1975

Bioeconomics of Iowa soybean-insect defoliators

Freddie Lee Poston Jr.
Iowa State University

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Bioeconomics of Iowa soybean-insect defoliators

by

Freddie Lee Poston, Jr.

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major: Entomology

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1975
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PREFACE

Insect-pest problems in Iowa soybeans have resulted primarily from 2 occasional indirect pests, the green cloverworm (*Plathypena scabra* (F.)) and the painted lady (*Cynthia cardui* (L.)). Recent outbreaks of both pests occurred during 1966, 1968, and 1973. The potential thus exists for economic damage to occur from both pests in the same soybean field.

Considerable information concerning biology, life history, economics, and control of the green cloverworm is available in the literature. Little, however, is known of the painted lady. Likewise, nothing is known of damage-yield relationships in soybeans resulting from infestations of both pest species.

Bioeconomics, the study of damaging pest-population levels on a given host, is an essential component of any pest-management program. It collates pertinent biological, ecological, and economic information to define conditions that justify initiation or continuation of pest-management procedures. Using this approach, a producer can maximize crop production and minimize monetary input.

Bioeconomic studies reported in this dissertation were conducted during 1973-75 to: (1) establish a development model for the painted lady based on temperature (Part I), (2) examine the applicability of artificial damage in simulating insect defoliation (Part II), (3) determine a leaf-consumption model and an economic-injury level for the painted lady on soybeans (Part III), and (4) establish damage-yield relationships in soybeans for both pest species (Part IV).
PART I: GROWTH AND DEVELOPMENT OF THE PAINTED LADY ON SOYBEANS
ABSTRACT

Laboratory tests were performed to establish a development model for the painted lady, *Cynthia cardui* (L.), on soybeans. Growth of the painted lady, *Cynthia cardui* (L.), on soybeans was linear below 90°F. Insects reared at 65 and 90°F required ca. 73 and 22 days, respectively, for egg-to-adult development. A thermal-unit system was established for painted lady development. An accumulation of 706 thermal units was required for egg-to-adult development. Based on the thermal-unit system and field observations, only 2 generations were able to complete development in central Iowa during 1973.
INTRODUCTION

The painted lady butterfly, *Cynthia cardui* (L.), is a migratory species occurring worldwide except for most of South America and Australia (Field 1938). Mexico and the southwestern United States serve as overwintering sites for the insect and reservoirs for Iowa infestations (Williams 1970).

*C. cardui* feed on more than 100 plant species, principally of the families Malvaceae, Compositae, and Leguminosae. The species is a serious pest of maize, alfalfa, beans, sunflowers, and soybeans (Williams 1970). Recent painted lady outbreaks in Iowa soybeans occurred during 1968 (Gunderson 1968) and 1973 (Stockdale 1973). In many regions of the United States, it is considered a beneficial insect-defoliator of thistles (Cooley 1927).

Considerable documentation exists concerning the migratory behavior of *C. cardui*, but little is known of its biology. Williams (1970) states that the insect prefers dry, open areas and is unable to withstand cold temperatures during any developmental stage. Schrader (1928) observed that pupae exposed to a dry 116°F and a moist 40°F matured in 3.5 and 28 days, respectively. Kuijken (1967) observed that painted ladies reared at 25°C and 70% R.H. required 30 days for egg-to-adult development. Pupae exposed to 40°C for 65 hr and then moved to 25°C failed to mature. Adults emerged from pupae exposed to 9°C for 16 hr suffering no apparent abnormalities.
Tilden (1962) reported that mating and reproduction occurred during migration and that gravid females dropped out along the flight path. He estimated that 4-5 broods developed before a migration was spent. Kadocsa (1927) reported 2-3 generations per year in Hungary. As many as 685 larvae have been obtained from a single painted lady female (Schrader 1928).

Because of the lack of information on the development of C. cardui, studies were initiated during 1973 to: (1) determine threshold and optimum temperatures for development, (2) establish a thermal-unit system for development, and (3) determine the potential number of generations per year in Iowa soybeans.
**METHODS AND MATERIALS**

**Growth and oviposition**

Painted lady larvae were field collected and established as a greenhouse colony. The colony was maintained under conditions outlined by Pedigo (1971) for the green cloverworm (*Plathypena scabra* (F.)). Greenhouse environmental conditions were: photophase -- 15 hr (supplied from auxiliary lighting), temperature -- 80 $\pm$ 10°F, humidity -- 60 $\pm$ 20% RH. During periods of mating and oviposition, saturated sucrose solutions were provided in 25-ml erlenmeyer flasks fitted with paper wicks.

Following oviposition (24 hr), 74 eggs were removed from the colony and placed in a growth chamber. Environmental conditions were: photophase -- 15 hr, temperature -- 80 $\pm$ 1°F, humidity -- 70 $\pm$ 7% RH. Following egg hatch, the larvae were placed in separate 0.5-1 waxed cartons. An Aqua-pic® containing a greenhouse-grown soybean leaf was fixed to the bottom of the carton (Fig. 1). The lid of the carton was removed, and the top covered with nylon mesh. Larvae were examined at 24-hr intervals, and head-capule widths measured with an optical micrometer. Soybean leaves were changed as needed.

Following butterfly emergence, sex was recorded, and 17 male-female pairs were placed in separate 1.9-1 cartons. Cartons were equipped with mesh tops and Aqua-pics® as previously described. Cartons were examined daily for the presence of eggs or dead adults. Date of oviposition and number of eggs laid per female were recorded.
Fig. 1. Rearing cage used for painted lady development
Temperature-development studies

Painted lady eggs were obtained 24 hr after oviposition and placed in growth chambers (ca. 30 eggs/chamber). Chamber photophase was set at 15 hr, and humidity at 76 ± 7% RH. Humidity was maintained with a saturated NaCl solution (Winston and Bates 1960). Chamber temperatures were 55, 60, 65, 70, 75, 80, 85, and 90°F ± 1°F. A completely randomized design was used, 2 replications, each with 8 treatments (temperatures constituted treatments). Following egg hatch, larvae were placed in separate 0.5-1 cartons. A total of 346 larvae were used in the experiment. Larvae were examined at 24-hr intervals, and development was recorded. Larval-instar determinations were based on head-capule widths. Soybean leaves were changed as necessary. Pupal weights were recorded, and adults sexed following emergence.
RESULTS AND DISCUSSION

Growth and oviposition studies

Head-capsule widths (Table 1) ranged from 0.36 mm for 1st-instar larvae to 3.38 mm for 5th-instar larvae. Growth of the head capsule conformed to Dyar's rule (Wigglesworth 1961). No significant differences (P < 0.05) were observed between head-capsule widths of male and female larvae.

Table 1. Mean (X) head-capsule widths and standard deviations (SD) for painted lady larvae

<table>
<thead>
<tr>
<th>Instar</th>
<th>X</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.40</td>
<td>†</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.64</td>
<td>†</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>1.10</td>
<td>†</td>
<td>0.06</td>
</tr>
<tr>
<td>4</td>
<td>1.89</td>
<td>†</td>
<td>0.13</td>
</tr>
<tr>
<td>5</td>
<td>3.17</td>
<td>†</td>
<td>0.13</td>
</tr>
</tbody>
</table>

In the oviposition containers only 9 (53%) of the 17.4 laid eggs. The number of eggs laid during the oviposition period ranged from 3 to 937.2. The maximum number of eggs per female laid on a single day was 240. Mean durations of the pre-oviposition and oviposition periods were 10.6 and 8.6 days, respectively. Females lived significantly (t = 3.17, P<0.05) longer than males, 26.4 and 18.4 days, respectively. No marked
ovipositional preference for the upper or lower surface of the soybean leaf was observed. Eggs were laid singly and measured $0.8 \pm 0.04$-mm high and $0.61 \pm 0.03$-mm diam.

