than glabrous and curly were not high enough to increase pod drop noticeably, even when an insecticide was not used (Table 2).

Three isolines of Harosoy were studied carefully throughout harvest for effects of leafhoppers (Table 3). Both the glabrous and curly strains showed signs of leafhopper feeding prior to treatment with dimethoate July 17, 1968. In spite of this fact, the average yield was significantly higher for the treated glabrous (27.6 bu/acre) than for the untreated comparison (10.2 bu/acre). Thus the treated plants were able to regain a considerable amount of their vigor before maturity. The average yields of the treated curly pubescent strain and the treated normal strain were also greater (but not significantly so) than the check of these strains. The treated glabrous strain had a significantly greater number of pods per node and nodes per main stem, and higher weight per 100 seeds than did the check plants. This was not true for the other 2 strains. However, they did show a consistently greater number of pods per node for the treated plants (Table 3). Another notable difference between the treated and untreated glabrous strain was the 1-week earlier maturity and earlier loss of leaves by the untreated plants (Fig. 2).

Leafhopper populations were affected by the pubescence of soybeans. However, the number of hairs did not appear to be the major factor. This is evidenced by the fact that the dense pubescent strains had considerably more hairs per mm^2 than the normal strains (Table 1), yet the leafhopper population was consistently higher on the dense types. Also the curly type had nearly the same number of hairs per mm^2 as the normal, but the hairs were lying down, and the leafhopper population was significantly higher. The glabrous strains with essentially no hairs had fewer leafhoppers than the curly strains, but this was probably due to extreme stunting of the glabrous plants by the early leafhopper attack which reduced the amount of stem and foliage for feeding and may have also reduced palatability as the plants appeared to senesce earlier. Final plant height for example in 1967 was, respectively, 12, 30, and 39 in. for the glabrous, curly pubescent, and normal Harosoy. The earliest leafhopper counts in 1967 showed glabrous plants to have the highest populations. Counts in 1968, however, were begun later and do not show initial population differences, but very early stunting was again observed on gla-

brous. Therefore, there is no evidence from these data that anything other than type of pubescence is responsible for the observed differences in leafhopper resistance. The opposite conclusion of Wolfenbarger and Sleesman (1963) working with similar pubescence types was partly based on their expectation that resistance should be related to concentration of hairs, whereas our experience suggests that orientation and perhaps size and other hair characteristics are significant factors in determining leafhopper resistance.

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Association of the Green Stink Bug[1] and the Yeast-Spot Disease Organism of Soybeans. III. Effect on Soybean Quality[2]

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ABSTRACT

Soybean seeds fed on late in their development by *Acrosternum hilare* (Say) displayed no significant damage to oil and protein content 9 and 18 months after harvest. Damage was not increased significantly in the presence of *Nematospori coryli* Peglion, the yeast-spot disease organism. Bean weight was affected by stink bug feeding alone and in 1 test also in the present of *N. coryli*.

The green stink bug, *Acrosternum hilare* (Say), is potentially a serious pest of soybeans in Kansas and elsewhere. Damage initially received attention when the United States began exporting large quantities of soybeans, and buyers for export began basing their prices on "no more than 2% damage." That damage included discolored, and commonly sunken, spots on the beans caused by stink bugs inserting their mouthparts through the soybean pods to feed.

Much controversy resulted in the soybean trade at first, because so little was known about the problem. Some buyers avoided storing stink bug-damaged soybeans, for fear that storing would increase detectable damage; many farmers thought the damage was of little importance.

Miner (1966) demonstrated that stink bug feeding had relatively little effect on soybean oil and protein content. Blickenstaff and Huggans (1962) reported that, under cage conditions, stink bug infestations decreased yield by decreasing the number of seeds harvested and increasing the percentage of small seeds and that the percentage of discolored and moldy seeds increased 10-fold during storage.

The relative significance became more complicated when Daugherty (1967) showed that a yeast, *Nematospora coryli* Peglion, transmitted by the green stink bug and other pentatomids to soybeans, presumably caused the type of damage attributed to stink bug feeding. In studying the biological relationship of *N. coryli* and the green stink bug, we (Clarke and Wilde 1970a, b) determined that once infested with *N. coryli*, adult stink bugs remain infested for their lifetime and transmit the organism in about 60% of their feedings; 23% of our field-collected adults were infested with *N. coryli*. Neither Miner (1966) nor Blickenstaff and Huggans (1962) studied the possible

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Table 1.—Analysis of soybeans 9 and 18 months after being fed on by green stink bugs.

	No. of replicates	Avg no. beans/ replicate	Avg no. stink bug punctures/ bean	Avg wt of beans[a] (g)	% protein[a]	% oil[a]
		Stored 9 months				
Beans fed on by infested stink bugs	5	6.8	3.4	0.1118 a	39.08 a	22.24 a
Beans fed on by noninfested stink bugs	5	7.4	3.6	.1154 a	37.30 a	21.28 a
Check	5	7.2	0.0	.1553 b	37.38 a	23.04 a
		Stored 18 months				
Beans fed on by infested stink bugs	6	6.2	2.9	.1064 a	38.43 a	21.32 a
Beans fed on by noninfested stink bugs	6	6.8	2.7	.1331 b	39.18 a	21.52 a
Check	6	6.5	.0	.1515 c	37.92 a	22.18 a

[a] Data with the same letter were not significantly different at the 5% level.

interaction of pathogenic organisms, but Miner suggested that such organisms, if present, presumably could alter or add to stink bug feeding damage.

MATERIALS AND METHODS.—'Clark 63' soybeans were planted May 16, 1968, at the Kansas State University Agronomy Farm, Manhattan. Adult green stink bugs from a laboratory culture were infested by allowing them to feed on a *N. coryli* suspension that we have described previously (Clarke and Wilde 1970a).

Treatments consisted of soybean pods exposed for 2 days to (1) bugs infested with *N. coryli,* (2) bugs not infested, and (3) no bugs. Bugs were caged singly on individual pods, and pods exposed to no bugs also were caged. Cages were transparent plastic boxes (11×5×5 cm) with 2 windows (ca. 3×10 cm) covered with Saran® screen on each side.

For each treatment, 21 pods were each exposed during Aug. 24–30 when they were ¾ to almost fully developed. These were arranged by 2 levels on the plant and 3 periods of exposure into 6 replicates of 3 or 4 pods each.

The 2 plant levels or caging sites were 71 and 94 cm above ground. Three cages/treatment were at the lower level and 4 at the upper level.

A duplicate set of pods was exposed during the same period on another group of plants with another group of bugs. The plants were not caged before or after being exposed to the green stink bugs, as there were no stink bugs or other pod feeders present in the area. Set A was stored 9 months and Set B for 18 months at room temperature (65–75°F). After storage, the USDA Regional Soybean Laboratory, Urbana, Ill., analyzed the beans for protein and oil content. One replicate of Set A did not contain enough damaged beans for analysis.

RESULTS AND DISCUSSION.—Table 1 summarizes the evaluations of Sets A and B. For Set A, analysis of variance of data on weight, percent protein, and percent oil showed significant differences only for weight of the beans not fed on by stink bugs; *N. coryli* apparently did not add to feeding damage. However, in the set B test the *N. coryli*-infected beans were significantly lower in weight than were beans fed on by stink bugs alone. Undamaged beans had slightly higher oil and slightly less protein than had damaged beans. The beans did not deteriorate or go "out of condition" in storage.

We cannot be positive that all beans became infected with *N. coryli.* However, because we (Clarke and Wilde 1970b) previously showed that bugs transmit the organism in about 60% of their feedings, and because each bean in this study was punctured about 3.4 (Set A) and 2.9 (Set B) times, we can assume that most, if not all, beans fed on by infested bugs became infected. The low levels of oil loss and the slight changes in protein content could be explained by the fact that even in damaged beans, only a relatively small amount of tissue generally is injured.

Seemingly when soybean seeds are fed on late in their development by green stink bugs, oil and protein content are not damaged significantly, and seeds do not deteriorate or go out of condition in storage; bean weight, however, is somewhat affected. In this study, the presence of *N. coryli* did not significantly increase damage to oil and protein content caused by stink bug feeding. In one case the organism's presence did affect the weight of soybeans.

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An Evaluation of Damage to Soybeans by Brown and Green Stink Bugs[1]

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ABSTRACT

Cages each containing from 1 to 4 pairs of brown stink bugs, *Euschistus servus* (Say), infesting 6 soybean plants were used to evaluate feeding damage. As the rate of infestation increased, the number of undeveloped beans produced in the middle third of the plant increased. A significant difference between the numbers of undeveloped beans in damaged and undamaged soybean pods was noted. Damaged beans were significantly smaller than undamaged beans. Oil content of damaged beans was an average of 7.0% less than that in undamaged beans. Oi content decreased and protein content increased as dam age increased. Germination was reduced in proportion tı the number of stink bug punctures per bean.

Additional tests were conducted with the green stink bug, *Acrosternum hilare* (Say), as the principal pest feeding on 5 varieties of soybeans planted on 4 different dates. The longer the period from bloom to maturation for a given variety the more severe the feeding damage became.

In Missouri and other soybean-producing States, considerable interest has been expressed in evaluating damage caused by feeding of certain species of pentatomids on soybeans. The oldest report of such damage to crops, according to Underhill (1934), was recorded in 1855. Injury to lima beans was first recorded in Virginia in 1889.

At least 4 species of stink bugs damage soybeans in Missouri, but the green stink bug, *Acrosternum hilare* (Say), and the brown stink bug, *Euschistus servus* (Say), are the 2 most important. Soybeans are not the preferred host of these insects, which appear to migrate to soybeans after their wild hosts become unattractive or cease to sustain them. Underhill (1934) showed that a succession of fruiting hosts is necessary for development of the young pentatomids and that the first eggs are deposited on elderberry, black locust, honey locust, wild cherry, redbud, dogwood, box elder, and maples. He indicated that the preferred cultivated hosts are lima beans, snap beans, and peach fruits.

Increased damage by stink bugs to soybeans in recent years has stimulated research on these insects. Miner (1961) published preliminary data showing the effect of damage principally by the southern green stink bug, *Nezara viridula* (L.), on oil and protein content of soybeans grown in Arkansas. Blickenstaff and Huggans (1962), at Columbia, Mo., conducted a preliminary evaluation of green and brown stink bug damage in relation to the time of attack. Cage and laboratory tests revealed that the green stink bugs decreased yield about 20%, increased by 3-fold the percentage of small beans, and increased by 10-fold the percentage of discolored and moldy beans after storage. Tests conducted by Blickenstaff and Huggans (1962) in 1960 showed that an infestation of *Euschistus* spp. as low as 1 bug per plant produced characteristic seed damage and reduced yield. They further demonstrated that damage from these stink bugs decreased progressively as the soybean plants matured.

Investigations were conducted with the brown and green stink bugs at Columbia, Mo., during the summer of 1961 to: (1) examine the density of infestation necessary to produce economic damage, (2) evaluate the effect of damage on soybean oil and protein content, and (3) obtain information on the effect of damage on soybean germination.

MATERIALS AND METHODS.—*Experiment I.*—On June 12, 28 rows of Clark soybeans were planted on the entomology farm at Columbia. On August 8, 18×18×42-in. plastic-screened cages were placed in every other row of beans, with 15–20 ft of row between cages. The cages, imbedded in the ground, enclosed plants thinned to 6 per cage. So that any stink bugs present within the cages could be eliminated before treatments were begun, on August 15 plots were given an application of mevinphos (Phosdrin®) at the rate of ¼ lb/100 gal of water. Mevinphos was used because its toxicity diminishes very rapidly.

The day after mevinphos was applied, brown stink bugs were caged at 4 levels: 1, 2, 3, and 4 pairs per cage. Treatments and check cages containing no stink bugs were randomized and replicated 4 times. At this time the soybeans were in bloom and small pods had developed on their lower portions.

The cages were left undisturbed until October 12, 1961, when they were opened and all insects removed and counted, since some reproduction had occurred. On November 8 the cages were removed and the plants pulled for examination in the laboratory. Each plant was divided into thirds and the beans were picked and shelled by hand. Ovules about ½ in. in

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diameter that were arrested in development and dry and parchmentlike were considered undeveloped seeds. These were separated from the more developed forms.

Soybeans from the cage experiments were used for a determination of oil and protein content and viability of damaged beans. Since soybeans may be punctured by stink bugs once or several times, depending on severity of infestation, movement of nymphs and adult bugs, and maturity of beans, damaged beans were examined for the actual numbers of feeding punctures. For this examination, the yields of beans from the 6 plants in each cage were pooled. Each yield of beans thus obtained was graded into 7 categories, according to the number of feeding punctures; namely, 0, 1, 2, 4, 6, 8, and 10 or more. From each of the categories with 1 puncture or more, a 15-g sample was selected and sent to the Grain Division, Agricultural Marketing Service, at Beltsville, Md., for chemical analysis of protein, fat, and fat acidity content.

Damaged beans were separated into 100-bean portions each containing 1, 2, 4, and 8 or more punctures and tested for germination, under standard seed germinating conditions, at the Field Crops Laboratory of the University of Missouri. Undamaged beans from the same cages were also tested for germination.

Experiment II.—Data used in the evaluation of stink bug damage to the commercial soybean varieties, Chippewa, Harosoy, Shelby, Clark, and Scott, with respect to oil, protein, and planting date were secured from an experiment designed by the Field Crops Department of the University of Missouri. This experiment was made to measure the effect of various planting dates on seed quality. Each variety and planting date was replicated 4 times and plots consisted of single 5-ft rows.

During the middle of July an infestation of stink bugs developed in the above planting and examination showed it was composed almost exclusively of the green stink bug. Both adults and nymphs were present in large numbers and considerable damage to the seed was expected. No attempt was made to control the pests, although chemical control measures had been planned. Arrangements were made with the agronomists to secure replicated samples from all plots at harvesttime. Varieties were harvested at their individual maturity dates and dried. Approximately 100 g of the harvested beans was taken from each replication and examined for stink bug damage.

Replicated samples of damaged beans from the 5 varieties were sent to the Agricultural Chemistry Laboratory, University of Missouri, for oil and protein analysis.

RESULTS AND DISCUSSION.—*Experiment I.*—Damage occurred first on the lower pods of the plant and progressed upward as the season progressed. When compared with the check, the numbers of undeveloped beans present in cages infested with different numbers of stink bugs was highly significant (Table 1). The effect of increasing abundance of stink bugs on the numbers of undeveloped beans was most pronounced in the middle third of the plants. This relationship is also shown in Table 1. Data from the entire plants and from the middle third were each subjected to an analysis of variance in conjunction with Duncan's multiple range test.

Considerable compensation for stink bug damage was observed in the plants, particularly in growth and

Table 1.—Average number of undeveloped beans at harvest in 4 replications of 6 soybean plants caged and infested with brown stink bugs.

Number of stink bug pairs	Average number of undeveloped beans[a]	Standard error of the means
	Entire plants	
0 (Check)	68.00 a	± 5.25
1	122.50 b	±10.58
2	134.00 b	±16.24
3	146.00 b	±15.40
4	151.25 b	± 9.23
	Middle third of plants	
0 (Check)	17.00 c	± 2.12
1	36.75 d	± 2.56
2	42.50 e	± 8.97
3	44.75 e	± 8.83
4	51.75 f	± 1.82

[a] For each set of data, values followed by the same letter are not significantly different at the 5% level.

delayed maturity. Test plants produced nearly the same number of beans as control plants. The average number of bean pods produced in the entire plant was not significantly different from that of the control at any level of infestation. However, at the higher rates of infestation (3 or 4 pairs of stink bugs per cage), plant maturity was delayed and pods continued to develop on the upper part of the plant after the time when such growth usually ended.

The delay in maturity in cages with 3 and 4 pairs of stink bugs was striking because plants at these infestation levels remained green and grew actively well beyond maturity of soybeans in the adjacent field and within the other cages. These delayed plants continued to grow actively until killed by the first severe frost.

Farmers frequently delay the combining of soybeans because of the so-called "duddy" condition of a few plants which remain green and have not matured at harvesttime. This condition has never been linked with the attack of insects. It is reasonable, however, that such a relationship exists. If this duddy condition is related to stink bug damage, it may be either a response of the plant to mechanical injury or to the feeding juices of the insect.

