Role of Trap Crops on Harlequin Bug, *Murgantia histrionica* (Hahn), Population Dynamics and Parasitism in Broccoli Plots

by

Scott W. Ludwig

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APPROVED:

Loke T. Kok, Chairman

Robert L. Pienkowski

Douglas G. Pfeiffer

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ROLE OF TRAP CROPS ON HARLEQUIN BUG, *MURGANTIA HISTRIONIC* (HAHN), POPULATION DYNAMICS AND PARASITISM IN BROCCOLI PLOTS

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Dr. L. T. Kok, Chairman

Department of Entomology

(ABSTRACT)

Trap crops were evaluated for harlequin bug control in broccoli field plots in 1994 and 1995. Mustard and rape prevented low densities of harlequin bug from reaching broccoli, but at high densities the insect moved from the trap plants into the broccoli. This indicates that harlequin bugs that are attracted to trap plants may damage the protected broccoli if their numbers are not prevented from increasing.

Harlequin bugs were shown to have two and a partial third generation a year. *Trissolcus murgantiae* Ashmead and *Ooencyrtus johnsoni* Howard, were identified as egg parasitoids. Their combined parasitization levels for the two years were 8% and 37%. *T. murgantiae* accounted for 87% and 96% of the parasitization, respectively.

When 19.6 cm and 11.9 cm broccoli plants were exposed to five densities of harlequin bug adults a negative correlation between plant mortality and insect density was observed ($y = 38.00 - 2.32x$, $r^2 = 0.95$ and $y = 22.17 - 1.17x$, $r^2 = 0.99$, respectively). No correlation was observed in broccoli plants 11.9 tall.

Host plants affected harlequin bug development. Nymphs developed faster when reared on rape in comparison with mustard. The preoviposition time for rape reared nymphs was shorter than mustard reared insects. Fecundity and viability of eggs were not different for harlequin bugs reared at different sex ratios.

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Table of Contents

List of Tables

List of Figures

Introduction

The harlequin bug, *Murgantia histrionica* (Hahn), an exotic pest from Central America, was first recorded in the United States in 1864 (Walsh 1866). Within a few years it had become one of the most destructive pests of cabbage in the United States. As the use of synthetic insecticides became more widespread, the occurrence of the harlequin bug as a pest declined. The harlequin bug was not identified as a major pest in recent studies of cabbage (Lasota et al. 1985) or broccoli (McAvoy et al. 1986). We believe that synthetic insecticides used for control of lepidopteran pests may be keeping harlequin bug populations under control. Recently the harlequin bug has become a pest in Cole crop research plots where no insecticides were used (Gaines 1992). It is possible that the harlequin bug will again become a serious pest if growers switch from the current practice of using synthetic insecticides to a more environmentally sound biological control approach.

Broccoli, *Brassica oleracea*, was first grown in Virginia in the 1980's by tobacco farmers who wanted to augment their tobacco crops when tobacco prices declined (Vail 1988). Unfortunately, as tobacco prices increased in the 1990's the production of broccoli decreased. Today broccoli is only grown in small acreage, but nationally broccoli has developed into an important Cole crop. Although Virginia's broccoli production has drastically declined, the

information gathered during my research should be applicable for the entire region.

Even though the harlequin bug was studied extensively in the early part of this century, very little research had been conducted with its control using nonchemical techniques. Trap crops were recommended for control of harlequin bugs on cabbage, but their use has not been evaluated with broccoli (Chittenden 1920, White and Brannon 1933). Apart from laboratory studies, very little is known about the harlequin bug life history. By determining the seasonality of the harlequin bug it may be possible to predict when they could become a problem, enabling growers better timing of control techniques.

The harlequin bug is known to have two dominant egg parasitoids, *Trissolcus murgantiae* Ashmead and *Ooencyrtus johnsoni* Howard, but neither has been shown to provide effective control. In Virginia, *O. johnsoni* is the only parasitoid that has been documented (Walker and Anderson 1933), but *T. murgantiae* has been recorded in North Carolina (Huffaker 1941).