<table>
<thead>
<tr>
<th>Temperature ($^\circ$F)</th>
<th>Egg stage</th>
<th>Larval instars 1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>Larval stage</th>
<th>Pupal stage</th>
<th>Egg to adult</th>
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<tbody>
<tr>
<td>55</td>
<td>ND$^a$</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>60</td>
<td>16.2</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>65</td>
<td>8.0</td>
<td>7.6</td>
<td>6.8</td>
<td>8.6</td>
<td>12.5</td>
<td>16.8</td>
<td>47.7</td>
<td>18.2</td>
<td>72.6</td>
</tr>
<tr>
<td>70</td>
<td>5.1</td>
<td>4.4</td>
<td>4.0</td>
<td>4.1</td>
<td>5.6</td>
<td>11.8</td>
<td>29.7</td>
<td>11.8</td>
<td>45.8</td>
</tr>
<tr>
<td>75</td>
<td>4.3</td>
<td>3.4</td>
<td>3.1</td>
<td>3.9</td>
<td>5.0</td>
<td>8.3</td>
<td>23.4</td>
<td>10.4</td>
<td>36.2</td>
</tr>
<tr>
<td>80</td>
<td>3.7</td>
<td>2.5</td>
<td>2.3</td>
<td>2.8</td>
<td>3.3</td>
<td>5.2</td>
<td>16.1</td>
<td>6.2</td>
<td>25.9</td>
</tr>
<tr>
<td>90</td>
<td>3.0</td>
<td>2.3</td>
<td>2.2</td>
<td>2.3</td>
<td>3.5</td>
<td>4.1</td>
<td>13.7</td>
<td>5.4</td>
<td>22.1</td>
</tr>
</tbody>
</table>

$^a$No development.

**Temperature-development**

Mean times required for egg-to-adult development (Table 2) ranged from 72.6 days at 65°F to 22.1 days at 90°F. Eggs maintained at 55°F failed to develop, and 1st-instar larvae held at 60°F died before
molting. Data for 85°F are not shown because a laboratory insect strain possessing an additional instar was selected during the final trial in the experiment.

Regressions of the reciprocals of time required for egg, larval, pupal, and egg-to-adult development (Fig. 2) on temperature indicated that painted lady growth was linear below 90°F ($r^2 = 0.942$). The thresholds for egg, larval, pupal and egg-to-adult development estimated from the regression lines were 48.5°F, 54.7°F, 55.0°F, and 55.9°F, respectively. Data for development at 55°F were not included in the regressions.

Significantly greater mortality (Table 3) occurred at the extreme temperatures (55, 60, 65, and 90°F) than at the moderate temperatures (70, 75, and 80°F). Most mortality in the extreme temperatures occurred during the 1st larval stadium, except for an unexplained high mortality during the 5th stadium at 65°F. No significant differences in mortality were observed during the 2nd, 3rd, and 4th larval stadia, or the pupal stage.

Pupal weights for males and females at different temperatures are contained in Table 4. Females were significantly heavier at all temperatures than males. No significant differences in pupal weights were observed between temperatures.

The thermal-unit system (Newman 1971) was calculated for the painted lady on soybeans. The equation used for the system was

$$Tu = \frac{(m_1 + m_2)}{2} - mc,$$
Fig. 2. Regressions of the reciprocals of egg, larval, pupal, and egg-to-adult development on temperature.
Table 3. Mortality (expressed as percent of total) of C. cardui for each growth stage at different temperatures

<table>
<thead>
<tr>
<th>Temp. (°F)</th>
<th>Egg stage</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>Pupal stage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>100</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>100a</td>
</tr>
<tr>
<td>60</td>
<td>*b</td>
<td>100a</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>100a</td>
</tr>
<tr>
<td>65</td>
<td>*</td>
<td>30.0bc</td>
<td>10.0a</td>
<td>2.5a</td>
<td>2.5a</td>
<td>30.0a</td>
<td>0.0a</td>
<td>75.0b</td>
</tr>
<tr>
<td>70</td>
<td>*</td>
<td>17.0c</td>
<td>4.6a</td>
<td>0.0a</td>
<td>3.4a</td>
<td>11.1b</td>
<td>4.6a</td>
<td>40.6c</td>
</tr>
<tr>
<td>75</td>
<td>*</td>
<td>6.1c</td>
<td>3.6a</td>
<td>5.0a</td>
<td>7.2a</td>
<td>0.0b</td>
<td>0.0a</td>
<td>21.8c</td>
</tr>
<tr>
<td>80</td>
<td>*</td>
<td>24.9bc</td>
<td>1.5a</td>
<td>7.5a</td>
<td>3.3a</td>
<td>0.0b</td>
<td>2.5a</td>
<td>39.7c</td>
</tr>
<tr>
<td>90</td>
<td>*</td>
<td>45.0b</td>
<td>15.0a</td>
<td>12.5a</td>
<td>0.0a</td>
<td>5.0b</td>
<td>0.0a</td>
<td>77.5ab</td>
</tr>
</tbody>
</table>

Numbers followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

Asterisk indicates no measurement taken.

Table 4. Mean pupal weights (mg) for male and female C. cardui at different temperatures

<table>
<thead>
<tr>
<th>Sex</th>
<th>Temperature (°F)</th>
<th>65</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>248.0a</td>
<td>186.2a</td>
<td>318.6a</td>
<td>250.3a</td>
<td>274.5a</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>350.8b</td>
<td>302.9b</td>
<td>411.7b</td>
<td>354.1b</td>
<td>302.9b</td>
<td></td>
</tr>
</tbody>
</table>

Numbers followed by the same letter are not significantly different at the 5% level.
where:

\[ m_1 = \text{maximum daily temperature}, \]

\[ m_2 = \text{minimum daily temperature} \geq 56^\circ F, \text{and} \]

\[ m_c = 56^\circ F \text{ (minimum cardinal temperature)}. \]

The minimum cardinal temperature was obtained from the threshold for total development. If the minimum daily temperature was \(< 56^\circ F\), it was adjusted to \(56^\circ F\). If the maximum daily temperature did not exceed \(56^\circ F\), thermal units were not accumulated.

An accumulation of 706 thermal units was required for the painted lady to complete egg-to-adult development. The egg, larval, and pupal stages required 83, 447, and 176 thermal units, respectively. The 1st, 2nd, 3rd, 4th, and 5th larval instars required 67, 67, 67, 89, and 157 thermal units, respectively. Thermal-unit calculations were based on the mean percentage time for each developmental stage of the total developmental time.

During the most recent outbreak, painted lady migrants arrived in central Iowa ca. 1 June 1973. Using the thermal-unit system described and max-min temperatures (U.S. Dept. Commerce 1973a,b,c,d,e) for central Iowa, it was calculated that 2053 thermal units were available for painted lady development. Assuming eggs were laid on 1 June, the F\(_1\) generation should have matured on 11 July. Following an 11-day pre-oviposition period, F\(_2\) generation eggs should have been laid on 22 July, and should have emerged 3 September. Based on these calculations, only 2 painted lady generations could have completed development during 1973.
An insufficient number of thermal units (341) were available for 3rd-generation development.