Correlation and regression coefficients were calculated to determine the relationship between the number of damaged beans and the number of adult stink bugs in the cages at harvesttime. Some reproduction had occurred within the infested cages. The correlation coefficient (r) between numbers of damaged beans and numbers of insects present, with 3 degrees of freedom, was 0.957, significant at the 5% level. The regression coefficient (b) indicated that each stink bug damaged about 5.36 beans per cage.

The chemical analyses of soybeans having different numbers of brown stink bug feeding punctures per bean revealed that oil content was reduced as the number of feeding punctures increased. A corresponding increase in protein content of damaged beans was noted. The samples were analyzed also for fat acidity. Fat acidity is defined as the number of milligrams of potassium hydroxide necessary to neutralize the free fatty acids in 100 g of dry grain. Results of these analyses showed that although fat acidity did not increase in proportion to the number of punctures per bean, a marked difference could be de-

Table 2.—Oil and protein content (moisture free) and fat acidity at harvest of caged soybeans damaged by the brown stink bug in relation to number of feeding punctures per bean in 15-g samples.

Number of punctures per bean	Oil (%)	Protein (%)	Fat acidity (mg KOH)
0	19.6	41.5	17
1	18.7	43.2	26
2	17.8	43.6	28
4	17.7	43.9	26
6	16.5	45.3	26
8	16.5	45.4	29
10 or more	15.6	46.7	25

tected between sound and damaged soybeans. Data for these analyses are given in Table 2.

Fat acidity increases when micro-organisms act on the bean fat, causing it to split into fatty acids and glycerine. Fat acidity continues to change after harvest and during storage increases more rapidly in damaged than in sound beans. Extracted or pressed soybean oil with a high free fatty acid content has less economic value than that with a low free fatty acid content.

Germination tests conducted by the Field Crops Department of the University of Missouri showed that impairment of germination was related to the number of stink bug punctures per bean. The germination of brown stink bug damaged soybeans in relation to the number of feeding punctures per bean is given in the following tabulation:

No. of punctures per bean	Germination (%)
0	98
1	93
2	91
4	81
8 or more	37

Observations indicated that germination was apparently reduced by the introduction of certain unidentified organisms which prevented germination.

Experiment II.—An evaluation of green stink bug damage with respect to time of planting in the 5 varieties of commercial soybeans showed pronounced evidence of lessened injury in later plantings of the individual varieties. When planting dates and amounts of injury were correlated, irrespective of varieties, the percentage of damage was seen to be a function of maturity or growth stage. The longer the period from blooming to maturation of varieties within each planting date, the greater the damage from stink bugs. The average number of days from blooming to maturity for each variety and planting date is shown in Table 3. Instead of exhibiting a resistance to insects, the faster maturing plants probably escaped much of the damage simply because of the shorter period they were available for feeding. Table 4 illustrates the relationship between damage and time of planting.

Table 3.—Average duration in days of the period from blooming to maturity of 4 replicates of soybeans in each of 5 varieties planted on 4 different dates.

Planting date	Variety					Avg days each date
	Chippewa	Haro-soy	Shelby	Clark	Scott	
April 19	77	80	86	92	97	86
May 24	65	71	73	75	79	73
May 31	61	66	63	67	75	66
June 19	56	57	60	66	67	61
Average days each variety	65	69	71	75	80	

Table 4.—Average damage (%) of beans punctured at harvest by green stink bugs in replicates of soybeans in 5 varieties planted on 4 different dates.

Planting date	Variety					Avg damage each date
	Chippewa	Haro-soy	Clark	Shelby	Scott	
April 19	42.98	37.53	36.83	36.82	60.83	43.00
May 24	7.39	16.52	28.58	21.86	44.10	23.67
May 31	5.84	13.08	19.29	17.12	26.66	16.40
June 19	1.43	2.94	10.27	9.80	17.84	8.45
Avg. damage each variety	14.41	17.52	23.74	21.40	37.35	

Chemical analyses of oil content of damaged soybeans from the 5 commercial varieties revealed that all 5 contained less oil when compared with undamaged beans (Fig. 1). Examination of damaged beans from the earliest planting on April 19, irrespective of variety, showed that their oil content averaged 18.50% as compared with 20.06% in undamaged beans. Damaged beans in this planting thus averaged 7.9% less oil than undamaged beans. Difference in oil content was not so great between damaged and undamaged beans in later plantings. The average reductions in oil content of damaged beans, irrespective of variety, planted May 24, May 31, and June 19 were 7.8, 5.5, and 6.9%, respectively. When data for all planting dates were combined, average reduction for all 5 varieties was 7.0%. Howell and Cartter (1953 and 1958) showed that the oil content of soybeans was greatly affected by temperature. Some of the reduction in oil content of stink bug damaged beans might have been the result of delayed maturity, which could have caused less oil to accumulate in the beans, since

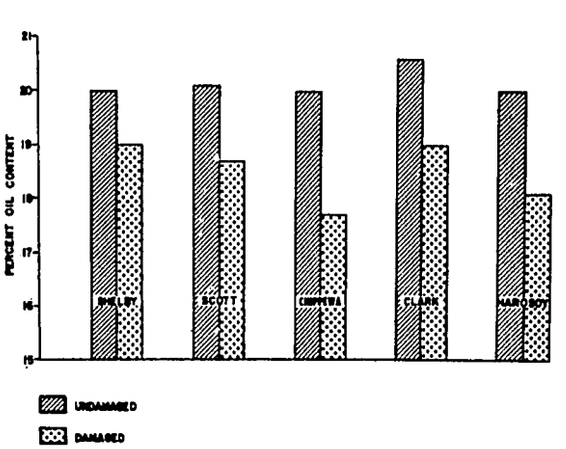

FIG. 1.—Comparison of oil content of soybeans damaged by green stink bugs and undamaged soybeans from 5 varieties planted April 19, 1962.

Table 5.—Increase of average protein content of 5-g samples of 4 replications of green stink bug damaged soybeans compared with similar samples of undamaged soybeans.

Variety		Planting date			
		April 19	May 24	May 31	June 19
Shelby	Undamaged	39.19	37.75	37.44	39.75
	Damaged	40.44	38.06	38.19	39.94
Scott	Undamaged	36.81	37.63	36.75	36.56
	Damaged	37.44	37.81	37.00	36.63
Chippewa	Undamaged	41.75	39.38	37.94	39.31
	Damaged	43.44	40.06	38.63	—
Clark	Undamaged	38.06	36.56	38.44	40.31
	Damaged	38.88	38.63	39.00	41.06
Harosoy	Undamaged	41.38	39.44	39.75	39.37
	Damaged	42.38	39.94	40.25	—
Average % protein increase		2.67	1.93	1.92	.38

they matured later in the season and, thus, at cooler temperatures. Compared with that of undamaged soybeans, the protein content of damaged beans increased for each variety and planting date (Table 5). Although Miner (1961) also found this increase in protein content, he attached no particular significance to it because of the small number of determinations.

The increase in protein content shown by the analyses led to an examination of the relative size of damaged and undamaged soybeans. By weighing and counting samples of damaged and undamaged soybeans, the number per 100 g was calculated for each replication. Student's t-test applied to differences in the number of damaged and undamaged beans per 100 g revealed a highly significant decrease in size of damaged beans, as summarized in Table 6.

Stink bug damage may reduce oil content in soybeans by affecting development and producing a smaller bean with a somewhat lower oil content. The average size of all soybeans decreased slightly at later planting dates. Damaged beans in later plantings were, however, smaller than undamaged beans.

Table 6.—Numbers of green stink bug damaged and sound soybeans harvested per 100 g in 5 varieties and 4 plantings.

Variety	First planting		Second planting	
	Sound	Damaged	Sound	Damaged
Chippewa	665	731	668	775
Harosoy	627	693	649	738
Clark	654	716	675	857
Shelby	608	651	662	739
Scott	781	864	736	885
Avg. number each planting	667	731	678	799
	Third planting		**Fourth planting**	
Variety	Sound	Damaged	Sound	Damaged
Chippewa	735	850	776	789
Harosoy	680	742	667	740
Clark	667	740	740	801
Shelby	689	740	737	799
Scott	748	800	784	876
Avg number each planting	704	774	741	801

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INTAKE AND UTILIZATION OF NATURAL DIETS BY THE MEXICAN BEAN BEETLE, *EPILACHNA VARIVESTIS*---A MULTIVARIATE ANALYSIS

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The Mexican bean beetle (MBB), *Epilachna varivestis* Mulsant, is normally associated with certain species of Leguminosae of the genera *Phaseolus* and *Desmodium*, and has developed considerable affinity for soybeans, *Glycine max* (L.), in certain areas of the United States. In a previous study, adult females of the MBB exhibited a wide range of feeding acceptance for a group of 22 plant types belonging to six species of Leguminosae (Kogan 1972). They also oviposited on the same 22 plants in the laboratory, but no quantitative data were recorded. Among the 22 plants, 17 were lines and varieties of soybeans, 8 of which differed only by one or a few genes that control leaf pubescence and another 9 which had been selected for MBB resistance (Van Duyn, Turnipseed and Maxwell 1971; J. A. Schillinger personal communication). The five other species of cultivated legumes were included because they represented the upper and lower limits of adult food acceptance when compared to a standard soybean variety. The same plant array was used for this larval study in order to correlate adult feeding preferences with the nutritional quality of the food for larval development.

The work discussed here is part of a long-range program to study the nutrition and host-selection behavior of insects associated with soybeans. The research should also assist in evaluating and defining the nature of soybean resistance to insect defoliators. With the larvae on an exclusive diet of each of the 22 plant types previously designated, food intake was measured and a series of nutritional and other biological parameters was computed. One can infer that at comparable rates of food intake, differences in rates of growth and development necessarily derive from nutritional deficiencies in the diet.

Oligophagous insect species display maximum preference for a single plant species or a limited group of related plant species, but at least under experimental conditions, they frequently accept some plant outside their normal host range. A question that has practical importance in the fields of biological weed control (Zwolfer and Harris 1971) and host plant resistance (Saxena 1969, Pathak 1969, Maxwell *et al.* 1969) is how much and under what conditions will the insect depart from this set of preferred hosts and still evince some degree of acceptance. Furthermore, after a plant is accepted for feeding, how will it affect the insect's normal growth and development?

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It is in the context of this latter proposition that this paper is developed.

MATERIALS AND METHODS

Insect and plant cultures

The stocks for the MBB culture originated from a population breeding on soybeans in south-central Indiana, U.S.A. The insects were maintained on leaves of soybeans of the variety Harosoy--occasionally leaves of snap beans, *Phaseolus vulgaris* L., were also added to the diet. The rearing method was described in Kogan (1972). Larvae used in the experiments were from the 6th–7th generations of this colony.

All plants were grown in a greenhouse, where a 16 hr photophase was maintained throughout the vegetative growth period. Only plants 40 days old or older were used and attempts were made to use completely developed trifoliolates. The species, varieties and lines of the 22 plants included in the experiments are described in Table 1.

Experimental design

A standard growth curve was obtained for 24 MBB larvae reared on leaf cuttings of normal and glabrous Harosoy soybeans. Weights of larvae were recorded daily.

The basis for the experimental design used in the comparison of the nutritional value of the 22 plant types followed the observation of McGinnis and Kasting (1959) that a simplified growth curve could be obtained by measuring the weight of the larvae in each instar on that day when the variability of weights within the population was least. This was found to be 1 day after molting for the MBB during the first 3 stages and 2 days after the molt into the 4th stage and onset of prepupation.

Twenty larvae in 5 groups of 4 were offered each test plant. The day of molting was considered the day that half the larvae in the group completed the molting process. Food was given *ad libitum* but adjusted so that minimum amounts were left over to reduce the relative error in the computations of food consumption (see Waldbauer 1968). Food consumed was calculated from the difference between the corrected weight of food introduced and the weight of food left after a feeding period. Dry feces that occasionally accumulated on the leaves were removed prior to weighing, thus true consumption was measured. Aliquots for the calculation of the dry weight of food consumed were obtained following standard procedures in gravimetric techniques (Waldbauer op. cit). No data on weights of feces were recorded, therefore parameters of digestibility were not computed.

Experiments were conducted at 27 + 2°C, R.H. close to saturation, and in constant darkness.

Table 1. List of plants tested with reference to their nutritional value for the Mexican bean beetle.

Species	Variety	Line	Pubescence type	Maturity group	Source	Origin
Glycine max	Harosoy	L-2	Normal	2	USDA Soybean Lab. Urbana, Illinois	a
	"				"	
	"	L62-561	Glabrous	2	"	a
	"	L63-1097	Curly	2	"	a
	"	L62-801	Dense	2	"	a
	Clark	L-1	Normal	4	"	a
	"	L62-1385	Glabrous	4	"	a
	"	L63-2435	Curly	4	"	a
	"	L62-1686	Dense	4	"	a
		PI171,451	Dense	7	USDA-DELTA Res. Sta. Stoneville, Miss.	Japan
		PI227,687	Normal	8	"	Ryukys Is.
		PI229,358	Dense	7	"	Japan
		PI80,837	Dense	4	College Park, Mar.	Japan
		PI181,777	Normal	4	"	Japan
		PI89,784	Normal	3+	"	China
		PI103,091	Appressed	4	"	China
		PI157,482	Normal	4	"	Korea
		PI243,519	Normal	4	"	Japan
Phaseolus vulgaris	Burpees stringless	6163	-	-	Commercial variety	
Phaseolus luntatus	Fordhook	6183	-	-	"	
Phaseolus aureus	b	-	-	-		
Phaseolus mungo	b	-	-	-		
Medicago sativa			-	-	Ill. Nat. Hist. Survey	

[a] Improved varieties. Both Clark and Harosoy soybeans include germplasm of Manchurian origin, through breedings of the varieties Mandarin and/or Mandchu. Each variety was crossed with the same 3 strains containing the gene or genes for glabrous, curly or dense pubescence. Continuous selections have produced in each variety a series of near-isogenic lines differing almost exclusively by the type of pubescence. They are referred to here as isolines of Clark and Harosoy (see Bernard and Singh (1969).

[b] Unidentified varieties obtained from local supplier.

Computation of nutritional parameters

All nutritional parameters were based on the fresh weight of the larvae and dry weight of food consumed. All parameters except the mean body weight were computed according to Waldbauer (1968), as follows:

Mean body weight: $A = \sum_{i=1}^{n} (a_i \times t)/T$: in mg.

Consumption index: CI = F/AT: mg food consumed per mg body weight per day.

Growth rate: GR = G/AT: mg body weight gained per mg body weight per day.

Efficiency of conversion of ingested food: ECI = GR/CI or (G/F) x 100: fresh body weight gained per dry weight of food consumed, expressed on a percent basis.

where: a_i = fresh weight of the ith animal at a certain feeding period.

t = duration in days of the feeding period completed when the animal reached the a_{ith} weight.

T = duration of total feeding from larval emergence through prepupation.

F = dry weight of food consumed.

G = fresh weight gain of the animal during one feeding period.

Together with these parameters were recorded: maximum weight gained by the larvae, total weight of food consumed, total development time, percent survival through prepupation and weight of the pupa.

Statistical analyses

The 22 plants used in each series of tests were considered as a population, the components of which were characterized by the effect they had on the insects feeding upon them. Therefore, each plant type represented "OTU's" (operational taxonomic units) defined by the series of nutritional and other biological parameters computed for the MBB. The relative nutritional value of each plant type was consequently expressed as the total effect the plant had on the insect's feeding, growth, development and survival. A classification or ranking of the plants according to these parameters was attempted by means of techniques of numerical taxonomy (cluster analysis, Sokal and Sneath 1963). The computations were performed using University of Illinois Agronomy Statistical Laboratory programs on an IBM 360/75 computer. The original data (an array of 22 "OTU's" (plant types) by 10 characters) was transformed into standard normal deviates and a Q-correlation matrix (product-moment correlation coefficients) was calculated for all pairs of "OTU's." The Q-correlation coefficients were transformed into Fisher's Z values and clustered by the unweighted pair group method with simple averages (Sokal and Sneath op. cit, and for an example of application and details of the method see Rhodes *et al.* 1968).

RESULTS

A detailed growth curve of the MBB feeding on fresh soybean leaves is shown in Fig. 1. The mean total development time through pupation was 18.3 ± 1.2 days, and the mean total weight gained by the larvae was 29.1 ± 3.6 mg.