No research has been conducted on the effect of harlequin bug densities on broccoli development. Unlike the lepidopteran pests, which are common pests of broccoli, the harlequin bug does not chew holes in leaves. It feeds by sucking plant juices and causes the plant to wilt. To determine when harlequin bugs need to be controlled, the density at which damage will occur needs to be known.

The objectives of this study were to determine the:

1. effectiveness of trap crops for harlequin bug control in broccoli.
2. seasonality of the harlequin bug and its egg parasitoids.
3. effect of host plants (mustard, broccoli, and rape) on harlequin bug development.
4. relationship between plant size and harlequin bug density.
5. effect of sex ratio on egg production and viability.

Chapter 1

Literature Review

Cole Crop History and Pests: Broccoli originated from *Brassica oleracea*, a wild plant found in Europe along the Mediterranean and northwest coasts. Other crops that share this common ancestor include kale, head cabbage, cauliflower, and brussels sprouts (Proulx 1981). These plants are members of the Cruciferae or mustard family, which also includes the turnips, rapes, and mustards.

Some experts believe broccoli has been in existence for thousands of years, while others believe it to have been first cultivated in modern times (Proulx 1981). In the 1800's, broccoli was a popular garden vegetable with Italians in New York and Boston. It was not until 1923 that an Italian family in California started commercial production of broccoli in the United States (Proulx 1981).

Broccoli was not widely grown for commercial production in Virginia until 1983 when tobacco farmers in Halifax and surrounding counties started to experiment with alternative crops to supplement tobacco production. By 1986, nearly 800 acres of broccoli were being produced (Vail 1988). As tobacco prices increased in the early 1990's, tobacco farmers abandoned broccoli production, and only small acreages are currently being planted in Virginia.

Studies on cabbage (Lasota et al. 1985) and broccoli (McAvoy et al. 1986) in Virginia identified more than 10 insect pest species. The harlequin bug, *Murgantia histrionica (*Hahn) (Hemiptera: Pentatomidae), was not recorded as a

major pest in any of these studies, but was once a major pest of cabbage production (White and Brannon 1933). In recent years the harlequin bug has caused damage in research plots where no chemicals were used for pest control (Gaines 1992).

Harlequin Bug Introduction: The harlequin bug, first identified in 1834 as *Strachia histrionica* by C. W. Hahn (Hahn 1834) from individuals collected in Mexico (Paddock 1918), is believed to have originated from Central America (Paddock 1918). In 1872 it was placed into the genus *Murgantia* by Stal (Stal 1872).

In 1866, Walsh published the first account of the harlequin bug in the United States. This record indicated that the bug was in Washington County, Texas in 1864, but it is believed that the harlequin bug had entered the United States several years earlier (Paddock 1918). By 1867, it had reached North Carolina (Riley 1870), Georgia, Alabama, and Mississippi (Stelle 1870a,b). The harlequin bug continued to move north to the 40° N latitude, below which it overwinters (Chittenden 1908, Hodson and Cook 1960). Harlequin bugs have been recorded north of the 40°N latitude, but it is believed the insects were carried by wind currents or seasonally migrated (Hodson & Cook 1960).

Walsh (1866) recognized the severity of the problems this pest would cause on cruciferous crops. As a result of the devastation caused by this insect, many studies were conducted around the turn of the century on the bug's

biology (Howard 1895, Chittenden 1908, Smith 1909, Paddock 1918). After the advent of synthetic insecticides, few major studies were reported.

Damage and Host Range: The harlequin bug feeds by piercing plant stems and leaves with its piercing-sucking mouth parts causing white areas or blotching where the puncture occurred. When a young plant is attacked by several individuals the plant wilts, turns brown, and eventually dies. A larger plant is better able to withstand an attack, but its growth can be stunted (White and Brannon 1933). Overwintered adults have been shown to prefer clusters of plants over single plants. This should result in their progeny having an adequate food supply (McLain 1981).