Weekly samples taken from a naturally infested field 2 miles east of Carlisle, Iowa, tend to support these calculations. The field was first sampled 14 June 1975. Painted lady larvae were evenly distributed throughout the field at ca. 1 larva/row-ft. The field was devoid of weeds, indicating that eggs were laid directly on soybeans. Larvae collected from the field were predominantly 3rd instars. On 25 June, 5th-instar larvae were collected. On 2 July pupae were observed attached to the lower surface of soybean leaves. At that time, a total of 526 thermal units were accumulated. According to the thermal-unit system, 530 units are required for pupation.
PART II: EFFECTS OF ARTIFICIAL AND INSECT DEFOLIATION ON SOYBEAN NET PHOTOSYNTHESIS
ABSTRACT

Greenhouse and field trials were conducted during 1974-1975 to determine the effects of artificial and insect defoliation on soybean net photosynthesis. Net carbon exchange rates were measured by using an excised-leaflet technique. Cork-borer, paper-punch and along-the-midrib leaflet bisections adequately simulated defoliation of soybean leaflets by *Plathypena scabra* (F.) and *Cynthia Cardui* (L.). Across-the-midrib leaflet bisections increased net photosynthesis and, thus, did not adequately simulate defoliation by these insects. Net carbon exchange rate was significantly reduced 12 hr postdefoliation, but was not significantly different from the check 24 hr postdefoliation.
INTRODUCTION

Insect-damage simulation has been a popular technique used to establish crop damage-yield relationships independent of economic pest populations. Kalton et al. (1949) simulated hail damage to soybeans by shredding leaves and breaking stems. Stone and Pedigo (1972) used the hail data to establish an economic-injury level for the green cloverworm (GCW), *Plathypena scabra* (F.), a soybean defoliator. Turnipseed (1972) removed soybean foliage (½ or entire leaflet) with scissors to simulate damage by *Epilachna varivestis* Mulsant, *P. scabra*, *Heliothis zea* (Boddie), *Pseudoplusia includens* (Walker), and *Anticarsia gemmatalis* Hubner. Thomas et al. (1974) excised entire leaflets and pods to simulate *H. zea* damage.

The majority of simulated defoliation investigations involved the removal of entire leaflets or uniform portions of leaflets. Damage by insect defoliators, e.g., *P. scabra* and the painted lady (PL), *Cynthia cardui* (L.), usually results in a ragged appearance of the leaves. Most often, only irregular parts of leaflets, rather than entire leaves, are defoliated. Leaves rarely are excised from the plant. Hall (1975) observed a reduction in net photosynthesis of apple leaves following feeding by the mite, *Tetranychus urticae* (Koch). Little is known, however, of photosynthetic responses in soybean leaves following defoliation.

Dornhoff and Shibles (1974) reared 4 soybean cultivars (Corsoy, Amsoy, Hawkeye, and Richland) in pots under competitive field conditions.
Net carbon exchange (NCE) was measured in the laboratory by using infra-red gas-analysis techniques (Dornhoff 1971) with 340/W/m² irradiance at the leaf surface. The authors observed no significant differences between NCE rates of the different cultivars. The maximum NCE rate was ca. 39 mg dm⁻² hr⁻¹. Light saturation of early and late-season fully expanded leaves occurred at 120 and 340 W/m², respectively. These results substantiated earlier observations of Kumara and Naniwa (1965) that successively produced soybean leaves have greater NCE rates.

Beuerlein and Pendleton (1971) obtained an NCE rate of ca. 40 mg dm⁻² hr⁻¹ and light saturation at 400 W/m² in soybeans grown under normal field conditions. Other researchers (Bohning and Burnside 1956, Brun and Cooper 1967, Curtis et al. 1969, Kriedeman et al. 1964, and Kumara 1965, 1968, 1969) reported lower NCE rates for soybeans. Measurement of plants grown under low-light conditions may have been responsible for some of the discrepancies in NCE rates (Dornhoff and Shibles 1974).

Dornhoff and Shibles (1974) examined attached and excised soybean leaves and observed a 50% reduction in the NCE rates of excised leaves. They stated, however, that increased chamber humidity (above 60% R.H.) could decrease the effects of leaf excision.

Pearce et al. (1976) developed a rapid technique for measuring NCE rates by using excised-leaf sections. Excised leaves were collected and maintained in a holding chamber at ca. 100% R.H. preceding measurement. Sections were cut from each leaf and placed in a preconditioning chamber for 20-30 min. Following preconditioning, a section was transferred to a chamber for NCE measurement with an infra-red gas analyzer. They
compared NCE rates in maize by using attached- and excised-leaf methods and obtained similar results. Pearce et al. obtained NCE rates of 26-34 mg dm$^{-2}$ hr$^{-1}$ by using excised (field grown) soybean leaves. These rates compared favorably with those of Dornhoff and Shibles (1970) and Curtis et al. (1969).

Studies were conducted during 1974 and 1975 using greenhouse and field-grown soybeans to determine the effects of artificial and insect defoliation on soybean net photosynthesis.
METHODS AND MATERIALS

Greenhouse trials

Studies were conducted during the winter of 1974 and spring of 1975 in the Insectary greenhouse at Iowa State University. Steele Var. soybeans were grown in 3.5-dm x 4.75-dm soils flats with plants spaced equidistantly (5 cm). A randomized complete-block design was used in all trials. Treatments in trials 1, 2, and 3-4 were replicated 15, 13, and 10 times, respectively.

Trial-1 treatments were: (1) no defoliation, (2) GCW defoliation (~25%), (3) GCW defoliation (~50%), (4) PL defoliation (~25%), (5) PL defoliation (~50%), (6) paper-punch (6.5-mm diam) defoliation (~10%), and paper punch defoliation (20%). Soybean flats receiving treatments were placed in cages 8 days before measurement. Designated flats were infested with GCW and PL larvae at that time. Cages were removed and artificial-defoliation treatments applied 24 hr preceding measurement. Leaflets were selected and excised for measurement on 4 Oct. 1974. Leaflet selections, constituting blocks, were based on: (1) leaflet location within the plant stand (center or periphery), (2) leaflet position on the plant (leaf node), and (3) leaflet position on the leaf (lateral or terminal).

Trial-2 treatments were: (1) no defoliation, (2) PL defoliation (~50%), and (3) cork-borer (1.4-cm diam) defoliation (~50%) 12-hr premeasurement. Soybean flats were placed in cages, and 1 flat was infested with PL larvae 48 hr before measurement. Cages and larvae
were removed and the cork-borer defoliation was completed 12 hr before measurement. Leaves were selected, as in trial 1, and excised for measurement on 11 Oct. 1974.

Trial-3 treatments were: (1) no defoliation, (2) GCW defoliation (~50%), (3) leaflet bisection along midrib (30% defoliation) 72-hr premeasurement, (4) leaflet bisection across midrib (50% defoliation) 72-hr premeasurement, (5) paper-punch defoliation (~50%) 12-hr premeasurement, (6) paper-punch defoliation (~50%) 24-hr premeasurement, (7) paper-punch defoliation (~50%) 48-hr premeasurement, and (8) paper-punch defoliation (~50%) 72-hr premeasurement. Soybean flats were placed in cages on 19 May 1975, and 1 flat was infested with GCW larvae. Cages and larvae were removed on 21 May, and 72-hr premeasurement treatments completed. Appropriate treatments were applied on 22, 23, and 24 May. Leaflets were selected, as in trial 1, and measured on 25 May 1975.

Trial-4 treatments were: (1) check, (2) leaflet bisection across midrib (50% defoliation) 72-hr premeasurement, and (3) paper-punch defoliation (~50%) 72-hr premeasurement. A block consisted of a single trifoliate leaf with treatments randomly assigned to the leaflets. Defoliations were completed on 22 June and leaflets excised for measurement on 25 June 1975.

Field trial

Steele Var. soybeans were hand planted on 19 May 1975 at the Kelly Farm 3.2 km west of Ames, Iowa. Plots were thinned to 8 plants/row-ft.
on 19 June 1975. A randomized complete-block design was used, 10 blocks, each with 4 treatments. Treatments were: (1) no defoliation, (2) GCW defoliation (~50%), (3) leaflet bisection across midrib (50% defoliation) 96-hr premeasurement, and (4) paper-punch defoliation (~50%) 96-hr premeasurement. Trifoliate leaves on the 5th plant node were selected for treatment within each plot. Treatments were applied and leaves secured in special leaf cages on 14 July 1975. GCW larvae used in the experiment were collected from a naturally infested soybean field.

Leaf cages were composed of transparent plastic petri dishes with large ventilation holes cut in the bases and lids. Ventilation holes were covered with saran screen (32 x 32 mesh). A hole was cut in the side of the dish and lined with rubber insulation for insertion of the leaf petiole. The insulation protected the petiole and prevented escape of the GCW larvae. Leaf cages were secured with tape to 9-dm wire flags for support (Fig. 3). Cages were removed and leaves excised for measurement on 18 July 1975. Leaflet selections for blocks were based on leaflet position on the leaf.