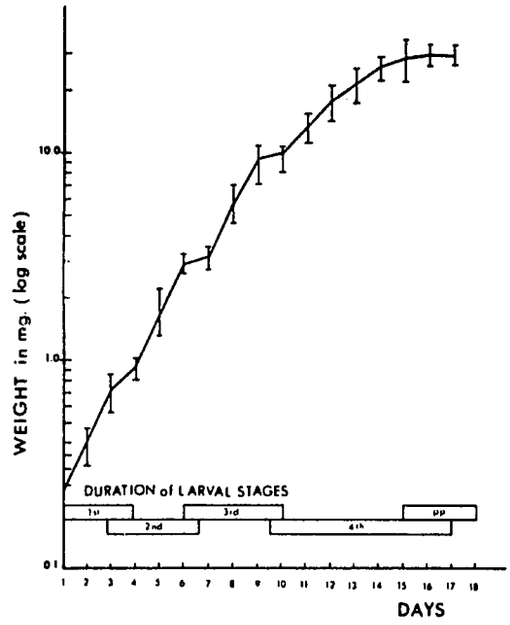

Figure 1. Growth curve and duration of developmental stages of Mexican bean beetle larvae reared on a mixture of normal and glabrous Harosoy soybeans. Vertical bars indicate standard deviations.

The growth curves of the larvae feeding on the 22 test plants are represented in Figs. 2-3, which also include the dry weight of food consumed during each feeding period. The points on the curves represent the weights of the approximate central point in each stage of development, that is, one day after emergence for the 1st stage, one day after molting for the 2nd and 3rd stages, and 2 days after molt to 4th stage and onset of prepupal stage (compare feeding periods to mean duration of larval stages in the detailed growth curve, Fig. 1). Table 2 summarizes the recorded and computed values of the mean fresh body weight (A), total dry weight of food consumed (F), total weight gain (G), development time in days (T), gross efficiency of conversion of ingested food (ECI), gross consumption index (CI), mean growth rate (GR), percent survival through prepupation, mean weight of pupae, and adult preference index (C).

The mean body weight as calculated here differed from the method suggested by Waldbauer (1964) and approached that used by Soo Hoo and Fraenkel (1966). In general the values of A thus calculated were higher than those obtained by Waldbauer's method and therefore reflected on the

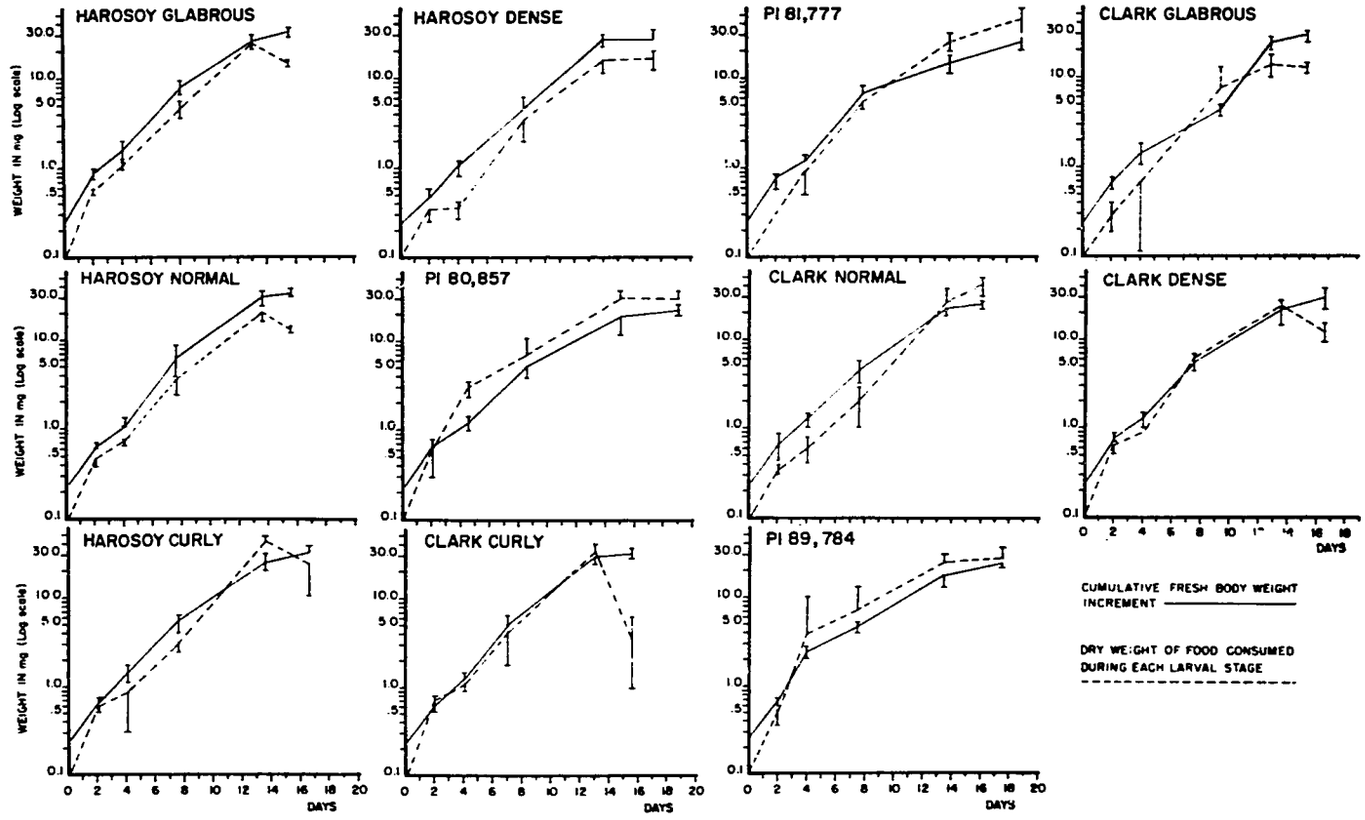

Figure 2. Cumulative fresh body wt increments and dry wt of food consumed during each larval stage. Mexican bean beetle larvae on an exclusive diet of each plant type.

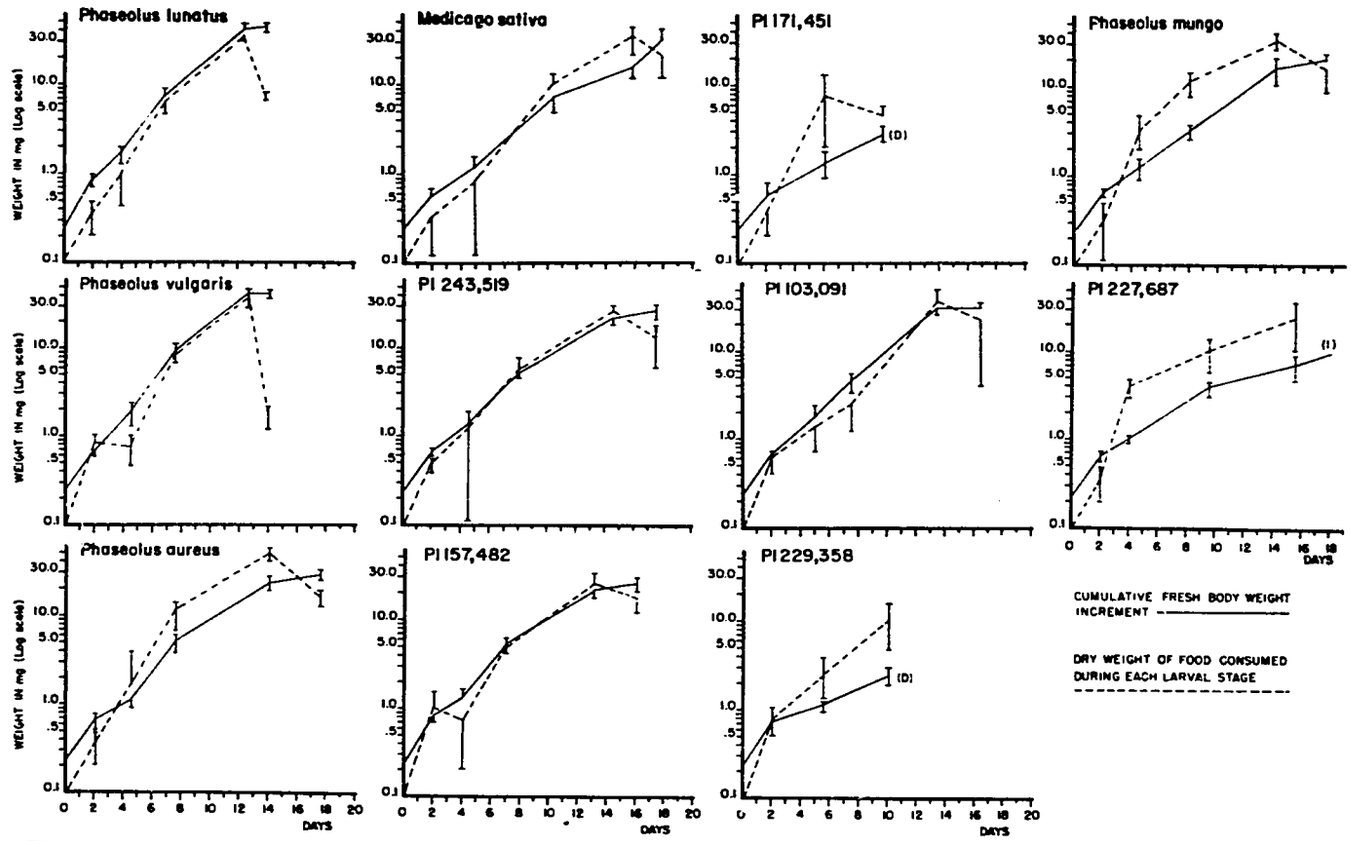

Figure 3. Cumulative fresh body wt increments and dry wt of food consumed during each larval stage. Mexican bean beetle larvae on an exclusive diet of each plant type.

Table 2. Nutritional value and other biological parameters obtained with Mexican bean beetle larvae feeding upon 22 plant types (weights in mg), and preference index for adults.

Food plants[a]	Mean body wt (A)	Total wt gain (G)	Wt food consumed (F)	Development time (T) days	Efficiency of conversion (ECI)	Consumption index (CI)	Growth rate (GR)	Mean wt of pupae	Survival	Pref. index (C)x10
H. Normal	18.15±2.46	36.27± 2.76	38.51± 8.32	15.76±0.44	92.54±29.84	0.134±0.030	0.128±0.041	33.64±2.42	65.0	10.00
H. Glabrous	16.95±1.29	32.25± 2.33	55.18± 9.49	15.81±0.40	59.98±10.77	0.206±0.033	0.121±0.009	30.81±2.97	70.0	11.22
H. Curly	16.71±3.14	32.38± 2.09	50.50± 8.90	16.23±1.19	67.64±24.06	0.191±0.040	0.121±0.014	29.55±4.69	85.0	11.51
H. Dense	15.58±1.82	30.22± 4.60	38.45± 6.06	17.42±0.79	79.18± 9.94	0.144±0.032	0.112±0.017	27.43±5.45	50.0	9.82
C. Normal	15.13±1.77	27.56± 3.21	56.13± 7.17	16.13±0.64	50.38±11.57	0.232±0.035	0.114±0.017	24.81±1.18	65.0	11.04
C. Glabrous	15.16±2.21	29.54± 2.46	35.84± 8.01	15.41±0.51	86.72±21.00	0.164±0.010	0.135±0.030	29.48±2.96	75.0	11.03
C. Curly	19.59±2.30	34.63± 2.69	44.83±10.09	15.86±0.35	79.75±12.32	0.162±0.053	0.112±0.008	32.66±1.53	75.0	11.44
C. Dense	16.56±1.00	31.41± 4.57	46.82± 1.77	16.67±1.30	67.48±12.32	0.184±0.053	0.126±0.030	28.26±5.15	50.0	11.86
PI 80857	14.06±1.92	25.89± 4.73	70.93± 7.83	18.78±0.43	37.54±11.57	0.276±0.056	0.097±0.004	22.25±1.08	45.0	10.13
PI 81777	12.92±1.35	26.27± 3.51	86.30±15.83	19.00±0.00	31.80± 9.43	0.357±0.084	0.107±0.008	26.10±8.04	75.0	9.31
PI 89784	13.15±1.85	25.33± 3.31	77.13±16.67	17.58±1.54	34.43± 8.42	0.340±0.084	0.110±0.01	23.96±3.16	80.0	9.42
PI 103091	18.27±0.96	31.35± 1.83	54.23±13.58	17.00±0.12	61.16±14.59	0.174±0.041	0.101±0.005	27.96±1.72	50.0	10.07
PI 157482	15.40±2.13	27.77± 2.63	53.07±10.86	16.35±0.49	54.18±11.40	0.154±0.075	0.111±0.007	21.19±3.83	65.0	10.03
PI 245519	14.56±0.47	28.38± 1.56	49.64± 6.45	17.80±0.41	57.76± 5.47	0.192±0.026	0.110±0.009	25.65±1.86	65.0	9.06
PI 171451	2.08±0.62	2.60± 0.35	12.65± 4.43	0[b]	23.03± 7.81[c]	0.661±0.249	0.135±0.020	0[b]	0.0	6.89
PI 227687	4.97±0.75	10.69± 0.0	66.21± 0.0	18.00±0.0	27.95± 8.60[c]	0.516±0.201	0.115±0.014	0[b]	5.0	6.00
PI 229358	1.75±0.73	3.08± 0.0	22.44± 0.0	0[b]	18.15±10.14	0.737±0.211	0.123±0.036	0[b]	0.0	8.63
P. vulgaris	22.95±1.76	43.13± 3.41	51.26± 7.98	14.00±0.0	86.86±19.44	0.160±0.026	0.134±0.009	38.30±2.41	45.0	12.09
P. lunatus	21.47±1.99	42.57± 2.12	53.35± 5.32	14.00±0.0	80.44± 8.12	0.180±0.033	0.142±0.014	40.38±1.92	75.0	11.27
F. mungo	12.31±3.14	23.40± 5.30	74.97±19.31	17.64±1.12	32.37± 7.87	0.351±0.069	0.110±0.017	22.87±3.67	30.0	9.23
P. aureus	16.50±0.97	30.50± 1.52	72.35± 6.03	17.25±1.18	42.28± 2.00	0.258±0.042	0.108±0.074	27.93±1.02	70.0	9.14
M. sativa	12.66±0.91	32.75±14.91	76.95±10.69	18.43±1.40	42.82±18.11	0.338±0.026	0.142±0.055	24.40 –	15.0	9.26

[a]Identified in Table 1.
[b]None completed development on these plants.
[c]ECI computed up to 3rd stage larvae.

computations of GR and CI that were proportionally lowered. The total weight gain was obtained by subtracting the mean weight of newly emerged larvae from the maximum weight recorded. The mean initial weight of the larvae was 0.25 mg.

ECI was computed on the basis of fresh animal body weight and dry weight of food consumed (Waldbauer 1962). This method, of course, yielded very high ECI values, which, for purposes of comparison with values obtained for other insect species can be divided by 4, considering a gross 25% dry matter content in MBB throughout their whole larval period.

For identical reasons the CI was lower than usual and for comparative purposes the values reported here could be multiplied by 4. Since GR is based exclusively on the animal body weight, its values conform with those computed by other authors.

The preference index (C) was determined by comparing all plants to Harosoy normal. A C value of about 1 indicates that test plants were about as acceptable as H. normal. C>1 corresponds to test plants preferred, and C<1 corresponds to test plants partially rejected (or non-preferred) in comparison with H. normal (Kogan 1972).

The mean values of the 10 parameters listed in Table 2 were used to compute a Q-correlation matrix for all 22 plants. The Q-correlation coefficients are presented in Table 3. These correlation coefficients were used in the cluster analysis, the results of which are graphically represented in Fig. 4, in the form of a dendrogram. The levels of affinity, in this case denoting similar effect of the plants on MBB larvae feeding upon them, are defined by the Q-correlation coefficients.

In general the graph in Fig. 4 followed the computed sequence of clustering except in the case of Clark dense. This "OTU" clustered with *P. vulgaris* and *P. lunatus* at a .697 level mainly due to similar percent survival and preference index, but as most nutritional parameters did not follow this trend the .697 cluster was omitted and the position of Clark dense was shifted to the bottom of the cluster formed at the .579 level, including also H. normal, H. dense and Clark glabrous.