The harlequin bug has been documented to feed on over 50 species of plants (Appendix 1). Crucifers tend to be preferred and are the most easily damaged. Plants of economical importance which are attacked include cabbage, collards, broccoli, Brussels sprouts, kale, mustard, turnip, radish, rape, horseradish, Chinese cabbage, kohl rabi, rutabaga, and cauliflower (White and Brannon 1933). Before the use of synthetic insecticides, the harlequin bug was considered to be the most destructive insect on cabbage and related crops (Brett and Sullivan 1974). The harlequin bug has also been recorded on many wild plants allowing it to survive when cruciferous crops are not in production.

Walker and Anderson (1933) reported a Virginia harlequin bug outbreak in 1932 that destroyed fields of kale, collards, and cabbage, in addition to

harming many other crops. Recent reports of this insect's damage come from field research plots, where harlequin bug's feeding destroyed broccoli, cabbage, and kale (Gaines 1992).

Biology: The maximum life span for females ranges from 100 days (Streams and Pimentel 1963) to 120 days (Paddock 1918). Streams and Pimentel (1963) reported average life spans of 68.2 days for males and 82 days for females. Mating occurs 6-9 days after overwintering adults emerge and eggs are laid 2-8 days after mating. Females only need to mate once with a male to produce five fertile egg masses (Canerday 1965). The preoviposition period has a range of 15 to 27 days, with an average of 20.5 days (Streams and Pimentel 1963). Egg masses generally consist of 12 eggs laid in two rows of six. At 22.5° C, incubation takes 6 to 11 days with a 7.1 day average (Paddock 1918). Each nymphal stadium is different (Table 1). Laboratory studies indicated the harlequin bug has a sex ratio (F:M) ranging from of 53:47 (Streams & Pimentel 1963) to 43:57 (Canerday 1965).

The number of generations completed in a year by the harlequin bug varies by geographic location. In North Carolina there are three and a partial fourth generation a year (Brett and Sullivan 1974). Chittenden (1908) speculated that there is the possibility of four or five generations in the South and two generations in the North. There is no information in the literature concerning the insect's phenology in Virginia.

Table 1. Development time in days of *Murgantia histrionica.*

	Instar					
Temp.	1st	2nd	3rd	4th	5th	Source
22.5 °C	4.4	9.5	7.6	9.9	14.8	Streams & Pimentel (1963)
25 °C	3.6	4.7	8.3	11.1	13.1	Canerday (1965)

Natural Enemies: There are few natural enemies of the harlequin bug. Hymenopterous parasites appear to be the main methods of natural control. In North Carolina, the two dominant egg parasites are *Ooencyrtus johnsoni* Howard (Hymenoptera: Encyrtidae) and *Trissolcus murgantiae* Ashmead (Hymenoptera: Scelionidae). From field data, they were determined to have a parasitization rate of 30% and 45% respectively (Huffaker 1941). In Virginia, *O. johnsoni* was reported to parasitize between 35% to 55% of the eggs collected during August and September of 1932 (Walker and Anderson 1933).

Ooencyrtus johnsoni is an egg parasitoid of *Arilus cristatus* (L.) (Hemiptera: Reduviidae), *Chlorochroa sayi* Stahl (Hemiptera:Pentatomidae), *Murgantia histrionica* (Hahn), and coccinellid eggs (Krombein et al. 1979). This parasitoid has been recorded in seven states, including California (DeBach 1942, Essig 1922, Hoffmann et al. 1991), Florida (Drake 1920), Georgia (Miller 1971), Hawaii (Zimmerman 1948), Maryland (Howard 1898), North Carolina (Huffaker 1941), and Virginia (Walker & Anderson 1933).