**NCE measurement**

The excised-leaf method (Pearce et al. 1976) was used for NCE measurement. Following excision, leaflets were placed between moist paper towels (1 block/towel) on a screen rack inside a styrofoam ice chest. The chest was partially filled with water to prevent leaflet desiccation. Leaflets were randomly selected from each block, and cut
Fig. 3. Cage used to confine green cloverworm larvae on soybean leaves during the field trial
into strips, and each was placed in a plexiglass slide. Slides were put in a preconditioning chamber at 5-min intervals and held there for 20-30 min. After preconditioning, a slide was transferred to the NCE measuring chamber. Each slide remained in the NCE chamber for 5 min to allow equilibration. Flow rates for trial 1, trials 2-4, and the field trial were 2, 1, and 1 l/min., respectively. Leaf temperature was 28° ± 1°C. After NCE measurement, leaflets were removed from the slides and area (Cm²) was measured. Leaflet areas were measured with a photometric device. NCE (mg CO₂ uptake dm⁻² hr⁻¹) was calculated according to the formula given by Hesketh and Moss (1963):

\[
NCE = \frac{[\text{CO}_2 \text{ uptake (ppm)} \times \text{Flow Rate (l/hr)} \times 0.53638]}{[\text{Leaf Area (dm}^2) \times \text{Chamber Temperature (°K)}]}
\]
RESULTS AND DISCUSSION

Table 5 contains the results of net-photosynthesis studies in the greenhouse and field. As indicated by the NCE rates in the check, rates were lowest on plants grown during the fall under poor light conditions. The difference between the 4 Oct. and the 11 Oct. NCE rates (5.2 and 9.3 mg CO$_2$ dm$^{-2}$ hr$^{-1}$) was attributed to differences in the air-flow rate across the leaf 2.0 and 1.0 l/min., respectively. The NCE rate of the check on 25 June (19.2) was less than that on 25 May (22.2). Plants used for experimentation on 25 May and 25 June were in growth stages V5 and R2 (plant classification of Fehr et al. 1971). As observed by Dornhoff and Shibles (1974), leaves on younger plants were less photosynthetically efficient. The NCE rate on 18 July (32.2) compared favorably to rates obtained from measurements of field-grown leaves by other researchers (Dornhoff and Shibles 1974, Beuerlein and Pendleton 1971).

In trial 1 (4 Oct.), NCE rates of the high-level (50%) insect defoliations were significantly less (P<0.05) than those of the artificial defoliations (10 and 20%) and the check. The discrepancy between rates for the insect and artificially damaged leaves was attributed to the low level of defoliation in the paper-punch treatments. No significant differences were observed between rates of the low-level (25%) insect defoliations, the artificial defoliations, and the check.

In trial 2 (11 Oct.), NCE rates of the cork borer (50%) and PL (50%) defoliations were significantly less than that of the check. Artificial
Table 5. Net-carbon exchange rates (mg CO$_2$ dm$^{-2}$ hr$^{-1}$) obtained from treatments in the greenhouse and field trials$^a$

<table>
<thead>
<tr>
<th>Damage</th>
<th>Def. (%)</th>
<th>Premeas. time (hr.)</th>
<th>Trials and dates</th>
<th>Field 18 July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check</td>
<td>5,2 ab</td>
<td>9.3 a</td>
<td>22.2 ab</td>
<td>19.2 a</td>
</tr>
<tr>
<td>GCW$^b$</td>
<td>5.2 a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCW</td>
<td>3.3 cd</td>
<td>23.0 bc</td>
<td>34.8 a</td>
<td></td>
</tr>
<tr>
<td>PLC$^c$</td>
<td>4.1 bc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PL</td>
<td>2.9 d</td>
<td>4.6 b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cork borer</td>
<td>5.2 a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>5.0 ab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>4.6 ab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>18.6 d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>19.6 ad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>21.3 abd</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>21.2 abd</td>
<td>17.3 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper punch</td>
<td>33.8 a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Along midrib</td>
<td>23.9 bc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Across midrib</td>
<td>25.7 c</td>
<td>18.4 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Across midrib</td>
<td>43.2 b</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Numbers followed by the same letter are not significantly different (P<0.05) using Duncan's multiple range test.

$^b$Green cloverworm.

$^c$Painted lady.
damage was inflicted 12 hr before rate measurement. The NCE rate of the cork-borer defoliation was not significantly different from that of the insect defoliation. The cork-borer damage, therefore, was an adequate simulation of the insect damage.

In trial 3 (25 May), the NCE rate of the 12-hr paper-punch defoliation was significantly less than that of the check. Paper-punch defoliations, having greater time lapses (24, 48, and 72 hr) between damage and measurement, were not significantly different from the check. These results indicated a temporary NCE-rate depression 12 hr after defoliation and a subsequent recovery 24 hr after defoliation.

Likewise, the NCE rate of the GCW defoliation was not significantly different from that of the check, the 48-hr defoliation, or the 72-hr defoliation. It was, however, significantly different from those of the 12-hr and 24-hr defoliations. The NCE rate of the along-the-midrib defoliation was not significantly different from that of the check or the GCW defoliation. The rate of the across-the-midrib defoliation, however, was significantly greater than that of the check. This indicated an increase in net photosynthesis as a result of that type of damage.

In trial 4 (25 June), treatments (3) were randomized across leaflets on a single leaf (1 trifoliate leaf = 1 block) to minimize plant variation. No significant differences were observed between NCE rates of the check, paper-punch defoliation, or the across-the-midrib defoliation.
In the field trial (18 July), NCE rates of the check, the GCW defoliation, and the paper-punch defoliation were not significantly different. The paper-punch defoliation again was an adequate simulation of the insect damage. The rate of the across-the-midrib defoliation, however, was significantly greater than those of the other treatments. The across-the-midrib defoliation, therefore, was an inadequate simulation of insect defoliation. This phenomenon may have resulted from differences in photosynthetic efficiency in various areas of a leaflet. Specifically, the proximal end of a soybean leaflet may have a greater NCE rate than the distal end.¹

CONCLUSIONS

Cork-borer, paper-punch, and along-the-midrib defoliations adequately simulated insect damage based on their effects on leaflet photosynthesis. It may be necessary, however, to consider other factors (e.g., light diffusion within the plant canopy) before an accurate evaluation can be made. An NCE-rate depression was observed 12 hr after defoliation, and a recovery 24 hr after defoliation. Across-the-midrib defoliations caused an increase in NCE rate (compared with the check) in 2 of 3 trials. In the field trial, the NCE rate was significantly greater, and thus did not adequately simulate the insect defoliation. Across-the-midrib defoliation, therefore, is considered a questionable technique for simulation of insect defoliation in soybeans.
PART III: ECONOMIC-INJURY LEVEL AND LEAF-CONSUMPTION MODEL
FOR THE PAINTED LADY ON SOYBEANS
ABSTRACT

Soybean-leaf consumption studies were conducted with the painted lady, *Cynthia cardui* (L.), during 1975. Soybean-leaf consumption was measured for treatments of 1, 2, and 3 larvae/container. Crowding had no effect on larval mortality, development, or leaf consumption at these levels. Leaf consumption per larval instar was regressed on the thermal units required for successive instar development to establish a leaf consumption model. Economic-injury levels of ca. 2 and 16 larvae/row-ft were calculated for the 2- and 6-trifoliate leaf stages.
INTRODUCTION

The painted lady, *Cynthia cardui* (L.), is a migratory pest of Iowa soybeans. The species overwinters in Mexico and the southwestern United States, migrating north in the spring (Williams 1970). Eggs are laid on Iowa soybeans during early June when plants are in initial growth stages. Early instar larvae web protective coverings over prospective feeding sites and skeletonize the leaves. Late-instar larvae web leaflets together, forming feeding enclosures. A larva constructs and feeds on several enclosures before pupating (Pedigo 1974). Based on a minimum cardinal temperature of 56°F, an accumulation of 530 and 706 thermal units are required for larval stage and egg-to-adult development, respectively (Part I, p. 15).