The sequence of "OTU's" from top to bottom generally follows the tendencies indicated in the upper left corner of the graph--a decrease in mean body weight, total weight gain, gross ECI, gross GR, weight of pupae, larval survival, and preference index, and an increase in gross CI and developmental time.

For the purpose of the discussion of results, the four large clusters formed above the .40 level and the 9 clusters formed above the .60 level will be considered separately.

The means of parameter values (extracted from Table 3) of all "OTU's" in each cluster formed above the .40 correlation level are presented in Table 4. The means for those clusters formed above the .60 level are shown in Table 5.

Table 3. Q-Correlation matrix of 22 plant types based on their nutritional value for the Mexican bean beetle; decimal points and diagonal of self-comparisons omitted.

Plant types[a]	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.
H. Normal																						
H. Glabrous	44																					
H. Curly	51	90																				
H. Dense	80	36	45																			
C. Normal	-18	72	68	05																		
C. Glabrous	76	40	58	53	-06																	
C. Curly	66	78	81	76	51	50																
C. Dense	52	67	59	46	35	60	57															
PI 80857	-59	-02	-14	-07	52	-73	-00	-28														
PI 81777	-70	-18	-23	-43	32	-79	-34	-67	77													
PI 89784	-68	-13	-11	-47	37	-69	-31	-68	67	97												
PI 103091	23	41	31	63	45	-14	70	15	60	17	09											
PI 157482	20	61	68	45	72	02	65	19	43	29	34	67										
PI 245519	31	21	33	59	24	03	45	-20	36	36	36	64	72									
PI 171451	-32	-66	-57	-61	-62	01	-69	-35	-49	-20	-15	-84	-85	-71								
PI 227687	-62	-92	-85	-49	-50	-57	-87	-68	22	43	38	-41	-43	-15	53							
PI 229358	-50	-61	-54	-68	-41	-12	-65	-33	-28	-08	-05	-73	-79	-76	95	51						
P. vulgaris	72	56	39	49	-01	50	58	77	-43	-76	-79	25	03	-18	-28	-72	-34					
P. lunatus	78	61	51	34	-08	62	48	59	-68	-67	-62	-01	03	-08	-17	-73	-33	84				
P. mungo	-80	-50	-68	-49	-00	-91	-61	-54	74	76	63	07	-14	-03	02	68	14	-58	-74			
P. aureus	-33	07	-02	-09	34	-65	03	-55	72	85	82	53	54	63	-52	10	-46	-42	-33	53		
M. sativa	-28	-50	-69	-45	-54	-36	-77	-11	-11	02	-07	-50	-57	-46	37	58	27	-04	-05	48	-16	

[a]Identified in Table 1.

Table 4. Summary of nutritional parameters that define the suitability for MBB larvae of 22 plant types grouped in 4 clusters formed above the .40 correlation level.[a]

	No. of OTU's	A (mg)	G (mg)	F (mg)	T (days)	ECI	CI	CR	Wt. Pupae	% Surv.	C X10
Cluster I	6	18.31	35.52	44.04	15.54	82.02	.121	.129	32.91	60.0	11.01
Cluster II	7	16.65	30.62	51.94	16.45	61.52	.187	.113	27.51	67.8	10.62
Cluster III	5	13.78	26.28	76.33	18.05	35.68	.316	.106	24.62	60.0	9.44
Cluster IV	4	b	b	b	b	27.98[c]	.563[c]	b	24.40[d]	15.0	7.69

[a] For meaning of symbols see Table 2.

[b] Only 3 larvae completed development through prepupation on 1 plant in this cluster (*M. sativa*). There was no meaning in the avg values for this cluster as they would combine results of animals in different stages of development.

[c] Based on larvae that reached at least the 3rd stage.

[d] Only 1 pupa developed on *M. sativa*, none on the 3 other plants in this cluster.

(Cluster I: *P. vulgaris*, *P. lunatus*, H. normal, H. dense, Clark glabrous, Clark dense; Cluster II: H. glabrous, H. curly, Clark curly, Clark normal, PI's 157482, 103091, 243519; Cluster III: *P. aureus*, PI's 81777, 89784, 80857, *P. mungo*; Cluster IV: *M. sativa*, PI's 227687, 174451, 229358.)

Table 5. Summary of nutritional parameters that define the suitability for MBB larvae of 22 plant types grouped in 9 clusters formed above the 0.60 correlation level.[a]

	No. of OTU's	A (mg)	G (mg)	F (mg)	T (days)	ECI	CI	GR	Wt. Pupae	% Surv.	C X10
Cluster I	2	22.21	42.85	52.30	14.0	83.65	.170	.138	39.34	60.0	11.68
Cluster II	3	16.29	32.01	37.60	16.19	86.16	.147	.125	30.18	63.3	10.28
Cluster III	1	16.56	31.41	46.82	16.67	67.48	.184	.126	28.26	50.0	11.86
Cluster IV	5	16.75	30.91	51.94	16.07	62.38	.189	.115	27.80	72.0	11.04
Cluster V	2	16.41	29.86	51.93	17.40	59.46	.183	.105	26.80	57.5	9.56
Cluster VI	5	13.78	26.28	76.33	18.05	35.68	.316	.106	24.62	60.0	9.44
Cluster VII	1	12.66	(32.75)[b]	76.95	18.43	(42.82)[b]	.338	(.142)[b]	24.40[c]	15.0	9.26
Cluster VIII	1	4.97[d]	10.69	66.21	18	27.95	.516	.115	e	5.0	6.00
Cluster IX	2	1.91[d]	2.84	17.54	f	20.59	.699	.129	e	0.0	7.76

[a] For meaning of symbols see Table 2.
[b] Only 3 larvae completed development through prepupation, 2 were hypertrophic and did not pupate, hence the high value of G.
[c] Wt of 1 pupa.
[d] Based on larvae that reached at least the 3rd stage.
[e] None reached pupal stage.
[f] None reached prepupal stage.

(Cluster I: *P. vulgaris*, *P. lunatus*; Cluster II: H. normal, H. dense, Clark glabrous; Cluster III: Clark dense; Cluster IV: H. glabrous, H. curly, Clark curly, Clark normal, PI 157482; Cluster V: PI's 103091, 243519; Cluster VI: *P. aureus*, PI's 81777, 89784, 80857, *P. mungo*; Cluster VII: *M. sativa*; Cluster VIII: PI 227682; Cluster IX: PI's 171451, 229358.)

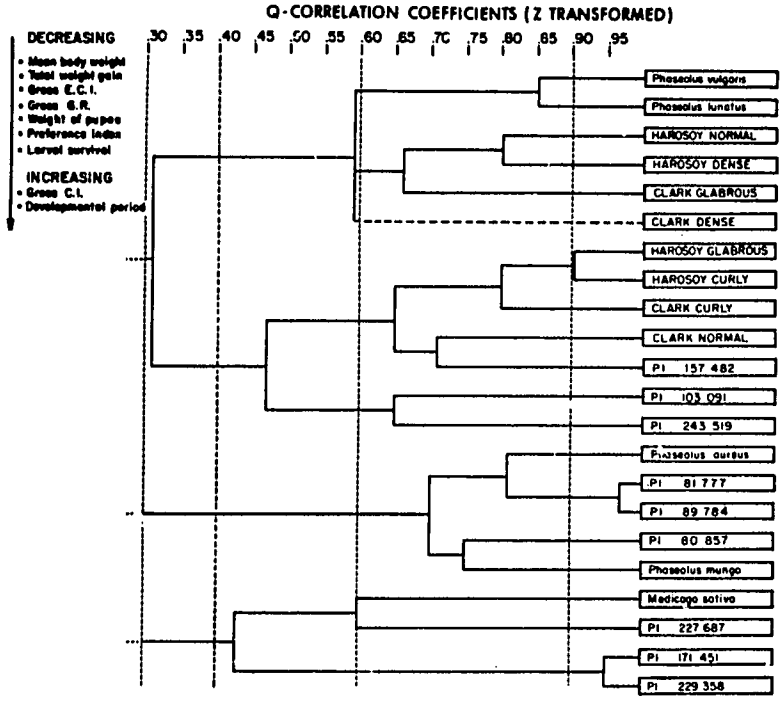

Figure 4. Correlation dendrogram resulting from unweighted pair group method of clustering using simple averages.

DISCUSSION

Proper evaluation of results of food intake and utilization by the MBB must take into consideration the unique feeding mechanisms of this species. Howard (1941) described the MBB larval feeding process as follows: "The larva swings the left mandible to the left, moving the anterior portion of the body slightly to the left also. The mandible scrapes the parenchymatous tissue to the right, or toward an imaginary extension of the median sagittal plane of the insect, and usually leaves the epidermis on the opposite side of the leaf intact. The right mandible moves to the right in a similar manner, usually alternately, and tissue from a distance as far as the mandible can reach is drawn to the left toward the imaginary line mentioned. At intervals both mandibles meet and the tissue is compressed. It is assumed that during this operation the larva ingests the sap and plant juices, for the most part cellulose and chloroplasts are left in a ridge similar to a windrow in a hayfield."

MBB therefore ingests a highly liquefied diet and the bulk of the fiber never enters the animal's digestive tract. Excretion in the first two larval stages is very reduced, and adults and older larvae eliminate a relatively small amount of feces. This feeding process probably results in a kind of ingested food that is intermediate between the liquid ingesta of sucking insects and the highly fibrous ingesta of chewing insects. A consequence of this feeding process is that AD is probably high, and ECI approaches ECD. A second consequence is that the water content of the diet probably plays a very critical role in food acceptance and continuation of feeding. Finally, the analysis of the role of leaf pubescence in the patterns of acceptance of a diet by the larvae has to consider that the cellulose hairs are probably never ingested, and therefore, do not add to the crude fiber content of the diet.

Sokal and Sneath (1963) commented that few Q-type studies conducted to that date have produced negative coefficients of correlation. They explained the generally positive nature of Q-correlation matrices by the unlikelihood of finding "... a pair of OTU's antithetical for an appreciable number of characters." (Sokal and Sneath *op. cit.*) In the current study there are several highly significant negative coefficients of correlation between certain pairs of "OTU's". Negative coefficients probably appear because four of the nutritional parameters used in the analysis, A, ECI, CI, and GR, are ratios calculated on the basis of the original data used to compute three other single parameters, G, F, and T. Thus the differences between diets ("OTU's") are somewhat magnified. Seemingly an inconvenience in taxonomic studies, this was in fact one of the purposes of this investigation, i.e., to expand subtle nutritional differences so as to permit their detection and analysis.

Clusters at the 0.40 correlation level

Cluster I included 6 "OTU's" that were the best food plants for the MBB. The range of maximum larval weight was 43.38 - 29.79 mg, but weights of larvae did not necessarily correlate with survival as the best food plant in the cluster (*P. vulgaris*) produced a high larval mortality (65%). ECI reached a maximum of 92.54% with H. normal and a low of 67.48% with Clark dense, but the majority of the plants in this cluster had ECI's near the 80% level (~20% on a dry weight/dry weight basis), suggesting that despite differences in the growth of larvae, the plants in this group were nutritionally adequate for the MBB.

Cluster 2 included seven "OTU's". Larval weights in this group were more uniform, ranging from 34.88 to 28.33 mg, however, survival varied also rather widely from a high of 85% to as low as 50%. In this group, weights of food consumed were higher than in cluster 1, yielding considerably lower ECI values around the 60% level. H. curly was a discrepant component in this cluster, and by its assessed nutritional value it should rank with plants in

cluster 1. This cluster consists of moderately good food plants for the MBB.

Cluster 3 included 5 "OTU's". *P. aureus* was the only nutritionally adequate food plant, but if given a choice the larvae usually prefer H. normal to *P. aureus*. In general pupae produced from larvae feeding on these plants were very small, practically at the limit for survival, although in general survival through prepupation was as variable as in the other groups, suggesting that larval mortality in this experiment was not necessarily correlated to major antibiotic effects in the plants included in these first 3 clusters. Those were plants of low nutritional value for the MBB as reflected by the rather low ECI's of the order of 35%.

Cluster 4 included alfalfa (*M. sativa*) and PI's 227687, 171451, and 229358 that were selected for MBB resistance in South Carolina (Van Duyn, Turnipseed and Maxwell 1971). Only 3 larvae completed pupation on plants of this cluster. The few larvae that completed development on alfalfa were extremely large, as they continued to feed over an unusually long period of time (> 18 days). None of the larvae passed the third instar on PI's 171451 and 229358; values of ECI, CI, GR were based on larvae surviving through more than two stages. The inadequacy of these plants is reflected in the wide variance in total weight gain and weight of *M. sativa* consumed. These were inadequate food plants for the MBB. They also ranked lowest in the preference scale.

The steep increase of ECI from cluster I to IV reflects the gradual reduction of the nutritional value of the diets. The proportional increase of CI indicates that the insects compensated for the reduced nutritional value, up to a certain degree, by extending development time (T) and increasing daily consumption rates. Compensatory rates of food intake in practically all plants in Clusters I and II suggest that proper feeding excitants were present.

Percent survival on diets of these clusters was essentially the same (ca. 60%), indicating that no antibiotic effects were present to account for the reduced suitability of plants in clusters II and III. It is therefore hypothesized that nutritional inadequacies are probably due to an imbalanced reduction in the level of certain nutrients available to the larvae. The relatively mild effects suggest that the relative proportions of the nutrients must have been within tolerable limits, since according to House (1966, 1969), imbalances in the proportion of nutrients result in a reduction of food intake, weight gain, and efficiency of conversion. Diets in cluster III caused an average of 25% reduction in weight gain, but food consumption increased nearly 70%. Insects which emerged from pupae developed on these diets, however, were frequently malformed and much smaller than normal. The increase in food intake was not accompanied by compensation of ECI, and the signs of nutrient deficiencies expressed by adult malformations, especially of wings, suggest abnormal proportions of nutrients.

One noteworthy aspect of the summarization of the results at the 0.40 correlation level is the almost perfect direct correlation between diet suitability for the larvae and food preferences of the adults, as measured by the preference indices. As the argument on the role of nutrients in host-plant selection seems to be far from settled, results of this experiment hint at the possibility that some discrimination of the nutritional value of the plant does indeed occur, a question that remains open for future investigation.

Clusters at the 0.60 correlation level

At the 0.60 correlation level nine clusters were formed, three of them including one single "OTU". The summary of the average results in each cluster is presented in Table 5.

At this higher level of correlation more complex effects of the diets on the insects become apparent. Again, the general trend toward reduced nutritional value of the diets is demonstrated by the decrease of ECI.

The mean ECI of cluster II, however, was slightly higher than that of cluster I, as reduction in total dry weight of food consumed in the former occurred in the proportion of the decrease in weight gain. House (1965) reported that a series of diets containing a constant relative proportion of nutrients but in increasingly diluted amounts were fed to 5th-instar larvae of *Celerio euphorbiae* (L.). The larvae ate larger amounts of the more diluted diets but weight gain and ECI did not vary significantly. Such observations were later generalized in the rule of nutrient proportionality (House 1966). Mean parameter values in cluster II indicate that both proportions and total levels of nutrients should have been adequate, but that the total amount of food consumed was reduced. As *P. vulgaris* and *P. lunatus* are preferred hosts in nature and in the laboratory (Friend and Turner 1931, Howard and English 1924, Kogan 1972, Thomas 1924), differences in total amounts of food intake can be explained by the lower efficiency of feeding excitants in the soybeans. Lippold (1957) reported that different saponins in *P. vulgaris* and *G. max* elicited positive feeding responses of MBB adults. Nayar and Fraenkel (1963) did not confirm the presence of the active saponins, and reported that the cyanogenetic glycoside, phaseolunatin, was synergistic to glucose, acting as a feeding excitant on leaves of *P. lunatus*.

Augustine *et al.* (1964) stressed the role of sucrose, glucose and fructose as important feeding excitants for MBB. Gas chromatographic determinations of sucrose and reducing sugars (our unpublished data) revealed that indeed the preferred soybean lines were higher in total sugar content, but some of the more resistant lines were higher in sugars than several of the more susceptible ones, leaving the question of the role of these sugars open for further investigation.

Again evidence points to a great deal of interactions of factors, of which sugar concentrations is unquestionably a primary one. It seems,

however, that the variety of responses obtained cannot be explained by the levels of this component alone.

In considering results of cluster II the fact must finally be considered that those plants were used in regular maintenance of the cultures and that selection towards improved utilization of these diets may have occurred. Gordon (1959) stated that selection pressure favors genotypes that maximize food utilization.