Maple (1937) reported the only study on the biology of *O. johnsoni*. Females copulate only once, usually soon after emerging from the egg. Oviposition takes a minimum of 47 minutes. Females may oviposit between two and three eggs per harlequin bug egg. An average of 2.05 adults emerge per parasitized host egg. Parasite development is possible in eggs ranging from a few hours old up to less than 24 hours before eclosion, but evidence indicates

that eggs in the advanced stage of development are preferred over newly laid eggs. Arrhenotokous development, development of male progeny by virgin females, was shown to exist. Mated females produce a sex ratio (F:M) of nearly 4:1. At 25.6° C development takes 18 days. Immatures overwinter in the host egg. The adults exit the eggs through a hole chewed in the eggs, usually the side, by one of the parasites.

Much less information is known about *Trissolcus murgantiae*. Its only known host is the egg of the harlequin bug. It has been recorded in California (DeBach 1942), Florida (Drake 1920), Georgia (Miller 1971), Hawaii (Fullaway 1947), Maryland (Howard 1898), Mississippi (DeBach 1942), and North Carolina (Huffaker 1941).

Trissolcus basalis (Wollaston) (Hymenoptera: Scelionidae) (Buschman and Whitcomb 1980), *T. podisi* Ashmead (Chittenden 1908), *T. utahensis* (Ashmead), and *T. euschisti* (Ashmead), and *O. californicus* Girault (Hymenoptera: Encyrtidae) (Hoffmann et al. 1991) are also known to be parasites of harlequin bug egg masses.

Two dipteran species, *Trichopoda pennipes* (Fabricius) (Diptera: Tachinidae) (Buschman and Whitcomb 1980) and *Sarcodexia sternodontis* Townsend (Diptera: Sarcophagidae) (Drake 1920), are believed to parasitize harlequin bug nymphs and adults.

Nymphs of the harlequin bug have been observed to be preyed upon by the assassin bug, *Arilus cristatus* L. (Hemiptera: Reduviidae) (Chittenden 1908), and the nyssonid wasp, *Bicyrtes quadrifasciata* (Say) (Hymenoptera: Sphecidae) (Evans 1966). The leaf-footed bug, *Leptoglossus phyllopus* L. (Hymenoptera: Coreidae), is a predator of adult harlequin bugs (White and Brannon 1933). There is little evidence that predators provide any substantial control of harlequin bug nymphs or adults.

Chemical Control: Pesticides have been effective in controlling the harlequin bug. Fulton (1930) recommended using a 2 per cent soap solution for control. Nymphs, but not adults, were effectively controlled using this method during the Virginia infestation of 1932. The best results during this outbreak were obtained with 2% Ivory Soap + Serrid (Walker and Anderson 1933).

In collard field tests, Sevin® and Thiodan® knocked down 100% of harlequin bug adults and nymphs after 6 hours. Trithion® and Dylox® gave the same results after 72 hours (Hofmaster 1959). Acephate gave 99+% control of adults during an infestation of research plots in the Texas Rolling Plains (Rogers and Howell 1973). One hundred percent control was also obtained using a rotenone-sulfur mixture and a pyrethrum-sulfur mixture (Mendler and O'Neal 1944). Gains and Dean (1948) reported 98+% control of nymphs using 10% DDT-inert, 10% Chlorinated camphene-inert, or 20% sabadilla-inert. These insecticides showed 91.8%, 96.7%, and 80.6% control of adults. Brett &

Campbell (1956) used 20% sabadilla to get 100% mortality in 8 hours, 4% malathion gave 100% control in 24 hours, and 10% toxaphene only gave 64% mortality after 48 hours.

Non-chemical Control: Prevention is the best method of avoiding outbreaks of the harlequin bug. Once the harlequin bug starts to invade a field there is little that can be done for control, except the use of insecticides. Cultural methods and trap crops were recommended as methods of nonchemical control (Chittenden 1920, White and Brannon 1933), but no data have been reported to support their effectiveness.

Cultural methods consist of keeping the field in a condition that reduces the chance that the harlequin bug will use it as a source of food or as its overwintering site. Fields that are left with crop remnants after harvesting offer a place for the harlequin bug to breed and develop. After a crop has been harvested or if prices do not justify harvesting, it is recommended that they be plowed or disked under (White and Brannon 1933). Caution should be taken if plants are to be plowed under when infested with this pest. Approximately 40% were able to escape when covered with one half inch of soil. The number escaping decreased to less than 5% when covered with two or more inches of soil (Walker and Anderson 1933).