Recent painted lady outbreaks occurred in Iowa during 1968 and 1973. Approximately 110,000 (Gunderson 1968) and 14,000 (DeWitt 1973) soybean acres were treated with insecticides in those years, respectively. Treatment was recommended if numbers exceeded 3-4 larvae/3 row-ft (Stockdale 1973). Evidence to support these recommendations, however, is lacking in the literature.

The economic-injury level (EIL), i.e., the lowest population density that will cause economic damage (Stern et al. 1959), is a fundamental principle of integrated control (Smith 1968). Stone and Pedigo (1972) established an EIL for *Plathypena scabra* (F.) on soybeans by using a deductive laboratory approach. Control costs, crop market value, and defoliation-yield data were integrated with *P. scabra* leaf consumption. Soybean defoliation-yield relationships were obtained
by regression analysis of hail-simulation data (Kalton et al. 1949). Stone and Pedigo's approach, however, may be criticized because it fails to account for effects of intraspecific competition (crowding) on larval leaf-consumption.

Researchers have observed substantial effects in insect populations resulting from crowding. Jaques (1962) found that crowding of *Trichoplusia ni* (Hübner) caused a reduction in food consumption, sporadic feeding, excessive energy dissipation, and increased disease susceptibility. Stressed larvae often died from normally nonfatal infections. Park (1938) observed decreased larval survivorship among crowded *Tribolium confusum* Jacquelin du Val in flour that was changed infrequently. Crowded cultures of *Sitophilus oryzae* (L.), *S. granarius* (L.), and *T. confusum* produced small adults (Richards 1948, Birch 1953). Snyman (1949) observed a reduction in the oviposition rate of *Plodia interpunctella* (Hubner) following crowding of the larvae.

Pedigo (1974) infested 1 row-ft. soybean plots (beginning bloom stage) with 0, 5, 10, and 15 *C. cardui* (late-instar) larvae. Treated plots were evaluated for insect survivorship, defoliation (%), and subsequent yield reductions (bean weight). Pedigo found that 7 larvae/row-ft significantly reduced soybean yield, but that 5 larvae/row-ft did not. Larval survivorship at the low, medium, and high infestation levels (90, 70, and 47%, respectively) differed significantly. Estimates of defoliation were positively correlated with larval survivorship and plot yield. Pedigo stated that, as population intensity approached 15 larvae/row-ft, crowding became an important factor in
survivorship.

Studies were initiated during 1975 to: (1) quantify painted lady feeding on soybeans, (2) determine the effects of crowding on larval feeding, development, and survivorship, (3) establish a leaf-consumption model based on temperature, and (4) establish EIL's for the painted lady on soybeans.
METHODS AND MATERIALS

Leaf consumption

Painted ladies were maintained in a colony under conditions outlined previously (Part I, p. 5). Adults were placed in a cage and eggs removed 24 hr after oviposition. Eggs were placed in a growth chamber with environmental conditions set at 75° ± 1°F, the optimum temperature for survivorship, 70 ± 7% RH, and a 15-hr photophase. Humidity was maintained with a saturated NaCl solution (Winston and Bates 1960). Following egg hatch, a larva was placed in a 0.5-L waxed carton on a soybean leaf (terminal leaflet removed). The lid of the carton was removed, and the container covered with nylon mesh. Soybean leaves were replaced as needed.

A completely randomized design was used, 20 replications of 3 treatments. Treatments constituted 1, 2, and 3 larvae container with the 1 larva/carton treatment as the control. Cartons were checked daily for larval mortality and development. In the 2 and 3 larvae/carton treatments, development was based on mean development per container. Larval instars were determined according to head-capsule widths (Part I, p. 9).

Leaf consumption was measured after each larval stadium with a LI-COR™ leaf-area meter. Pupal weights were recorded, and adults sexed following emergence.
Soybean leaf surface area

Steele Var. soybeans were removed from the field twice weekly (10 plants/date). Leaf-surface area per plant was measured with a leaf-area meter. Plant population (plants/row-ft) was estimated by counting the number of plants per row at 10 locations within the field.
RESULTS AND DISCUSSION

Leaf consumption

Leaf consumption for each larval instar is presented in Table 6. Females consumed significantly ($P < 0.05$) more leaf tissue than did males (cf. 268.3 with 216.5 cm$^2$). Likewise, females were significantly heavier than males (cf. 231.3 with 354.4 mg).

Approximately 98% of the total leaf consumption occurred during the 4th and 5th larval instars. Cumulative leaf consumption per larval instar was regressed on cumulative thermal units required for successive instar development (Fig. 4). The thermal-unit system for painted lady larval development was obtained from Part I, p. 15. Leaf consumption below 170 thermal units (1st and 2nd instar larvae) was negligible. Differences between the rates of female and male leaf consumption became discernible at ca. 250 thermal units. At 447 thermal units, female larvae had consumed 24.1% more leaf tissue than had male larvae.

Crowding effects

Mortality, larval development, and leaf-consumption data for each treatment are presented in Table 7. Larval mortality ranged from 45.0-52.2%, and no substantial differences between treatments were observed. If larval mortality in the multiple-larvae per carton treatments occurred during the 1st or 2nd stadia, the carton was included in the appropriate treatment (determined by the number of survivors). If larval mortality occurred during a later stadium, data from that carton
Fig. 4. Regressions of cumulative, mean, and mid leaf consumption on thermal units required for larval development
CUMULATIVE LEAF CONSUMPTION (cm.²)

(♀) Y = -0.3675x + 0.0021x²
R² = 0.992

(♀+♂) Y = -0.3196x + 0.0019x²
R² = 0.993

(♂) Y = -0.2721x + 0.0017x²
R² = 0.994

CUMULATIVE THERMAL UNITS

1 2 3 4 5

LARVAL INSTAR S
Table 6. Mean leaf consumption (cm²) and pupal weight (mg) for male and female painted lady larvae

<table>
<thead>
<tr>
<th>Sex</th>
<th>Leaf consumption</th>
<th>Pupal weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Larval stage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>♂</td>
<td>0.22</td>
<td>1.35</td>
</tr>
<tr>
<td>♀</td>
<td>0.32</td>
<td>1.06</td>
</tr>
</tbody>
</table>

*aNumbers followed by the same letter are not significantly different at the 5% level.

Table 7. Painted lady mortality, larval development, and leaf consumption per larva per treatment

<table>
<thead>
<tr>
<th>Treatment (larvae/carton)</th>
<th>Mortality (%)</th>
<th>Larval dev. (days)</th>
<th>Leaf consumption (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45.0</td>
<td>28.0a</td>
<td>233.6a</td>
</tr>
<tr>
<td>2</td>
<td>52.5</td>
<td>25.6a</td>
<td>241.5a</td>
</tr>
<tr>
<td>3</td>
<td>48.3</td>
<td>25.0a</td>
<td>225.7a</td>
</tr>
</tbody>
</table>

*aNumbers followed by the same letter are not significantly different at the 5% level.

were excluded from the calculations. Analysis of variance and subsequent F tests indicated no significant (P > 0.05) differences between treatment means for larval development or leaf consumption. It was concluded that crowding at levels examined in this study had no effect on larval leaf-consumption and thus would not complicate EIL calculations.
The effects of crowding on weight gain per individual were evaluated by regressing pupal weight per carton on leaf consumption per carton (Fig. 5). Regression analysis yielded a linear model, with a coefficient of determination ($R^2$) of 0.934. Analysis of variance with regression indicated no significant ($P > 0.05$) deviations from the linear model. Crowding, therefore, had no effect on individual weight gain compared with that of uncrowded larvae, thus, excessive energy was not dissipated.

Results of this experiment fail to indicate any endogenous factor responsible for mortality of crowded painted lady larval populations. Larval mortality in cage infestations reported by Pedigo (1974) may have resulted from exogenous factors, viz., predators, parasites, or pathogens acting in a density-dependent manner.