Clusters II, III and IV include the four isolines each of Harosoy and Clark soybeans, plus PI 157482. It appears that no major differences exist between the Harosoy and Clark basic genotypes, as representative isolines of each variety clustered together in clusters II and IV. Leaf pubescence did not seem to affect food utilization, as Harosoy dense and Clark dense ranked among the best diets in clusters II and III respectively. As dense isolines have over 4 times more hairs per leaf unit area than the normal isolines (Singh, Hadley and Bernard 1971), a typical chewing insect would be expected to reflect the increased cellulose content of the diet by a lower ECI (unpublished data with the corn earworm, *Heliothis zea*, show this effect). The peculiar "scrape and suck" type of feeding of the MBB most likely excludes ingestion of the fibrous materials, which did not seem to interfere with normal intake and utilization. There was, however, a significantly higher than normal mortality on both dense isolines. With Harosoy dense, larval mortality occurred mostly during the first two stages. In this case leaf pubescence may have affected some of the young larvae by blocking their access to the nutritious parenchymatous tissues. Soybean leaf pubescence is a factor in soybean resistance to leafhoppers (Singh, Hadley and Bernard 1971; Broersma, Bernard, and Luckmann 1972). Van Duyn (1971) ascribed considerable importance to leaf pubescence, especially the length of hairs, in the resistance of PI's 171451, 227687 and 229358 to the MBB.

The additional variability in the eight isolines remains unexplained because, at least theoretically, they should be alike in all respects except leaf pubescence. Particularly difficult to explain were results with Clark normal, which was one of the preferred plants for adult feeding, and yet was of reduced nutritional value.

Clusters V and VI included five PI lines selected for MBB resistance in Maryland, and two species of beans--*P. aureus* and *P. mungo*. The two species of *Phaseolus* were reported as almost immune to the MBB (Thomas 1924), and ranked low in a preference scale (Kogan 1972). The low nutritional value of these plants is generally reflected in poor weight gain and low ECI, however, food consumption was high. In this case, even admitting the reduced level or absence of proper feeding excitants, higher food consumption in confinement was probably the result of starvation for some key nutrient that was probably present in disproportionally low amounts. One such nutrient that probably was in short supply was water. Leaves of plants

in this cluster were considerably thinner and percent moisture was reduced, thus larger amounts of dry matter may have been ingested to assure water intake in adequate levels. Whereas mean percent dry matter in H. normal was 17.5% and in H. glabrous 15.7%, these PI lines all had over 19.1% dry matter.

Cluster VII included *M. sativa* which is only a marginal food for the MBB. The few larvae that survived beyond the 3rd stage grew exceedingly large and died of bacterial septicemia, indicating a breakdown of defenses resulting from major disruptions of growth regulation. In this case one may suspect the presence of adverse chemical factors in the leaves.

Clusters VIII and IX included the three MBB resistant PI 227687, and PI's 171451 and 229358 respectively. The evident unsuitability of these plants for the MBB seems to be the result of a combination of factors including the absence of proper feeding excitants, presence of physical deterrents (pubescence), and nutritional imbalances.

CONCLUSIONS

A large spectrum of responses was obtained with MBB larvae feeding on these 22 plants. In broad lines (.40 level of analysis) adult preferences closely followed the nutritional suitability of the diets for the larvae. There was evidence that decreasing suitability from *P. vulgaris* to PI 229358 could be accounted for by one or a combination of the following factors: a) improper and/or suboptimal levels of feeding excitants, b) generally reduced levels of nutritional content of the diet, c) imbalanced alteration of nutrient proportionality, d) presence of physical feeding deterrents, and e) presence of chemical antibiotic factors.

Among the resistant lines that were tested, some (PI's 103091, 243519, 81777, 89784, and 80857) were partially resistant and their use as a potential source of resistance should not be neglected. PI's 227687, 171451, and 229358 were highly resistant, with evidence of both non-preference and antibiotic types of resistance.

This investigation was an initial step in the analysis of insect-soybean interactions at the nutritional level. Future progress in this area will largely depend upon the detailed knowledge of the nutritional requirements of insects associated with soybeans.

The cluster analysis was helpful in the interpretation of the results. Available programs put this technique within easy reach of the entomologist and it may certainly become a powerful tool in the analysis of complex data whenever some objective criteria for an orderly classification of elements based on a plurality of characters is desirable.

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Development and Economic-Injury Level of the Green Cloverworm[1] on Soybean in Iowa[2,3]

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ABSTRACT

Developmental and feeding trials were conducted with *Plathypena scabra* (F.) under 3 sets of environmental conditions. Durations of the egg, larva, prepupa, pupa, and adult stages were 4.8, 18.7, 1.3, 9.4, and 9.3 days, respectively. Significant differences were found between trials for the egg and total life cycle, but no significant difference in larval stadium was indicated. Soybean leaf consumption of each larval instar was determined with a photometric device. The mean soybean-foliage consumption was 19.89 in.^{2} per larva in trial 1 and differed significantly from the 17.06 in.^{2} and 15.55 in.^{2} obtained in trials 2 and 3. Estimates of total leaf area per soybean plant were made from field measurements. Predictive equations to establish the relationship between soybean defoliation and subsequent yield loss were calculated by using data from previous hail-damage investigations. Theoretical economic-injury levels for *P. scabra* on soybean in Iowa were calculated by using economists' cost and market data, agronomists' damage-yield data, and feeding data from this study. Calculated levels were 5.9, 18.3, 33.5, 28.7, and 40.5 larvae/row ft for soybean stages 1, 3, 5, 7, and 9, respectively. These values suggested that most recommended chemical treatment levels should be revised upward.

Knowledge of economic-injury levels is essential to establishment of an efficient chemical spray program, and their use is considered one of the 2 fundamental principles of integrated control (Smith 1968). Defined by Stern et al. (1959) as the lowest population density that will cause economic damage, economic-injury levels are difficult to determine (Chant 1966). Stern (1966) presented 3 empirical methods of establishment of these levels, each requiring visual estimation of loss.

A 4th approach may be developed by integrating cost, marketing, and yield data of agronomists and economists with feeding data obtained by entomologists. This deductive approach to laboratory determination of economic-injury levels allows experimental manipulation of the factors influencing these levels. In this manner, economic-injury levels may be calculated for variations in market value, insecticidal costs, application costs, plant tolerance, plant populations, and insect feeding behavior.

Determination of economic-injury levels is particularly difficult when the insect under investigation causes primarily indirect damage; e.g., reduction in yield through defoliation. Several insects cause this type of damage to soybean in Iowa, and the green cloverworm, *Plathypena scabra* (F.), is one of the most important.

As with the other species of soybean-foliage feeders, the economic-injury level of *P. scabra* is poorly known. Recommended treatment levels range from 2–5/row ft (Harding and Bissell 1966) to 5–10/row ft (Anonymous 1968). Experimental or observational data to support these treatment levels, however, could not be found in the literature.

Considerable expenditures in 1966 and 1968 in Iowa for suppression of this species prompted our study of the economic-injury level on soybean. Availability of economic and agronomic data and an efficient technique for quantification of feeding behavior allowed application of the deductive approach to determining economic-injury level.

METHODS AND MATERIALS.—*Feeding Trials.*—Three feeding trials were conducted in controlled laboratory cabinets. The environmental conditions maintained were: trial 1, constant 80°F and 24-hr photophase with 64–94% RH; trial 2, 14-hr photophase at 85°F and 82–96% RH with a 10-hr and 65°F nocturnal phase at 96% RH; trial 3, identical to trial 2 in temperature and photoperiod, but with 55–80% RH during the photophase and 85–96% RH during the nocturnal phase.

Conditions in trials 2 and 3 approximated those encountered by the larvae in the field. Trial 3 was initiated after noting high larval stress caused by water condensation in trial-2 rearing cages. Environmental conditions in the rearing chambers were monitored in all trials by a constant-recording hygrothermograph.

Feeding cages were necessary that would allow larval feeding under simulated field conditions and yet restrict the area of feeding to a circle with less than a 1.05-in. diam. Restriction was necessary, because accuracy of the photometric device used in the assessment of soybean-leaf consumption was reduced above this diameter (Pedigo et al. 1970). Other cage requirements were convenience for observation and space for young larvae to hang suspended from silken threads. These requirements and great differences in leaf consumption between young and old larvae necessitated 2 types of cages.

Type-1 cages (Fig. 1) were used for the 1st 3 instars and were constructed by affixing the bottoms of 1-oz jelly cups to 1.94-in.-tall clear-plastic containers with spring-type hair clips. The containers were 1.00 in. ID, and the rim on the bottom of the jelly cup was used to press a single soybean leaflet lightly, but firmly, onto the upper rim of the container. In this way, no leaf damage was caused by the cage, an essential accuracy requirement of the photometric device. Early instars fed on the lower surface of the leaf, so the position of the cage lid had no inhibitory effects on feeding.

Type-2 cages (Fig. 2) were constructed to hold 10 leaflets for later instars. Eleven 2×2-in. squares of 0.19-in. Plexiglas® were used, of which 10 had 1.05-in.-diam holes. Additional alignment holes were

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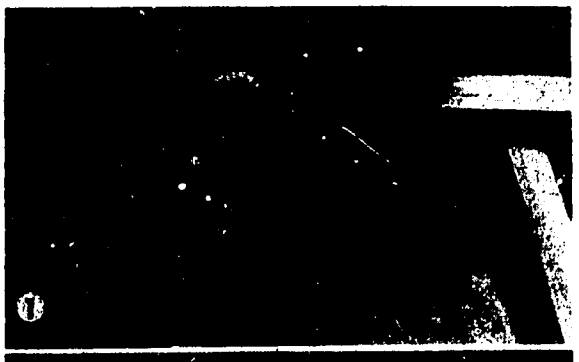


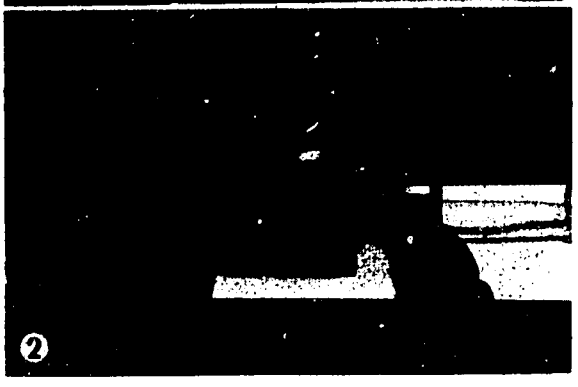


FIG. 1.—Type 1 cage used for instars 1, 2, 3.
FIG. 2.—Type 2 cage used for instars 4, 5, 6, 7.

drilled in opposite corners of all squares, and the squares were positioned on a 3×7-in. wood plate by running headless nails through the alignment holes. The square having only alignment holes served as the cage lid. The enclosed cavity thus formed was then filled by alternating squares and leaflets for presentation to a single larva.

Type-2 cages were modified for trial 3 by drilling a 0.25-in. hole in the lid and covering it with fine nylon mesh. This modification eliminated condensation that had been noted in trial 2 and yet prevented larval escape.

All plant leaves for these trials were maintained in plastic vessels (Aquapic®, Syndicate Sales Inc., Kokomo, Ind.) that allowed insertion of the leaf stem through a rubber cap into a reservoir of water. This reservoir was kept full, and the leaves stayed turgid, without obvious loss of color, up to 3 weeks.

Eggs for each of the trials were taken from a greenhouse colony of *P. scabra*. Egg age was unknown in trial 1 but was known (within 14 hr) in trials 2 and 3. Individual eggs were taken from leaves by removing a 0.50-in. disc with 1 egg. Because large numbers of nonviable eggs were selected in the 1st 2 trials, eggs were incubated for 2.5 days before selection and removal for trial 3.

The leaf discs with eggs were then clipped in place into the cage with a leaflet for incubation and observation. With this arrangement, the newly hatched larva was close to a fresh leaflet, and little searching by the larva was required.

Larval feeding was quantified by a previously described photometric technique (Pedigo et al. 1970). With this technique, increased light transmittance through the damaged leaf was transformed into surface-area removed by using a regression equation calculated from a previous instrument calibration.

In feeding trials, individual larvae were presented leaflets in the cages described. At the onset of molting, damaged leaflets were replaced with fresh leaflets, and light readings were taken on the damaged leaflets and recorded along with stadial length. Light readings were converted later to area removed with a computer program written for that purpose.

Termination of the larval stage was designated as that point at which construction of a prepupal web was initiated. Prepupae and pupae were kept in their respective larval feeding cages. Termination of the pupal stage was designated as the time of adult emergence.

Trial 1 adults were placed in greenhouse cages under conditions of 80±5°F and 40–60% RH. Trial 2 and 3 adults were placed in 11-in.-high × 1-ft² cages in a laboratory cabinet under larval rearing conditions. Water was supplied to the moths, and records were kept of date of emergence, sex, and date of death.

Estimation of Soybean Leaf Area.—Estimates of leaf-surface area per plant were required to determine relationships between feeding damage and yield loss. Field measurements of 2 leaflets in each vertical ⅓ of 15 plants ('Amsoy' var.) were taken at ca. 2-week intervals during a complete growing season. These measurements along with the mean number of leaflets per leaf stem and leaf stems per plant were used to calculate the mean leaf-surface area per plant for soybean growth stages (Kalton et al. 1949).

Soybean Defoliation–Yield Relationship.—Use of larval leaf-consumption data in calculation of the economic-injury level required detailed knowledge of the relationship between yield loss and defoliation. Several studies have been done on this subject (Dungan 1939, 1942; Fuelleman 1944; Camery and Weber 1953; Neill 1953; Weber 1955; Anonymous 1960; Gould 1960; Begum and Eden 1965).

The most usable results for our calculations were those of Kalton et al. (1949). After designation and description of 10 soybean growth stages, they removed 10, 25, 50, 75, and 100% of the foliage in stages 1, 3, 5, 7, and 9. Most other workers removed leaves or leaflets to achieve specified percentages of defoliation, a technique that would not simulate insect damage. Kalton et al. (1949) compared results from shredding the leaves with heavy wire and removing portions of leaves, and they found them similar. They used the shredding technique for further studies. This technique is presumed to give damage more comparable to that of foliage-feeding insects than does complete removal of leaves or leaflets.

A regression of yield loss on defoliation was calculated, and curves were fitted to the data of Kalton et al. (1949); this transformed their data into a usable form in calculating the economic-injury level.

Economic-Injury Level.—Establishment of the economic-injury level of *P. scabra* on soybean by our technique also requires prediction of the market value per bushel, the approximate cost of management procedures, and their relationship. The number of bushels that yield must be increased to compensate for the total cost of management, hereafter referred to as "gain threshold," expresses this relationship.

Gain threshold was calculated by dividing the total cost of management procedures by the market value

Table 1.—Mean duration of stages of *P. scabra* from 3 feeding trials (hours ± SE).

Age group	Feeding trial 1	Feeding trial 2	Feeding trial 3
Larva			
1st instar	93.24± 3.93 (25) [a]	73.76±1.84 (17)	57.20± 2.35 (20)
2nd instar		34.47±2.01 (17)	44.15± 1.66 (20)
3rd instar	44.12± 2.62 (25)	46.41±1.48 (17)	49.75± 1.14 (20)
4th instar	49.68± 4.21 (25)	50.29±1.43 (17)	49.45± 0.72 (20)
5th instar	76.08± 4.02 (25)	59.29±3.06 (17)	57.25± 2.39 (20)
6th instar	97.76± 4.58 (25)	89.53±4.53 (17)	73.60± 4.23 (20)
7th instar	110.33± 6.89 (6)	103.50± .71 (2)	101.70± 5.90 (7)
Prepupa	33.40± 1.44 (25)	29.58±2.36 (12)	29.30± 2.45 (16)
Pupa	218.22± 3.82 (23)	218.27±4.10 (11)	239.10±12.11 (10)
Adult	266.27±23.25 (22)	211.20±9.84 (10)	190.70±22.94 (7)
Mean total life	904.00±28.16	814.60±2.40	807.00±32.15

[a] Numbers in parentheses indicate the number of insects completing the stage, i.e., contributing to the mean.

per bushel of soybeans. Conversion of gain threshold to percentage yield loss allowed estimation of the total defoliation necessary to cause loss equal to the gain threshold. This defoliation value was then entered into the regression formulae to give the percentage of defoliation necessary to cause that percentage yield loss at growth stages 1, 3, 5, 7, and 9. Absolute defoliation necessary to cause yield loss equal to the gain threshold was calculated by multiplying the percentage defoliation necessary to cause that yield loss by the amount of total foliage present in each stage.