Trap Crops: Trap crops are planted to attract insects away from a primary crop to prevent its infestation. By concentrating the pest species into an area away

from the main crop, the pest can by destroyed by chemical spraying, burning, or being plowed under (Hokkanen 1991).

Trap cropping is based on the pest's host plant preference. This is accomplished by determining a plant species which is preferred over the crop or the plant stages which are preferred. If a preferred plant is present when the pest arrives then the pest is likely to go to the trap plant and not the crop (Hokkanen 1991).

Problems associated with insecticides often result in the need for developing alternate pest control measures. Pesticide problems include high insecticide costs (Swezey & Daxl 1988), development of insecticide resistance (Swezey & Salamanca 1987), and regulations against the use of insecticides before harvest (Hokkanen et al. 1986, Hokkanen 1989). Trap crops have been proven to be effective in controlling some pests when pesticides are no longer a practical control measure.

In Nicaragua, numerous applications of methyl parathion were needed to control the boll weevil due to insecticide resistance. This resulted in cotton production no longer being profitable. Cotton was used as a trap crop to attract the weevils between cropping seasons. The weevils were destroyed on these plants. The program resulted in lower boll weevil populations during the normal growing season (Swezey & Salamanca 1987, Swezey & Daxl 1988).

In Finland, during the 1980's, the rape blossom beetle became a major pest of cauliflower often resulting in a loss of one third of the harvest. The increase in beetle numbers was due to increased cultivation of oil seed rape, on which it is a pest, in areas where cauliflower was grown. The cauliflower losses occurred when the heads became ripe, since no chemical control was permitted. Trap crops consisting of Chinese cabbage, oilseed and turnip rape, sunflower, and marigold were planted on the side of the fields from which the beetle had been observed migrating. These plants intercepted the beetle before they reached the cauliflower. Beetles were then killed on the trap plants. In the first three years of the study crop losses were between 3% - 15% (Hokkanen et al. 1986, Hokkanen 1989).

Including the above references, there are currently thirteen trap crop systems which have shown positive results in agricultural use (Table 2). All the pests in these trap crop systems are either in the order Hemiptera or Coleoptera (Hokkanen 1991).

Some positive results have been obtained using mustard as a trap crop in field trials. *Brevicoryne brassicae* L. (Homoptera: Aphididae), the cabbage aphid, was shown to prefer flowering mustard over the non-flowering broccoli (Hughes 1963, Kloen and Altieri 1990). Syrphid adults (Diptera: Syrphidae) have been shown to be attracted to mustard flowers. This presents a chance to attract predators into the crop system (Altieri 1983). Mustard plants planted in

conjunction with collards reduced flea beetle (*Phyllotreta cruciferae* Goeze) (Coleoptera: Chrysomelidae) damage (Altieri and Gliessman 1983, Altieri and Schmidt 1986).

Trap Crops for Harlequin Bug Control: Spring trap crops may be planted before the main crops to attract the emerging harlequin bug adults which may lay their eggs on the trap crop that can be easily destroyed. This should reduce the number of harlequin bugs in the resulting generation and reduce the possibility of crop damage. Mustard, kale, and rape have been recommended as spring trap crops (Chittenden 1920, White and Brannon 1933). In the fall, part of the main crop can be left standing to attract the indigenous harlequin bug population. These plants should then be destroyed to kill the adults before they have a chance to overwinter (White and Brannon 1933).

Resistance to damage by the harlequin bug varies in different varieties of crucifers. Sullivan and Brett (1974) evaluated thirty-seven varieties of crucifers and found that plant damaged ranged from very little (Copenhagen Market 86-cabbage) to severe(Michihli-Chinese cabbage). In addition to less damage, resistant plants attracted fewer harlequin bugs than susceptible plants.