**Economic-injury level**

The EIL for painted lady on soybeans was calculated in a manner similar to that of Stone and Pedigo (1972). The soybean gain threshold (yield increase necessary to compensate for control costs), calculated by dividing management costs ($3.66/acre) by crop market value ($5.15 bu), was 0.71 bu/acre. Management costs were based on a single aerial application of carbaryl at 1.0 lb. AI/acre (Stockdale et al. 1975). Chemical and application costs were $1.16/acre (Felco-Land O'Lakes 1975) and $2.50/acre, respectively. Crop market value was estimated from 1975 market prices. Gain threshold (GT) then was converted to a
Fig. 5. Regression of painted lady pupal weight per container on leaf consumption per container
LEAF CONSUMPTION (cm²)/CONTAINER

PAINTED LADY PUPAL WT. (mg.)/CONTAINER

\[ Y = 23.213 \times + 1.343 \]

\[ R^2 = 0.934 \]
critical percentage yield-loss (\(\% = (\text{GT} \times 100)/\text{projected yield}\)). A 4-yr average (1971-1974) of Iowa soybean yields (32.2 bu/a) was used for projected yield (U.S. Department of Agriculture 1973, Skow and Stuber 1974, 1975). The critical percentage defoliation required to produce the critical percentage yield-loss (2.2\%) was calculated with defoliation yield-loss equations. Equations were derived for the 2-trifoliate (V3) and 6-trifoliate leaf (V7) stages by regressing percentage defoliation on percentage yield-reduction data of Kalton et al. (1949). Models for these stages were: 

\[ V3, \ Y = 0.02746x + 0.00189x^2 \quad (R^2 = 0.921) \]

and 

\[ V7, \ Y = 0.15928x + 0.00405x^2 \quad (R^2 = 0.976) \]

Critical percentage defoliations for plant stages V3 and V7 were 42.1\% and 50.2\%, respectively.

Table 8 contains estimates of leaf-surface area per row-ft for the unifoliate through the 6-trifoliate (V1-V7) leaf stages. Leaf area during growth stages V3 and V7 was ca. 1,267 and 7,254 cm\(^2\), respectively. Plant stages V3 and V7 (Fehr et al. (1971) classification) correspond to plant stages 1 and 3 used by Kalton et al. (1949).

Critical leaf-area reduction (cm\(^2\)) was determined by multiplying critical defoliation by leaf-surface area per plant stage (cm\(^2/\)row-ft). Critical leaf-area reductions for stages V3 and V7 were 533.5 and 3,792.2 cm\(^2\), respectively. EIL was calculated by dividing critical leaf-area reduction by the mean leaf consumption (\(\text{cm}^2/\text{larva}\)) per larva (242.3 cm\(^2\)). EIL's for plant stages V3 and V7 were 2.2 and 15.7 larvae/row-ft. These calculated EIL's compare favorably with Iowa treatment recommendations for 1973.
Table 8. Leaf-surface area (LSA) measurements (cm$^2$) for plant growth stages VI - V7a

<table>
<thead>
<tr>
<th>Plant stage</th>
<th>LSA/plant</th>
<th>LSA/row-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>30.0</td>
<td>225.0</td>
</tr>
<tr>
<td>V2</td>
<td>79.0</td>
<td>592.4</td>
</tr>
<tr>
<td>V3</td>
<td>169.0</td>
<td>1267.2</td>
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<tr>
<td>V4</td>
<td>259.7</td>
<td>1948.1</td>
</tr>
<tr>
<td>V5</td>
<td>366.2</td>
<td>2746.6</td>
</tr>
<tr>
<td>V6</td>
<td>726.2</td>
<td>5446.7</td>
</tr>
<tr>
<td>V7</td>
<td>967.2</td>
<td>7254.2</td>
</tr>
</tbody>
</table>

$^a$Plant population was 7.5 $\pm$ 0.48 plants/row-ft.

$^b$Growth stages based on Fehr et al. (1971) classification.
PART IV: SIMULATION OF PAINTED LADY AND GREEN CLOVERWORM DAMAGE TO SOYBEANS
ABSTRACT

Field studies were conducted during 1974-75 to simulate painted lady, *Cynthia cardui* (L.), and green cloverworm, *Plathypena scabra* (F.), damage to soybeans. Leaf rolling, characteristic of painted lady damage, had little effect on soybean yield. Defoliation-induced yield reductions during the 2-trifoliate leaf and full-bloom stages were additive. Reductions in bean weight per plot resulted from reductions in the number of pods per plot.
INTRODUCTION

Damage simulation has been a useful method in establishing damage-yield relationships of crops. Simulation studies are not unique to any one crop. Eldredge (1935), and Kiesselbach and Lyness (1945) obtained the greatest yield reductions in corn by artificially defoliating during the tasseling stage to simulate hail damage. Li and Lui (1935) observed the greatest yield reductions in kaoliang when plants were defoliated during the bloom stage. Eldredge (1937) found that wheat damaged during the heading stages yielded less than wheat damaged during the vegetative stages. The more advanced the vegetative stage, the greater the yield reduction. Hawthorn (1946) obtained the greatest yield reductions in onions with defoliation treatments applied at the beginning of bulb formation.

Soybean damage-simulation work has dealt primarily with hail damage. Dungan (1939), after defoliating (100%) and removing the upper one half of the soybean canopy, observed a severe reduction in the plant's ability to recover from damage. Many plants were totally devoid of pods. Dungan observed that during the pod-fill stage, leaves on the lower half of the plant were more important to yield. Dungan (1942), Fuelleman (1944), Kalton and Eldredge (1946), and Neill (1952) observed that heavy defoliation during early plant growth stages slightly reduced yield, and that heavy defoliation during later stages severely reduced yield. Kalton and Eldredge (1946) found that defoliation during early plant stages increased the time required to reach
maturity and decreased plant height. Defoliation during later stages reduced maturity time and oil content of the beans. Kalton et al. (1949) applied various combinations of defoliation and stem bruising to soybeans during different growth stages. They obtained similar yield responses to specific amounts of defoliation with 2 different plant varieties. Yield reductions from damage during the 2- and 4-trifoliate leaf stages were slight. Yield was severely decreased when plants were defoliated during the pod-fill stage. Weber (1955) observed that defoliation-induced yield reductions during years with good growing conditions were not as severe as reductions during years with bad conditions. Weber and Caldwell (1966) defoliated soybeans from emergence to the 2-trifoliate leaf stage. They found that at least one cotyledon during the 1st 10 days after emergence was necessary for a plant to achieve maximum yield. They stated that the plant's ability to recover from defoliation decreased with maturity. Hammerton (1972) observed that soybean defoliation caused a reduction in the number of pods and seed size. Rosas (1967) obtained a reduction in the number of pods and beans following defoliation. McAlister and Krober (1958) found that severe soybean defoliation decreased protein content and increased the iodine number of the oil.

During recent years researchers have also used artificial defoliation to simulate insect damage. Stone and Pedigo (1972) used hail-simulation data of Kalton et al. (1949) to establish economic-injury
levels for the green cloverworm, *Plathypena scabra* (F.), on soybeans. A similar technique was used to establish economic-injury levels for
the painted lady, *Cynthia cardui* (L.), on soybeans (Part III, p. 44).

Begum and Eden (1965) simulated damage by insect defoliators in
Alabama soybeans. Turnipseed (1972) removed soybean foliage with
scissors to simulate soybean damage by insect defoliators of southern
soybean varieties. Todd and Morgan (1972) simulated feeding of insect
defoliators in Georgia by removing soybean leaflets at specified times
and on a continuous basis. Thomas et al. (1974) excised leaflets and
pods to simulate *H. zea* damage.

In all of the above mentioned studies entire leaflets or uniform
portions of leaflets were removed to simulate the insect's damage.
However, insect defoliators, e.g., the green cloverworm and the painted
lady, generally tatter the leaves, and rarely excise leaves from a
plant. It has been shown that different types of defoliation have
significant effects on net photosynthesis of soybean leaves (Part II,
p. 32).