Economic-injury level was then calculated by dividing the amount of removal necessary to produce the gain threshold by the mean amount of foliage consumed per larva. The quotient (economic-injury level/plant) was subsequently multiplied by the number of plants per foot of row to convert this economic-injury level to row feet.

The following steps, given in order, represent a summary of this approach to calculation of the economic-injury level in numbers of larvae per row feet (EIL):

1. Gain threshold (bu/acre) = $\frac{\text{management costs (\$/acre)}}{\text{market value (\$/bu)}}$
2. % yield loss necessary = $\frac{\text{Gain threshold (bu/acre)}}{\text{projected yield (bu/acre)}} \times 100$
3. Determination of the percent defoliation necessary to cause that percent yield loss (step 2) from the regression equations of yield loss on defoliation.
4. Absolute defoliation necessary = (percent defoliation necessary) × (total foliage)
5. Plant EIL = $\frac{\text{absolute defoliation necessary (in.}^2\text{)}}{\text{foliage consumption (in.}^2\text{/larva)}}$
6. EIL = (plant EIL) × (number of plants/row ft)

Results and Discussion.—*Stadia.*—Table 1 shows the duration of each stage of *P. scabra*. Since the age of the eggs in trial 1 was not known, no comparisons with other trials can be made. The mean duration of the egg stage in the 2nd feeding trial was 129.53 hr. The lower relative humidity in the 3rd trial may have been important in the significant reduction of this value to 98.45 hr ($P<0.05$).

Analysis of variance showed that the mean life cycle (egg hatch to adult death) was significantly different among trials. Calculation of t values showed trial 1 to be significantly different from trials 2 and 3, but no difference between trials 2 and 3 was indicated. No difference in the total larval period was found among trials.

The total larval periods of 19.9, 19.0, and 18.0 days are shorter than those of Hill (1918, 1925), who reported values of 28 and 22.84 days, and Smith and Franklin (1961), who calculated a mean of 21.5 days; both studies were under summer conditions. Similarly, the prepupal periods of 1.4, 1.2, and 1.2 days are slightly shorter than those reported by Sherman (1920), Hill (1925), and Smith and Franklin (1961) (2.0, 2.0, and 1.5 days, respectively). The pupal periods, however, are intermediate to those reported by Hill (1918, 1925), Sherman (1920), Sherman and Leiby (1920), and Smith and Franklin (1961).

The period of the adult stage exhibited the greatest variability. Although similar to periods reported by others (Hill 1925, 7.3 days; Smith and Franklin 1961, 9.0 days), values from these trials (11.1, 8.8, and 7.9 days) are much shorter than those in our current *P. scabra* rearing program (unpublished data). Determination of the cause for this discrepancy requires further investigation.

Foliage Consumption.—Table 2 shows the values obtained in these trials for leaf consumption per larva. Data from 1st and 2nd instars were combined because of the extremely low consumption in each.

Table 2.—Mean soybean leaf consumption by larvae of *P. scabra* (in.^{2}±SE).

Instar(s)	Trial 1	Trial 2	Trial 3
1, 2	0.10±0.03	0.14±0.01	0.16±0.02
3	.30± .06	.30± .03	.28± .04
4	1.12± .16	1.19± .09	.84± .06
5	3.88± .35	2.81± .20	2.23± .16
6, 7	14.53± .94	12.76± .59	12.01± .55
Total	19.89± .90	17.06± .79	15.55± .48

Table 3.—Mean leaf area per plant in 5 soybean growth stages.

Plant stage	Mean leaf area/plant (in.²)
1	18.31
3	54.91
5	166.91
7	232.01
9	223.65

Although the 7th instar is mentioned in the literature as occurring only occasionally, 24.2% of the larvae in these trials had 7 stadia. Combination of the data of 6th and 7th instars was necessary because of the extremely low consumption and short duration of the 6th stadium if a 7th were to follow. The high standard error in consumption of this age group may be due to this combination.

Analysis of variance of these leaf-consumption data showed that a difference existed between the trials ($P<0.05$). The t test indicated that trial 1 differed from trials 2 and 3, with no difference in consumption between trials 2 and 3.

Soybean Leaf Area.—Table 3 shows estimates of soybean leaf area per plant by growth stage. The mean leaf area per plant is shown to increase up to stage 7 (pod fill) and decrease by stage 9 (bottom leaves yellowing and dropping).

Defoliation-Yield Relationship.—Fig. 3 shows the resultant regression formulae and curves from fitting the regression of yield loss on soybean defoliation. Sensitivity to defoliation changes with plant stage; it increases up to stage 7 and decreases thereafter. This relationship is understandable, since the stage of pod fill (stage 7) would be most critical in its photosynthate requirement.

Determination of the Theoretical Economic-Injury Level.—Calculation of the gain threshold was based on using carbaryl at 1.5 lb AI/acre. Cost of insecticide would be $1.50, based on $0.79/lb 80% sprayable (cost to pilot and normally conveyed as such to grower). Aerial application costs vary, but $1.50/acre in Iowa is a common charge and was used in the calculations. Approximate cost per acre was thus $3.00.

The market value of soybean fluctuates, so the mean of the average price per bushel paid to the grower in the past 5 years in Iowa, $2.60, was used in these calculations.

From these values, the gain threshold is $3.00/acre ÷ $2.60/bushel = 1.15 bu/acre. This value means that 1.15 bushels is the required yield gain per acre to pay exactly for the cost of treatment.

The projected yield per acre must be estimated to convert gain threshold to a percentage for use in the regression formulae. This value was estimated by taking the mean yield per acre in Iowa in 1967, 1968, and 1969. This value is 30.83 bu/acre (personal communication, H. E. Thompson, Department of Agronomy, Iowa State University, Ames. 1970).

The 1.15 bu/acre gain threshold represents 3.7% of the mean yield. The percentage defoliation necessary to cause 3.7% yield loss may be calculated from the regression equations or interpolated from the graph (Fig. 3). For plant stages 1, 3, 5, 7, and 9, these values are 52.35, 54.39, 32.78, 20.14, and 29.55%, respectively.

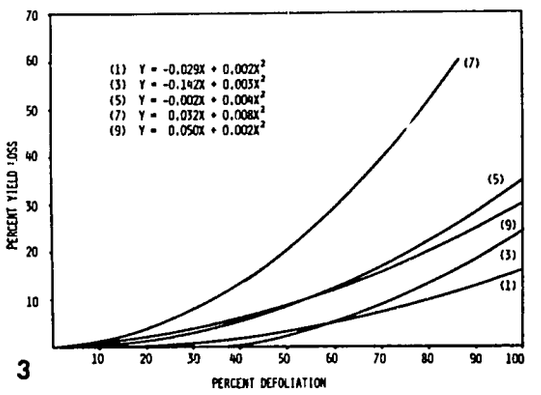
These percentages were multiplied by the amount of foliage present in each stage to obtain an estimate of the total foliage removal necessary in square inches (critical amount). For example, stage 1 has a mean of 18.31 in.²/plant (Table 3). The amount of foliage removal necessary to cause a yield loss equal to the gain threshold (3.7%) was (52.35%) (18.31 in.²) = 9.59 in.². Calculation of this value for stage 3, 5, 7, and 9 gave 29.83, 54.71, 46.73, and 66.09 in.², respectively.

The number of larvae required to consume the critical amount of foliage, i.e., the economic-injury level, was then determined by dividing the critical amount by the amount consumed per larva. Since the 2nd and 3rd feeding trials were more representative of Iowa field conditions, the mean of consumption in trials 2 and 3, 16.31 in.², served as consumption per larva. The theoretical economic-injury level for stage 1 thus becomes:

$$\frac{\text{Critical foliage removal (in.}^2\text{)}}{\text{Foliage consumption/larva (in.}^2\text{)}} = \frac{9.59 \text{ in.}^2\text{/plant}}{16.31 \text{ in.}^2\text{/plant}} = 0.59 \text{ larvae/plant.}$$

For stages 3, 5, 7, and 9, the theoretical economic-injury level calculated in this manner was 1.83, 3.35, 2.87, and 4.05 larvae/plant.

Conversion of these values to a standard 10 plants/



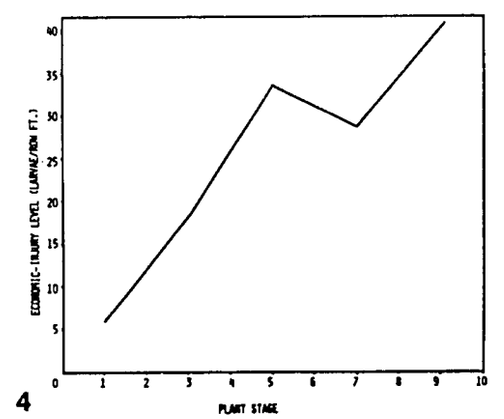


FIG. 3.—Regression of yield loss on defoliation of soybean. From the data of Kalton et al. (1949). Plant stage shown in parentheses.

FIG. 4.—Theoretical economic-injury level of *P. scabra* on soybean in Iowa at various plant stages.

row foot yields values of 5.9, 18.3, 33.5, 28.7, and 40.5 larvae per row foot (Fig. 4). The theoretical economic-injury level increases almost linearly up to growth stage 5, drops at stage 7 because of increased plant sensitivity, and increases again to stage 9. These values indicate that large numbers of *P. scabra* may be tolerated on soybeans without loss sufficient to pay for management procedures.

Results of stadial and leaf-consumption trials with the green cloverworm, indicate that significant differences may occur in these characteristics under different environmental conditions. Under quasi-field conditions, the larval foliage consumption may range from 15.55 to 17.06 in.^{2} during an 18– to 19-day larval period. These values may be combined with estimates of total leaf area per plant, defoliation-yield relationship, management costs, and projected yield to calculate the theoretical economic-injury level of this species on soybean in Iowa. The values obtained in this manner suggest that large population densities are required to cause sufficient damage to pay for treatment, and, thus, that existing treatment levels should be raised. Field tests of these values with experimental infestations are planned.

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Response of Soybeans to Foliage Losses in South Carolina[1]

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ABSTRACT

Defoliations of 17, 33, 50, and 67% were made during periods of insect activity on soybeans at midbloom, pod-set, pod-fill, and on a continued basis from midbloom to pod-set.

Foliage losses of 33% at bloom did not result in significant yield losses in any of 10 tests; 67% defoliation at pod-set, or on a continued basis from bloom to pod-set caused greatest losses; and 17% defoliation did not cause significant losses at any stage of growth or on a continued basis. Yield losses from defoliations at pod-fill were intermediate between those at bloom and pod-set. Yield reductions were generally accompanied by reductions in seed weight and protein content and increases in oil content. Seed germination was not affected. Although results were not affected significantly by date of planting and by use of irrigation or different varieties, there was a tendency toward generally lower yields at high production levels in the 'Hampton' variety after severe defoliations (50 and 67%) at bloom and pod-fill.

It was concluded that foliage losses of 17 or 33% allowed additional light penetration to lower leaves, resulting in compensation by increased photosynthate production in these leaves.

Recommendations for control of foliage-feeding insects on soybeans have been made with insufficient information on effects of foliage losses on yield and quality. Insects that often consume a high percentage of foliage in August and September include the Mexican bean beetle, *Epilachna varivestis* Mulsant; the green cloverworm, *Plathypena scabra* (F.); the corn earworm, *Heliothis zea* (Boddie); the soybean looper, *Pseudoplusia includens* (Walker); and the velvetbean caterpillar, *Anticarsia gemmatalis* Hübner. Since these insects feed most often in mixed populations rather than separately, total defoliation thresholds under various field conditions are more meaningful than separate thresholds for individual species.

Defoliation studies of indeterminate northern soybean varieties have been concerned primarily with plant response to simulated hail injury (Dungan 1939, Fuellman 1944, Kalton et al. 1945, Camery and Weber 1953, Weber 1955, McAlister and Krober 1958, Weber and Caldwell 1966, Johnston and Pen-

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Table 1.—Dates of defoliation of different soybean varieties from 1962 to 1967.

Variety	Year	Dates of defoliations		
		Midbloom	Pod-set	Pod-fill
Jackson[a]	1962	Aug. 3	Aug. 31	Sept. 20
Hampton[a]	1963	Aug. 8	Sept. 5	Oct. 2
	1964	Aug. 7	Sept. 2	Oct. 2
	1965	Aug. 9	Sept. 6	Sept. 30
Bragg[a]	1965	Aug. 7	Sept. 3	Sept. 30
	1967	Aug. 3	Aug. 30	
JEW 46[b]	1965	Aug. 19	Sept. 9	Sept. 30
Hardee[b]	1965	Aug. 26	Sept. 21	Oct. 14

[a] Planted in late May (full-season).
[b] Planted June 22 (late-planted).

dleton 1968). However, Gould (1960, 1963) compared artificial with natural defoliations by the Japanese beetle, *Popillia japonica* Newman, in Indiana. Also, Rosas (1967) removed 8.3–50.0% of soybean foliage at different plant ages to determine effects of defoliating insects in Brazil. These studies indicated that soybeans generally compensated for rather high percentages of defoliation prior to seed enlargement.

Most reports on the effects of defoliation by insects came from southern States and involved determinate varieties of soybeans. Sherman (1920) stated that early August defoliation by the green cloverworm in North Carolina ruined early-maturing varieties, but that late-maturing varieties recovered. Nickels (1926) observed that defoliation from the

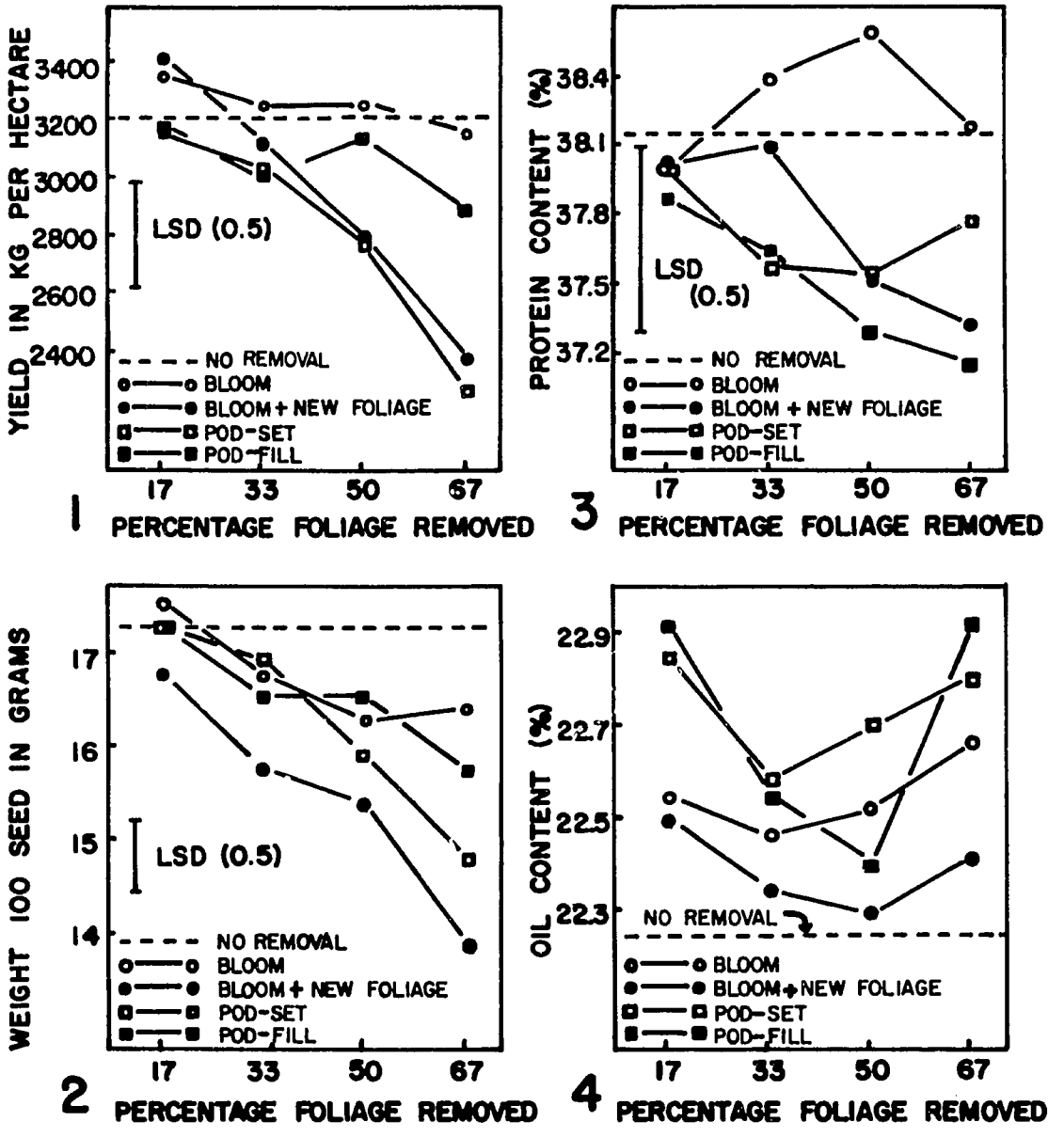

FIG. 1–4.—Yield, seed weight, protein, and soil content of Jackson soybeans after different percentages of defoliation at various stages of growth. 1962.