Table 2. Examples of trap crop systems successfully applied in agricultural practice (Hokkanen 1991)

Controlled Pests	Main crop	Trap crop	Location	Reference
Lygus bugs	cotton	alfalfa	California	Stern 1969, Stern 1981
[*Lygus hesperus* Knight,				
L. elisus Van Duzee]				
Cotton boll weevil	cotton	cotton	USA	Burris *et al* 1983,
[*Anthonomus grandis*	cotton	cotton	Nicaragua	Hardee 1982,
Boheman]				Swezey & Daxl 1988
Stink Bugs	soybeans	soybeans	SE USA	McPherson & Newsom
[*Nezara viridula* (L.),				1984, Newsom &
Euschistus spp.,				Herzog 1977, Todd &
				Schumann 1988
Acrosternum hilare (Say),	soybeans	soybeans	Brazil	Kobayashi & Cosenza
				1987

Table 2. (cont.)

Controlled Pests	Main crop	Trap crop	Location	Reference
Piezodorus guildinii]	soybeans	soybeans, cowpeas	Nigeria	Jackai 1984
Mexican bean beetle [*Epilachna varivestis* Mulsant]	soybeans	snap beans	SE USA	Rust 1977
Bean leaf beetle [*Cerotoma trifurcata (Foster]*	soybeans	soybeans	SE USE	Newsom & Herzog 1977
Colorado potato beetle	potato	potato	USSR	Chausov 1976,
[*Leptinotarsa decemlineata* (Say)]	potato	potato	Bulgaria	Dorozhkin et al 1975
Blossom beetle [*Meligethes aeneus* F.]	rape, cauliflower	rape, marigold	Finland	Hokkanen 1989, Hokkanen et al 1986

Table 2. (cont.)

Controlled Pests	Main crop	Trap crop	Location	Reference
Pine shoot beetle [*Tomicus piniperda* L.]	pine trees	pine logs	Great Britain	Bevan 1974
Spruce bark beetle [*Ips typographus* (L.)]	spruce	spruce trees, logs	Europe	Bakke & Riege 1982

Chapter 2

Evaluation of Trap Crops to Control Harlequin Bugs on Broccoli

INTRODUCTION

Before the advent of synthetic insecticides the harlequin bug was a severe pest of cabbage and other Cole crops (White & Brannon 1933). Mustard and rape were recommended as trap crops to control harlequin bugs on cabbage (Chittenden 1920, White and Brannon 1933). Once growers started to use insecticides, harlequin bugs were no longer a serious pest of Cole crops. Recently, the harlequin bug has again become a problem, this time in research plots where no insecticides are used (Gaines 1992). It is the objective of this experiment to evaluate the effectiveness of mustard, rape, and broccoli as trap crops in reducing harlequin bug numbers on broccoli.

MATERIALS AND METHODS

Experimental Design

Field research was conducted at Virginia Polytechnic Institute and State University's Kentland Agricultural Research Farm in Montgomery County during 1994 and 1995. Broccoli (*Brassica oleracea* 'Packman Hybrid'), mustard (*B. kabar* 'Southern Giant Curled'), and rape (*B. napus* 'Dwarf Essex') were planted using a randomized complete block design with four replicates. Each replicate contained three plots, mustard & broccoli, rape & broccoli, and broccoli & broccoli. Each plot contained the main broccoli crop surrounded by double rows of the trap crop. The main broccoli crop consisted of 6 rows with 18 plants per

row, with 1 meter between rows. In each row, plants were spaced 0.25 m apart. The trap plants were spaced 0.5 m apart, except for rape which was spaced 0.75 m apart, with 1 m between rows. There were 4 m between each plot and replicate to isolate plots. Plots measured 8 m x 9 m and the total area used was 32 m x 48 m. In 1994, the spring and fall plantings were 50 m apart. In 1995, the spring replicates were spaced 17 m apart with the fall replicates being placed between the spring replicates leaving 4 m between replicates.