The painted lady is an early season pest of Iowa soybeans when
plants are in the 2- or 3-trifoliate leaf stages (V3 - V4, Fehr et al.
(1971) plant classification). Larvae web trifoliate soybean leaves
together forming enclosures. A larva constructs and then feeds inside
several enclosures during the larval stage. Approximately 98% of the
total defoliation occurs during the 4th and 5th larval stadia (Part
III, p. 40).
The green cloverworm is a mid-season Iowa pest, usually reaching peak numbers during the full-bloom stage. Larvae consume tissue in the interveinal areas of the leaf, and defoliation is generally concentrated in the upper one half of the plant canopy. Approximately 95% of the plant defoliation occurs during the 5th and 6th larval stadia (Stone and Pedigo 1972).

Recent outbreaks of both the painted lady and the green cloverworm occurred in 1966, 1968, and 1973. The potential thus exists for yield reductions to ensue from economic infestations of both pests in the same field.

To effectively deal with these pest problems, field studies were conducted during 1974 and 1975 to: (1) quantify the effects of simulated painted lady and green cloverworm damage on soybean yield components, and (2) evaluate the effects of combined early and mid-season defoliation on yield.
METHODS AND MATERIALS

1974 study

Steele Var. soybean plots (34) were established on the Ross farm 2 mi northwest of Ames, Iowa. A plot consisted of 1 soybean row with 3 ft/plot. Soybean plots (30-in. centers, 3 row-ft/plot) were hand planted on 24 June and thinned to 8 plants/ft on 15 July. An earlier plant stand was destroyed by hail necessitating replanting.

Plots were arranged according to a randomized complete-block design, 2 blocks, each with 17 treatments. Treatments (Table 9) consisted of various types and levels of damage inflicted during early (stage V3) and mid-season (stage R2). Early season treatments were composed of different levels and combinations of defoliation and leaf rolling to simulate painted lady damage. Mid-season treatments consisted of different levels of defoliation to simulate green cloverworm damage. Specified plots received different levels of early and mid-season defoliation to simulate damage resulting from infestations of both pests.

Leaves were rolled by adhering soybean leaflets to a 1.3-cm diam. transparent tape loop. Early season defoliation was inflicted with a paper punch (6-mm diam.). A cork-borer (2.1-cm diam.) was used for mid-season defoliation. Early and mid-season defoliations were initiated on 20 July and 15 Aug., and required 6 days to complete each. Damage was inflicted in this manner to simulate protracted feeding of late-instar larvae. The defoliation schedule for days 1, 2, 3, 4, 5,
and 6 was 7, 7, 21, 21, and 23% of the total desired damage, respectively. In the early season treatments leaves were rolled on days 1 and 4.

Leaf-surface area per plot was estimated with a technique developed by Wiersma and Bailey (1975) before treatments were applied. The number of holes punched per plot was adjusted to give the desired percentage defoliation level based on foliage area present at the beginning of defoliation. Plants were reared to physiological maturity and harvested with a small-plot thresher. Various yield components (Table 9) were examined for treatment effects.

1975 study

Steele Var. soybean plots (96) were located on the Kelly farm 2.5 mi west of Ames, Iowa. Plots measured 2.5 row-ft with 8 plants/ft. Soybeans (30-in. centers) were hand planted on 19 May and thinned on 19 June.

Treatments were arranged according to a factorial randomized complete-block design, 3 blocks, each with 32 treatments. Early and mid-season treatments (Table 10) were applied as in 1974. Mean leaf-surface area per plot was again estimated before treatment application, and the quantity of leaf area removed was adjusted to give the desired percentage defoliation.

Soybeans were reared to physiological maturity and harvested with a small-plot thresher. Selected yield components (Table 10) were evaluated for treatment effects.
RESULTS AND DISCUSSION

1974 study

Yield-component means for the 1974 study are presented in Table 9. The high level V3 defoliation (50DL) significantly (P<0.05) reduced bean weight per plot, but the medium defoliation (33DL) did not. Data presented for the low defoliation treatment (20DL) is misleading because a portion of the yield was lost from one plot. High level (100L) leaf rolling significantly reduced bean weight, but low (40L) and medium (66L) levels did not. Medium and high combination leaf rolling and defoliation treatments (33DL+66L, 50DL+100L) significantly reduced bean weight but the low level combination (20DL+40L) did not. A comparison of the sum of the means for leaf rolling (66L) and defoliation (33DL) with the mean for leaf rolling and defoliation combined (33DL+66L) indicated no significant (t = 0.15, P< 0.05) interaction at the medium level. Therefore, damage at this level was additive. A significant interaction (t = 2.67, P< 0.05), however, was observed for the high-level treatments. Yield reduction in the high-level combination treatment (50DL+100L) was less than the sum of the reductions for the high leaf rolling (100L) and high defoliation (50DL) treatments.

All R2-defoliation treatments (20D2, 33D2, and 50D2) significantly reduced bean weight per plot, as did all combination V3- and R2-damage treatments. Yield reductions caused by single defoliation treatments were greater in R2 than in V3. No significant V3-R2 defoliation
Table 9. Yield-component means from 1974 damage simulation treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Bean wt/plot</th>
<th>No. pods/plot</th>
<th>No. beans/pod</th>
<th>Bean cwt/plot</th>
<th>% yield reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 20D1</td>
<td>85.8de</td>
<td>435.5bcde</td>
<td>1.67a</td>
<td>16.8a</td>
<td>38.5</td>
</tr>
<tr>
<td>2 33D1</td>
<td>121.1abc</td>
<td>477.0abc</td>
<td>1.96a</td>
<td>13.0a</td>
<td>13.1</td>
</tr>
<tr>
<td>3 50D1</td>
<td>95.9cd</td>
<td>419.5cde</td>
<td>1.95a</td>
<td>11.7a</td>
<td>31.2</td>
</tr>
<tr>
<td>4 40L</td>
<td>129.9ab</td>
<td>502.5ab</td>
<td>1.96a</td>
<td>13.2a</td>
<td>6.8</td>
</tr>
<tr>
<td>5 66L</td>
<td>129.3ab</td>
<td>501.5ab</td>
<td>2.01a</td>
<td>12.9a</td>
<td>7.3</td>
</tr>
<tr>
<td>6 100L</td>
<td>104.4bcd</td>
<td>451.0bcdde</td>
<td>1.83a</td>
<td>12.7a</td>
<td>25.1</td>
</tr>
<tr>
<td>7 20D1+40L</td>
<td>118.0abc</td>
<td>483.5abc</td>
<td>1.90a</td>
<td>12.9a</td>
<td>15.4</td>
</tr>
<tr>
<td>8 33D1+66L</td>
<td>108.9bcd</td>
<td>461.5bcd</td>
<td>1.78a</td>
<td>13.3a</td>
<td>22.0</td>
</tr>
<tr>
<td>9 50D1+100L</td>
<td>100.6bcd</td>
<td>454.0bcde</td>
<td>1.74a</td>
<td>12.8a</td>
<td>27.9</td>
</tr>
<tr>
<td>10 20D2</td>
<td>116.2bc</td>
<td>445.0bcde</td>
<td>2.11a</td>
<td>12.4a</td>
<td>16.7</td>
</tr>
<tr>
<td>11 33D2</td>
<td>106.4bcd</td>
<td>481.5abc</td>
<td>1.95a</td>
<td>11.2a</td>
<td>23.8</td>
</tr>
<tr>
<td>12 50D2</td>
<td>85.3de</td>
<td>379.0e</td>
<td>1.95a</td>
<td>11.6a</td>
<td>38.8</td>
</tr>
<tr>
<td>13 10D1+20L+10D2</td>
<td>109.8bcd</td>
<td>447.0bcde</td>
<td>1.83a</td>
<td>13.6a</td>
<td>21.2</td>
</tr>
<tr>
<td>14 20D1+40L+20D2</td>
<td>95.4cd</td>
<td>425.5bcde</td>
<td>1.81a</td>
<td>12.4a</td>
<td>31.5</td>
</tr>
<tr>
<td>15 33D1+66L+33D2</td>
<td>83.7de</td>
<td>385.5de</td>
<td>1.89a</td>
<td>11.6a</td>
<td>39.9</td>
</tr>
<tr>
<td>16 50D1+100L+50D2</td>
<td>58.6</td>
<td>286.5f</td>
<td>1.87a</td>
<td>10.9a</td>
<td>58.0</td>
</tr>
<tr>
<td>17 Check</td>
<td>139.3a</td>
<td>527.6a</td>
<td>2.01a</td>
<td>13.2a</td>
<td>--</td>
</tr>
</tbody>
</table>

Numbers followed by the same letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

Defoliation during the 2-trifoliate leaf stage (V3).