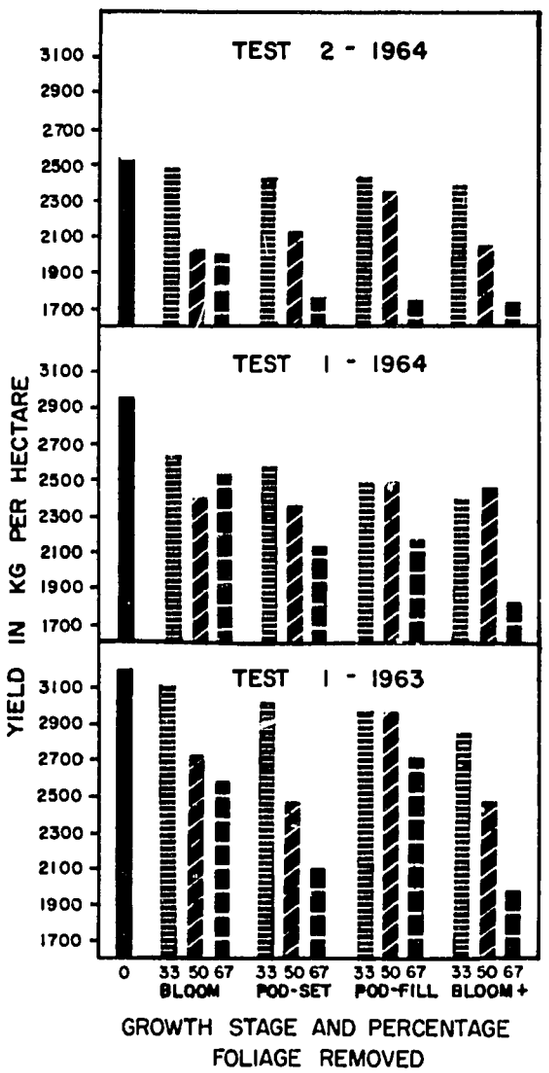

FIG. 5.—Yield of Hampton soybeans after different percentages of defoliation at various stages of growth from 1 test in 1963 and 2 tests in 1964.

velvetbean caterpillar and the corn earworm in South Carolina caused yield reductions as high as 70% in some varieties and as low as 5% in others. In Arkansas, Miner (1963) observed that insecticidal applications based on light or moderate foliage damage did not appear to be justified economically. Begum and Eden (1965) indicated that yields in Alabama were not significantly affected by 33% foliage removal at blooming, but that the same removal when pods were half filled caused significant yield reduction. They also reported that 67 or 100% defoliations caused significant yield reductions at both stages of growth, and that effects of defoliation were less important after pods were filled completely.

The study reported here was undertaken to determine the response of soybeans to different degrees of foliage loss at stages of growth corresponding to periods of insect activity and to determine effects of variety, irrigation, and date of planting on this response. Studies were conducted from 1962 through 1967.

MATERIALS AND METHODS.—In 1962, defoliations were made on 'Jackson' soybeans planted in late May. Plots consisted of 1 row (1.02 m wide × 3.66 m long) separated by 1 guard row replicated 4 times in a randomized block design. Soybeans were grown by using recommended cultural practices and sufficient application of insecticides to eliminate natural foliage losses from insects. Foliage was removed by cutting (with scissors) ½ of 1 leaflet from each leaf for 17% defoliation, 1 leaflet for 33%, 1½ leaflets for 50%, and 2 leaflets for 67%. Treatments were made at midbloom, at pod-set when most pods were full length and seed were just beginning to enlarge, at pod-fill when 90% or more of the pods were completely filled, and on a continued basis beginning at midbloom, with new growth being cut at 2 biweekly intervals thereafter (bloom + new foliage). No new leaves developed after the pod-set stage.

Responses of the 'Hampton' variety to defoliations of 33, 50, and 67% at bloom, pod-set, and pod-fill were determined in 1 test in 1963 and 2 tests in 1964. Methods were similar to those used in 1962.

In 1965, a split-plot design was used to compare 33 and 67% leaf removals at bloom, pod-set, and pod-fill on the Hampton and 'Bragg' varieties planted early (May 31) and receiving irrigation, on Hampton and Bragg planted early and without irrigation, and on the 'Hardee' and 'JEW 46' varieties planted late (June 22). Irrigated plots received ca. 1½ in. of water on Aug. 20, Sept. 4, and Sept. 24 from large overhead booms. Other methods were similar to those of 1962.

In 1967, defoliations of 17 or 33% at bloom and 0 or 17% at pod-set were made on the Bragg variety to determine effects on leaf number and yield. Methods were similar to those of 1962.

Table 1 gives dates of defoliation treatments for all tests. Soybeans from all tests were cut, threshed, dried, and weighed. Oil and protein content of seeds were determined by personnel of the U. S. Regional Soybean Laboratory in Urbana, Ill.

RESULTS.—Removal of 17 to 67% of foliage at midbloom did not reduce yields of Jackson soybeans in 1962 (Fig. 1), and although yields were reduced somewhat following removals at pod-fill, these reductions were not significant. Yields were reduced significantly by 50 and 67% removals at the pod-set stage and on a continued basis (bloom + new foliage). Reductions in seed weight (Fig. 2) were more pronounced but corresponded generally with yield reductions. Protein content (Fig. 3) was reduced except at the bloom stage, and oil content (Fig. 4) increased slightly but not significantly after all treatments.

Responses were similar in Hampton soybeans in 1 test in 1963 and 2 tests in 1964 (Fig. 5). Lowest yields were obtained from 50 and 67% removals at the pod-set stage and on a continued basis (bloom +). There were no significant yield decreases in any of these tests after 33% removal at midbloom. However, yields were generally lower following the more severe (50 and 67%) defoliations at bloom and pod-fill.

In 1965, there were no significant variety × leaf removal interactions in tests comparing different varieties planted late, not irrigated, or irrigated (Fig. 6).

In late plantings, yields were significantly lower only after 67% defoliation at bloom and pod-set in the Hardee variety and after 67% at pod-set in the JEW 46 variety. The only significant reduction in the nonirrigated Hampton variety was with 67% removal at pod-set. There were no significant yield differences in treatments with the nonirrigated Bragg variety. With irrigation, significant reductions were observed after 67% defoliation of the Bragg variety at pod-set and in the Hampton variety after 67% at pod-set and 33 and 67% at pod-fill. Although data are not shown, yield and seed weight were correlated significantly in each of the tests, with seed weights being lower for all treatments that caused yield reductions.

In 1967, low-level defoliations on the Bragg variety at bloom and at bloom plus pod-set did not cause

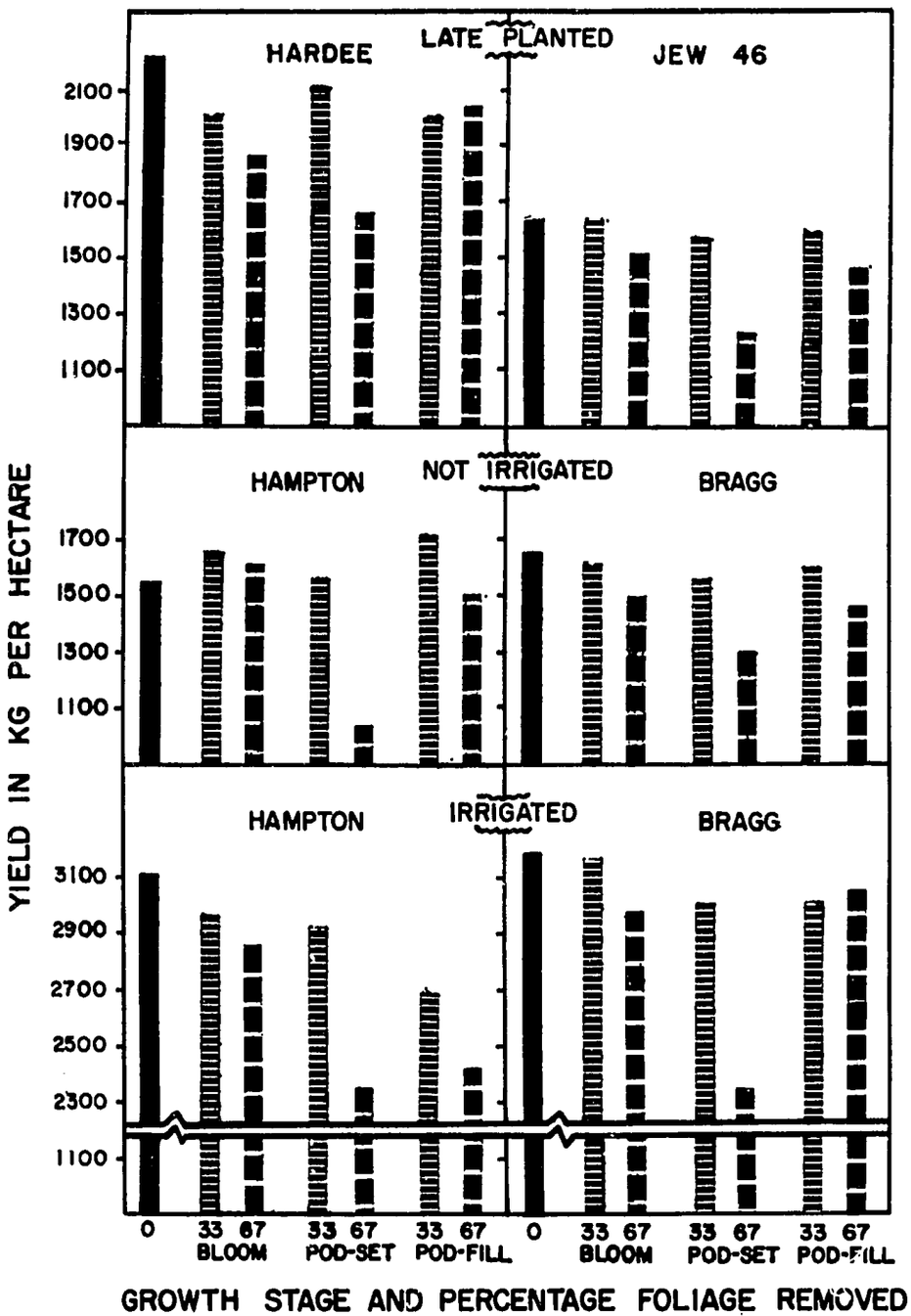

FIG. 6.—Yield of irrigated and nonirrigated Hampton and Bragg and late-planted Hardee and JEW 46 soybeans after different percentages of defoliation at various stages of growth. 1965.

Table 2.—Effect of low-level leaf removals at bloom and at bloom plus pod-set on leaf number and yield of Bragg soybeans. 1967.

% foliage removed		No. leaves on 45.7 cm of row		Yield[a] (kg/ha)
Bloom	Pod-set	Bloom	Pod-set	
17	0			2829.1 a
17	17			2465.4 a
33	0	140.1	236.3	2849.3 a
33	17			2579.9 a
0	0	125.0	207.3	2795.4 a

[a] Means followed by the same letter are not significantly different at the 5% level. Duncan's multiple range test.

significant yield reductions (Table 2). However, 17 and 33% defoliations at bloom followed by an additional 17% at pod-set did tend to cause lower yields. Development of leaves from bloom to pod-set was not influenced by a 33% defoliation at bloom.

Table 3 provides a summary of data for 33 and 67% defoliations at bloom, pod-set, and pod-fill from all tests (Fig. 1, 5, 6). Losses in yield and market value were lowest after 33% defoliation at bloom and highest after 67% at pod-set.

Although not shown, data on protein and percent oil obtained in 1963 and 1964 were similar to data from the Jackson variety in 1962. The data also showed that seed protein was significantly lower from defoliations at pod-set and pod-fill, and oil was generally but not significantly higher. Seed germination was not affected even by the most severe defoliations.

Discussion.—Removal of 33% of foliage from soybeans at midbloom did not result in significant yield losses in any of 10 separate tests, and 67% defoliation at pod-set or on a continued basis (which includes pod-set) caused greatest losses. A 17% defoliation did not cause significant yield loss at any stage of growth or on a continued basis from bloom through pod-set. Yield reductions after 50 and 67% defoliations at pod-fill were usually intermediate between similar treatments at bloom and pod-set. In treatments causing yield reductions, seed weight and protein in seed generally decreased and oil content increased.

Results were not affected significantly by different varieties, dates of planting, or use of irrigation. However, in irrigated Hamptons where level of production was high, there was a tendency toward generally lower yields after severe defoliations (50 and 67%) at bloom and pod-fill. Also, yields of the Jackson, JEW 46, and Bragg varieties were reduced very little after 50 or 67% defoliations at bloom.

Borst and Thatcher (1931) indicated that vegetative growth ceases at about the time seed enlargement starts. This period corresponds to the pod-set stage, during which yields were affected most from foliage losses. Foliage development continued 4 weeks after mid-bloom, and soybeans compensated to a large extent for foliage losses at this stage. Rate of new leaf development was not affected by 33% foliage removal. Also, Sakamoto and Shaw (1967) indicated that the periphery of the soybean canopy shaded lower leaves causing them to receive inadequate radiation. Foliage losses of 17 or 33% apparently allowed more light penetration to lower leaves, resulting in compensation by increased photosynthate production in these leaves.

Table 3.—Summary of yield, % yield loss, and loss in market value of soybeans receiving 33 and 67% defoliations at bloom, pod-set, and pod-fill (all tests—1962 through 1965).

Stage of growth	% defoliation	Yield (kg/ha)	% yield loss	Loss in market value ($U.S.)[a]	
				Ha	(Acre)
Bloom	33	2452.4	2.9	7.23	(2.93)
	67	2260.1	10.5	26.65	(10.79)
Pod-set	33	2366.5	6.3	15.91	(6.44)
	67	1818.2	28.0	71.29	(28.87)
Pod-fill	33	2342.7	7.8	18.31	(7.42)
	67	2149.8	14.8	37.79	(15.30)
Check	0	2524.0			

[a] Using market value of $2.75 U. S. bushel (27.3 kg.).

Recommendations for control of foliage-feeding insects in South Carolina are based on these data, and applications of pesticides are suggested only after reaching 35% defoliation through the blooming stage and 20% thereafter (Nettles et al. 1968). Cost of a single insecticidal application would approximate the loss in market value caused by 33% defoliation at bloom. Wider use and acceptance of recommendations based on overall defoliation thresholds would result in substantial reductions in the pesticidal load on soybeans. A reduced pesticidal load would cause adequate suppression of many populations of defoliators by allowing development of natural enemies such as diseases, predators, and parasites.