Planting

1994 Seedlings used for field planting were grown in 128 cell "Speedling ™" flats. Broccoli and rape produced normal growth in the flats, whereas mustard bolted within a few weeks of germination. In the 1994 spring planting, seeds were planted nine weeks before transplantation of the trap crops. Trap crops were transplanted April 21 and the main broccoli was transplanted May 8.

In the fall planting, seedlings were started eight weeks before they were transplanted. Extra broccoli flats were planted 24 days before transplantation and used as replacement plants. The trap crops were transplanted August 10 and the main broccoli crop on August 20.

1995 Spring seedlings were started 9 weeks before transplantation. Trap crops were transplanted on May 30 and the main broccoli June 13. Due to a problem with rabbits eating the main broccoli seedlings, most of the plants were

retransplanted on June 21. The trap crops survived the rabbits, but some of the main broccoli was lost.

Sampling

In each plot, six trap crop plants and six main broccoli plants were randomly selected and flagged for weekly harlequin bug sampling. The number of egg masses, nymphs, and adults were recorded. Sampling started approximately two weeks after the planting of each respective crop.

Data Analysis

Friedman's method for randomized blocks, a nonparametric method of analysis, was used in the analysis of the population data. This test was used instead of an ANOVA because the data were not normally distributed. The response for the treatment (host plant) was ranked within each block for each date sampled. The ranks of each treatment group were summed and a statistic X^2 was computed. X^2 has a $X^2_{[a-1]}$ distribution, where a is the number of treatments. The P value was determined using a X^2 table (Sokal & Rohlf 1995).

RESULTS AND DISCUSSION

Spring 1994 The first harlequin bug was observed June 13 on mustard (non-sample plant) and the following week the first individual was recorded on a sample mustard plant. Harlequin bugs were observed on mustard for three weeks before they were seen on rape (Tables 3-5, Fig. 1), but as the mustard

senesced, the population on the plants declined. After July 25, sampling was terminated on mustard (dead) and broccoli (leaves defoliated by flea beetles), but was continued on rape until August 26, at which time the majority of plants had succumbed to harlequin bug feeding. The trap crops were 100% effective in preventing harlequin bugs from reaching the main broccoli.

In the final four weeks of the rape sampling, the nymph population increased from 1.5 per plant to 30.5 per plant. This shows the capability of harlequin bugs to increase their population over a short period of time.

From June 20 to July 25 there was a higher number of nymphs on mustard than the trap broccoli, rape, or the main broccoli which was surrounded by mustard ($P<0.05$, Friedman's method) (Tables 6 & 14).

Fall 1994 The first harlequin bugs were observed on September 3 and individuals were observed in low numbers during the entire sampling period (Tables 7-9, Figs. 2-3). A lower number of adults was observed than expected. The low number may have been due to the presence of a broccoli field between the spring and fall plots which attracted high numbers of harlequin bug adults.

Between September 16 and October 21, there was a higher number of adults on the mustard and rape than on the trap broccoli ($0.01<P<0.025$, Friedman's method). Mustard and rape also had higher numbers of nymphs than the trap broccoli from September 30 through October 28 ($P<0.05$, Friedman's method). These results indicate that under low harlequin bug

pressure, rape and mustard are preferred over broccoli when used as a trap crop.

The same trend was shown in the trap plants and their protected broccoli. There were higher numbers of nymphs on mustard and rape in comparison with their associated main broccoli from September 30 to October 28 ($P<0.05$, Friedman's method). Similarly, from September 16 through October 21, a higher number of adults was observed on mustard and rape than on their associated broccoli ($0.01<P<0.025$, Friedman's method). These data further confirm that harlequin bugs prefer mustard and rape over broccoli as host plants.

These data show that for low harlequin bug populations, mustard and rape can be used as trap crops to prevent harlequin bugs from reaching the main broccoli planting. On a few occasions, adults were found on the main broccoli, but the numbers were low compared with the trap plant populations.