Leaf rolling during the 2-trifoliate leaf stage (V3).

Defoliation during the full-bloom stage (R2).
interactions were observed. Percentage yield reductions accrued from damage in V3 and R2, therefore, were additive.

Except for the 33% mid-season defoliation treatment, all treatments that significantly reduced bean weight per plot also reduced the numbers of pods per plot. No significant reductions in the number of beans per pod or bean hundred weight per plot were observed. The reduction in pod numbers, therefore, was primarily responsible for the reduction in bean weight.

Yield reductions resulting from defoliation in V3 and R2 were substantially higher than those of Kalton et al. (1949). Kalton et al. reported reductions of 3 and 9% following 50% defoliation during soybean stages V3 and R2, versus reductions of 31 and 39% in this study. A large part of the discrepancy in these results may be attributed to poor 1974 growing conditions. As previously mentioned, the original plots for this experiment were destroyed by hail necessitating replanting in late June. Growth in the new plant stand was slow because of moisture stress during July (1.73 negative deviations from normal, U.S. Dept. Commerce 1974). Plants also suffered damage in the fall from an early frost (21 Sept. 1974).

1975 study

The effects of defoliation (V3), leaf rolling (V3), and defoliation (R2) on soybean yield are presented in Table 10. Analysis of variance and subsequent F tests indicated no significant 1st or 2nd-order interactions for the yield components bean weight per plot, number of pods
Table 10. Main factor means of defoliation (V3), leaf rolling (V3), and defoliation (R2) for various soybean yield components\textsuperscript{a}

<table>
<thead>
<tr>
<th>Damage level (%)</th>
<th>Bean wt./ plot (g)</th>
<th>No. pods/ plot</th>
<th>No. beans/ pod</th>
<th>Yield reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Defoliation V1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>145.6a</td>
<td>462.1a</td>
<td>1.90a</td>
<td>--</td>
</tr>
<tr>
<td>10</td>
<td>147.9a</td>
<td>447.1a</td>
<td>1.94a</td>
<td>0.0</td>
</tr>
<tr>
<td>33</td>
<td>132.1b</td>
<td>403.4b</td>
<td>1.96a</td>
<td>9.3</td>
</tr>
<tr>
<td>50</td>
<td>125.7b</td>
<td>400.5b</td>
<td>1.89a</td>
<td>13.7</td>
</tr>
<tr>
<td>Std. error</td>
<td>(4.6)</td>
<td>(13.8)</td>
<td>(0.03)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leaf rolling V1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>140.6a</td>
<td>414.2a</td>
<td>1.92a</td>
<td>--</td>
</tr>
<tr>
<td>75</td>
<td>134.9a</td>
<td>415.3b</td>
<td>1.92a</td>
<td>0</td>
</tr>
<tr>
<td>Std. error</td>
<td>(3.1)</td>
<td>(9.8)</td>
<td>(0.02)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Defoliation R2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>142.9a</td>
<td>442.6a</td>
<td>1.91a</td>
<td>--</td>
</tr>
<tr>
<td>10</td>
<td>144.5a</td>
<td>444.8a</td>
<td>1.91a</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>129.4b</td>
<td>411.8a</td>
<td>1.91a</td>
<td>9.4</td>
</tr>
<tr>
<td>50</td>
<td>134.5b</td>
<td>413.8a</td>
<td>1.94a</td>
<td>5.9</td>
</tr>
<tr>
<td>Std. error</td>
<td>(4.6)</td>
<td>(13.8)</td>
<td>(0.03)</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a}Numbers followed by the same letter are not significantly different at the 5% level using student's $t$. 

per plot, and number of beans per plot. Main factor means (Table 10) were thus the most precise measurements of main factor effects for these yield components.

Medium (33%) and high (50%) level defoliations during plant stages V3 and R2 significantly ($P < 0.05$) reduced bean weight per plot. Low level (10%) defoliations during V3 and R2, and leaf rolling did not reduce bean weight per plot. Medium and high-level V3 defoliations and leaf rolling also significantly reduced the number of pods per plot. The low-level V3 defoliation, and low, medium, and high-level R2 defoliations did not reduce the number of pods per plot. No significant main effects were observed for the number of beans per pod. Percentage yield reductions were again higher than those of Kalton et al. (1949). Yield reductions during 1975 however, were less than those of 1974 probably because of better environmental conditions, viz., early planting, adequate moisture, and no frost damage. A trend was observed towards higher yields, resulting from low level defoliations, in stages V3 and R2. Unlike 1974 results, V3 defoliation yield reductions were not substantially different from R2 reductions.

No significant main factor effects were observed for the yield component, bean hundred weight. A 1st-order interaction (V3 defoliation-leaf rolling), however, was significant. The effects of different levels of V3 defoliation and leaf rolling on bean hundred weight are presented in Table 11. Bean hundred weight increased significantly from medium- and high-level defoliations in the absence of leaf rolling.
Table 11. The effect of levels of defoliation (V3) and leaf rolling (V3) on soybean cwt.\(^a\)

<table>
<thead>
<tr>
<th>Defoliation (%)</th>
<th>Leaf roll (%)</th>
<th>(\bar{X}) leaf roll effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>0</td>
<td>16.57a</td>
<td>17.08a</td>
</tr>
<tr>
<td>10</td>
<td>16.65ab</td>
<td>16.86a</td>
</tr>
<tr>
<td>33</td>
<td>17.00bc</td>
<td>17.08a</td>
</tr>
<tr>
<td>50</td>
<td>17.31c</td>
<td>16.85a</td>
</tr>
<tr>
<td>(\bar{X}) defoliation effect</td>
<td>16.88</td>
<td>16.97</td>
</tr>
</tbody>
</table>

\(^a\)Numbers followed by the same letter are not significantly different at the 5\% level.

No significant differences were observed in bean hundred weight for defoliation treatments combined with leaf rolling.
CONCLUSIONS

Leaf rolling at the 100% level caused a significant yield reduction during 1974, but did not at lower levels. During 1975, no significant reduction was obtained from 75% leaf rolling. Likewise during 1974, a significant interaction was observed between high-level defoliation and leaf rolling, but not at the lower levels. No significant interactions were observed during 1975. Based on these results, painted lady defoliation, rather than leaf rolling, was deemed primarily responsible for soybean yield reductions. Significant effects of high-level leaf rolling during 1974 were attributed to adverse growing conditions.

No significant interactions between defoliations during V3 and R2 were observed. Reductions, therefore, were additive, i.e., a 10% estimated yield reduction during V3 followed by an estimated 20% reduction in R2 should cause a 30% reduction in final yield. The primary expression of defoliation was a reduction in the number of pods per plot, thereby decreasing bean weight per plot.

Substantial differences in yield were obtained from given quantities of defoliation applied during 1974 and 1975. These differences were attributed to 1974-75 growing conditions. Poor growing conditions (late planting, moisture stress, etc.) probably interact with damage to cause greater than normal yield reductions. Substantial differences were also observed between yield reductions in these studies and reductions obtained by Kalton et al. (1949). It is not clear, however, whether the discrepancy in these data resulted from different growing conditions or differences in damage technique.
LITERATURE CITED


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