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Transmission of Bean Pod Mottle Virus by Bean Leaf Beetles

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Disease surveys of soybeans [*Glycine max* (L.) Merr.] during the last 3 years revealed a high percentage of plants infected with bean pod mottle virus (BPMV) in fields with heavy infestations of bean leaf beetle [*Ceratoma trifurcata* Forst.]. This virus was first described on bean (*Phaseolus vulgaris* L. var. Tendergreen) (7). It was later found infecting soybean plants in Arkansas (6) and North Carolina (4) and is now widespread in soybeans throughout Arkansas. Shepherd (3) reported an isolate of cowpea mosaic virus (CPMV) from Arkansas and one from Trinidad were serologically closely related, but not identical. He also showed that the 2 isolates of CPMV were antigenically related to BPMV. Smith (5) transmitted a mosaic virus of cowpea present in Louisiana, Arkansas, and Indiana with the bean leaf beetle; and Dale (1) reported that a related bean leaf beetle (*Ceratoma ruficomis* Oliv.) was a vector of the Trinidad cowpea mosaic virus. This paper reports the transmission of BPMV from naturally infected soybean plants to Black Valentine bean and Dortchsoy 67 soybean by the bean leaf beetle (*C. trifurcata*).

Bean leaf beetles were collected from a field of Lee soybeans near Wilson, Ark., in which approximately 95% of the plants were infected with a virus which caused distinct mottling symptoms, particularly in the young trifoliate leaves. Approximately 100 beetles were placed in each of 3 cages, 2 of which contained potted soybean seedlings, and the other bean seedlings. After the insects had fed 4 days, the plants were removed from the cages and observed for symptoms. Feeding injury ranged from a few tissue breaks caused by the insects' mandibles in search of suitable feeding sites to almost complete consumption of the plant, including feeding on stems, cotyledons, and leaflets. Approximately 3 weeks after the test feeding, 11 of 16, or 69% of the bean plants developed systemic mottling in the young trifoliate leaves. With the soybean plants, 21 of 35, or 60% showed virus symptoms. No controls were used in these tests.

In other tests, field-collected beetles were placed in plastic bags containing field-collected, virus-infected soybean leaves and were transported in an ice chest. In the laboratory, the plastic bags were transferred to a constant temperature chamber at 7°C. After 4 days, they were removed from the cool chamber and brought to room temperature. The beetles became active and fed on leaves in the plastic bags for 2 hr. The desired number of beetles then were transferred to a small cage clipped to a primary leaf of 1 of 2 seedlings in a 4-in. pot of either bean or soybean and allowed to feed for 12 hr. In one test with 5 beetles/cage, 5 of 8, or 63% of the bean plants became infected. When 2 beetles were caged on individual plants, 8 of 10 bean plants and 6 of 10 soybean plants became infected. No infection occurred in any of the check plants.

Assays for the virus were made from all test plants on primary leaves of seedlings of both Pinto and Black Valentine beans. When test plants exhibited systemic symptoms after beetle feeding, the inoculated leaves of Pinto bean assay plants developed local lesions and veinal necrosis with no systemic infection. Systemic symptoms followed by pod mottling occurred in all Black Valentine assay plants inoculated with sap from infected test plants.

The physical properties of the virus isolated from naturally infected soybean plants and an isolate from a composite of 12 plants infected with virus transmitted by bean leaf beetles were compared with a known isolate of BPMV from soybean reported previously (6). With BPMV, plants of bean var. Pinto and Bountiful develop only local lesions, whereas those of Sutter Pink and Black Valentine become systemically infected with the pods of the latter mottled (4, 7). No differences in symptoms were observed when similar test plants were inoculated with each of the 3 virus isolates at dilutions of 10^{-4}. No infection occurred at dilutions of 10^{-5}. These isolates were inactivated by heating to 75°C for 10 min, but not at 70°C. In gel-diffusion serological tests (2) with antiserum provided by Dr. J. B. Bancroft, the 3 virus isolates were antigenically not distinguishable.

These data show that the characteristics of both isolates of the unknown virus are similar and are the same as those described for BPMV (7) and that bean leaf beetles are efficient vectors of the bean pod mottle virus.

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Part 4

INSECTICIDE RESIDUES

Insecticide Residues in Soybeans Grown in Soil Containing Various Concentrations of Aldrin, Dieldrin, Heptachlor, and Heptachlor Epoxide

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SEVERAL investigations have reported on the translocation of aldrin, dieldrin, heptachlor, and heptachlor epoxide in crops grown on treated soil. Lichtenstein (*5–8*), working with vegetable crops, found the highest residues in root crops such as carrots and radishes. Peanuts grown in soil treated with aldrin and heptachlor contained significant amounts of dieldrin, heptachlor, and heptachlor epoxide, as reported by Beck (*1*) and Bruce (*2*). Soybeans grown on heptachlor-treated soil contained heptachlor and heptachlor epoxide according to Eden and Arthur (*4*). Bruce (*2*) established a direct relationship between oil content of seeds and residue content of crops grown on aldrin- and heptachlor-treated soil.

Because of the economic importance of soybeans in Illinois and the large

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A 4-year residue study of soybeans grown on soil treated with aldrin and heptachlor establishes a basis for computing the amount of pesticides translocated into soybeans from soils of known residues. Aldrin and heptachlor granules were applied and soil was analyzed during each growing season to find the average residue levels. The level of insecticide in soybeans from each plot was related to the concentration of pesticide in the soil. Through the 4 years of study the residues decreased in both the soybeans and the soil—e.g., soybean residues from the 2-pound-per-acre treatment decreased from 0.066 p.p.m. of heptachlor plus heptachlor epoxide in 1961 to 0.007 p.p.m. in 1964 and from 0.043 p.p.m. of aldrin plus dieldrin in 1961 to 0.006 p.p.m. in 1964. Soil residues were 10 to 15 times as great as the soybean residues.

Table I. Recovery of Heptachlor Epoxide and Dieldrin from 500-Gram Samples of Soybeans Fortified with Pesticide

P.P.M. Added	P.P.M. Recovered[a] Heptachlor epoxide	Dieldrin
0.050	0.046	0.045
0.024	0.021	0.022
0.012	0.010	0.009
0.006	0.003	0.004

Probability	Heptachlor Epoxide, Md	Dieldrin, Md
0.05	0.0248	0.0216
0.01	0.0343	0.0290

[a] Average of six replicate analyses by specific methods.

number of acres of soil treated with aldrin and heptachlor for the control of soil insects, experiments were initiated in 1961 to establish the relationship between residues found in soil and those found in soybeans.

Method of Study

Clay loam soil plots measuring 20 × 100 feet were treated once April 14, 1961, with 5% aldrin and 5% heptachlor granules at rates of 2, 5, 10, and 20 pounds of chemical per acre. A small 10-foot broadcast applicator calibrated to deliver 40, 100, 200, and 400 pounds of granules per acre was used to treat the soil, which was disked just after application. Soybeans were grown on these plots for 4 successive years. The harvested beans were stored in a refrigerated room until they were analyzed. Soil samples, consisting of 50 6-inch cores, were collected twice during each growing season from each plot and frozen until analysis. Analyses of soil and soybeans were replicated five times.

Methods of Extraction, Cleanup, and Analysis. For each analysis, 500-gram replicates of soybean seed were first rinsed with 1000 ml. of hexane to remove possible external residue. Less than 1% of the total seed residue was found in the hexane rinse. The beans were then finely ground and extracted with 2000 ml. of 10% acetone in hexane. From the 500-gram sample of soybeans, approximately 85 to 90 grams of soybean oil were obtained for analysis. Oils extracted from the beans were saponified with 200 ml. of 50% KOH and 400 ml. of 95% redistilled ethyl alcohol. Oil extracts containing heptachlor and heptachlor epoxide residue were saponified with warm KOH and alcohol for 15 minutes to prevent degradation of the pesticides. Oils containing aldrin and dieldrin residue were heated 1 hour on the steam bath with the saponification mixture. The pesticides were recovered by adding 800 ml. of water to the saponified mixture and extracting with four successive 200-ml. portions of hexane. After combined hexane extracts were

Table II. Comparison of Residues in Soybeans with Soil Residues and Soybean Residues Calculated from Soil Concentrations of Aldrin and Dieldrin, P.P.M.

Treatment, Lb. Aldrin per Acre	Year	Soil Residue Aldrin	Soil Residue Dieldrin	Soybean Residue, Aldrin + Dieldrin Found	Soybean Residue, Aldrin + Dieldrin Calcd.[a]
2	1961	0.206	0.184	0.043	0.038
	1962	0.039	0.214	0.026	0.020
	1963	0.017	0.157	0.017	0.014
	1964	0.011	0.081	0.006	0.007
5	1961	0.280	0.490	0.066	0.069
	1962	0.121	0.513	0.052	0.052
	1963	0.056	0.529	0.044	0.046
	1964	0.019	0.214	0.020	0.018
10	1961	0.960	0.717	0.176	0.164
	1962	0.235	1.089	0.105	0.108
	1963	0.116	0.869	0.075	0.078
	1964	0.032	0.445	0.034	0.037
20	1961	2.535	1.042	0.330	0.371
	1962	0.645	1.402	0.147	0.178
	1963	0.398	1.425	0.113	0.152
	1964	0.054	0.942	0.066	0.076

[a] Calculated soybean residue = p.p.m. aldrin in soil × 0.116 + p.p.m. dieldrin in soil × 0.074.

Table III. Comparison of Residues in Soybeans with Soil Residues and Soybean Residues Calculated from Soil Concentrations of Heptachlor and Heptachlor Epoxide, P.P.M.

Treatment, Lb. Heptachlor per Acre	Year	Soil Residue Heptachlor	Soil Residue Hept. epoxide	Soybean Residue, Hept. + Hept. Epoxide Found	Soybean Residue, Hept. + Hept. Epoxide Calcd.[a]
2	1961	0.421	0.027	0.066	0.042
	1962	0.186	0.141	0.021	0.025
	1963	0.095	0.140	0.018	0.016
	1964	0.030	0.039	0.007	0.005
5	1961	1.140	0.045	0.121	0.112
	1962	0.536	0.337	0.074	0.068
	1963	0.237	0.230	0.038	0.034
	1964	0.045	0.132	0.012	0.011
10	1961	1.961	0.100	0.196	0.194
	1962	0.872	0.667	0.119	0.116
	1963	0.539	0.525	0.076	0.077
	1964	0.177	0.228	0.031	0.028
20	1961	3.321	0.178	0.308	0.329
	1962	1.548	1.169	0.198	0.206
	1963	0.962	0.801	0.110	0.131
	1964	0.512	0.399	0.066	0.069

[a] Calculated soybean residue = p.p.m. heptachlor in soil × 0.0964 + p.p.m. heptachlor epoxide in soil × 0.0483.

washed several times with distilled water, cleanup procedures continued in the usual manner, as described in the Shell Method Series (*13*). Replicate soil samples, 500 grams each, were extracted with 2000 ml. of 10% acetone in hexane and cleaned up by column chromatography. Two chromatographic columns, 330 × 19 mm., containing MgO-Celite and Florisil were found adequate for the three kinds of analyses used. The Florisil was partly deactivated by adding 5% water, in order that dieldrin and heptachlor epoxide could be quantitatively eluted with 250 to 300 ml. of 10% ether in hexane.

Aldrin and dieldrin samples were analyzed according to the specific colorimetric method of O'Donnell (*11*, *12*). Heptachlor and heptachlor epoxide were determined by the Davidow (*3*) colorimetric method.

Along with the colorimetric methods of analyses, tests using Mills' (*10*) method of paper chromatography and gas chromatography with electron-capture detection as described by Lovelock and Lipsky (*9*) were employed especially to establish residue levels below 0.04 p.p.m. The gas chromatograph was fitted with a $^1/_4$-inch stainless steel column 24 inches long packed with 60- to 80-mesh Chromosorb W containing 2.0% Epon 1001, 0.5% Viton A, and 0.2% silicon 710 fluid. The column and detector temperature was 172° C. with a port temperature of 210° C. Fifty milliliters of nitrogen per minute effected excellent resolution of pesticides peaks.

Chemical calculations were based upon recoveries from soybeans and soil fortified with known amounts of insecticides. Analytical standards run with each set of tests indicate a recovery of 80 to 95% in samples fortified with more than 0.025 p.p.m. Recovery data are shown in Table I.

Results and Discussion

As in previously reported experiments, most of the residues found in soybeans were epoxides of aldrin and heptachlor. On an average 90% of the total heptachlor residue was heptachlor epoxide and 97 to 99% of the aldrin residue in soybeans was dieldrin.

As shown in Figures 1 and 2, total residues in soybeans through the 4 years decreased faster than the total residues of the plots. This trend is explained by the fact that aldrin and heptachlor were converted into dieldrin and heptachlor epoxide during this time, and that these epoxides are not absorbed by the plants so rapidly as the parent compounds. A contributing factor may be the relative penetration rates of the pesticides through the plant membrane as influenced by the polarity of the compound. Possibly the less polar compounds, aldrin and heptachlor, may be absorbed and translocated more readily than the more polar dieldrin and heptachlor epoxide. Whether the pesticide enters the plant through a dissolved, gaseous, or solid contact phase is not known. Additional studies involving soybeans grown in nutrient solutions without soil would help to resolve this problem.

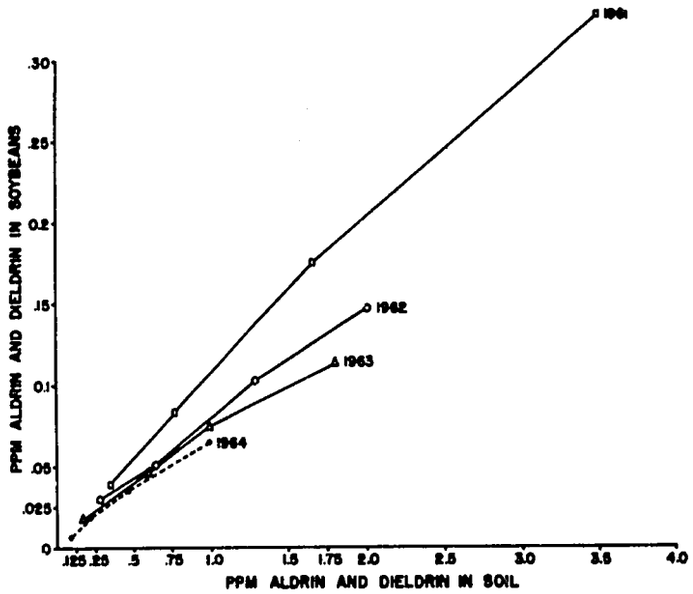

Figure 1. Residues in soybeans grown 4 successive years on soil treated once with 2, 5, 10, and 20 pounds of aldrin per acre

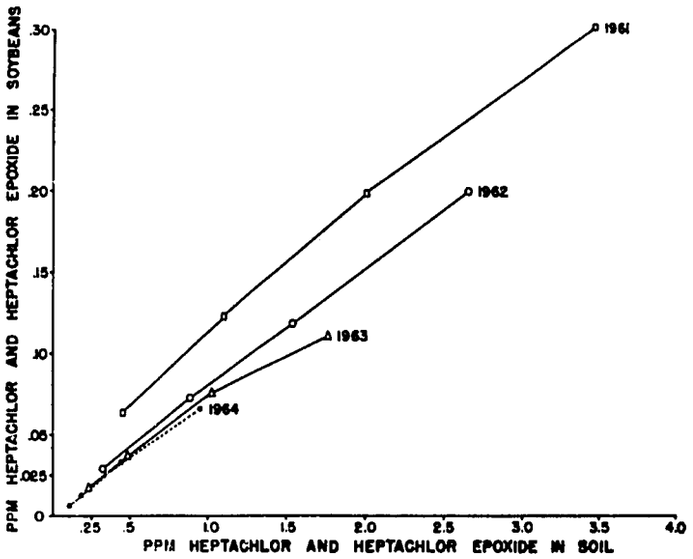

Figure 2. Residues in soybeans grown 4 successive years on soil treated once with 2, 5, 10, and 20 pounds of heptachlor per acre

The obvious conclusion is that aldrin and heptachlor contribute more to soybean contamination than do dieldrin and heptachlor epoxide. To support this conclusion, Tables II and III show the actual residues and residues calculated by a formula obtained by equating soil residue values to soybean residue values. The aldrin residue in soybeans (97 to 99% dieldrin) is equal to the sum of 0.116 times the soil aldrin and 0.074 times the soil dieldrin. The heptachlor residue in soybeans (90% heptachlor epoxide) is equal to the sum of 0.0964 times the soil heptachlor and 0.0483 times the soil heptachlor epoxide. There is a high degree of agreement between the found and calculated residues, as shown in Tables II and III.

Figures 1 and 2 graphically illustrate the direct relationship between the concentration of pesticides in the soil and residues in the soybean seed. The parts per million of total residue in the soil was 10 to 15 times the residue found in soybeans.

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