Spring 1995 The first harlequin bug adult was observed June 27 on a non-sample mustard plant. On July 12, adults and eggs were recorded on trap mustard plants, and adults were recorded on trap broccoli (Tables 10-12, Figs. 4-6). On August 2, two harlequin bug adults were recorded on the main broccoli; one was surrounded by mustard and the other by trap broccoli. The harlequin bug population on the main broccoli continued to increase over the next two sample periods as individuals from the overcrowded trap plants moved into the main crop (Table 13). The increased number of eggs, nymphs, and adults on

the main broccoli shows movement from trap plants to the main broccoli from August 2 through the end of the sampling period. The last sample was taken on August 18 due to the mustard senescing and rape and broccoli succumbing to flea beetle damage.

From July 25 through August 18, there were significantly higher number of egg masses on rape than on mustard or broccoli ($P<0.05$, Friedman's method). The adult population on rape was higher than those on trap broccoli or mustard from July 17 to August 18 ($P<0.05$, Friedman's method).

With the decline of the trap crops in August due to senescing and flea beetle damage, the harlequin bugs were able to get through to the main broccoli plants. However, significantly more eggs, nymphs, and adults were found on the trap plants than on the main broccoli they surround in all but two cases ($P<0.05$, Friedman's method) (Table 14). There were no differences in the eggs on mustard and its main broccoli, and the nymphs on rape compared with its main broccoli.

Although the harlequin bugs stayed on the trap plants for six weeks, they eventually moved onto the main broccoli. This indicates that although there is a preference for mustard and rape, it may not be enough to keep high densities of harlequin bugs from reaching the main broccoli. This would suggest that if this system were put into commercial use, trap plants should be monitored to determine the size of the harlequin bug population. If the harlequin bug

population is increasing rapidly and the trap plants are senescing, then the trap plants should be destroyed together with the harlequin bugs. Spraying or destroying trap plants would be cheaper for growers than spraying the whole field.

The results of the trap crop and main broccoli comparisons suggest that trap crops can be used to control harlequin bugs. Rape had five instances where its harlequin bug population was higher than the population on the main broccoli, mustard had four, and broccoli had three (Table 14).

When the number of adults, nymphs, and eggs are compared on the trap crops, rape and mustard are preferred by harlequin bugs over broccoli for feeding and oviposition (Table 6). In the ten instances where there were significant differences in population, broccoli never had a higher population than rape or mustard.

Trap plants were shown to attract the initial harlequin bug infestation, but over time some individuals moved onto the main broccoli, especially when there was a heavy infestation (August 1995). Therefore, both the trap plants and the main crop should be monitored to determine if control of the harlequin bug is needed. Limiting the size of the population entering winter diapause should result in lower harlequin bug populations the following year. After harvest, remnants of trap crops and broccoli should be destroyed since they act as a food source for harlequin bugs until the next planting or until they hibernate.

CONCLUSION

Mustard and rape were shown to protect the main broccoli during its active growth stage, but in both spring plantings mustard senesced earlier than the other plants. This could be alleviated by manipulation of planting times such as planting mustard before and after the main plantings of broccoli. Since mustard bolts within a few weeks of germination when planted in flats, direct seeding may be a better method for planting.

Since both mustard and rape attracted harlequin bugs, I would recommend that rape be used as the preferred trap crop because it does not senesce as early as mustard. Even though mustard delays harlequin bug development slightly more than rape, the difference is not great enough to affect harlequin bug development (Chapter 3). Although trap crops can be effectively used against low populations of harlequin bugs, additional measures need to be considered when the harlequin bug population is high. Due to the large number of nymphs that are capable of accumulating in a short period of time on rape, a method to control them while on the trap plant should also be considered.

Table 3. Weekly mean number of harlequin bug egg masses per plant for each of the three trap crops in spring 1994[1].

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
June 20	0	0	0
June 28	0	0	0
July 5	0.08 ± 0.06	0	0
July 11	0	0	0
July 19	0	0	0
July 25	0	0.04 ± 0.04	0
August 4	-	1.13 ± 0.40	-
August 10	-	2.04 ± 0.55	-
August 19	-	2.83 ± 0.55	-
August 26	-	2.38 ± 0.60	-

[1]No egg masses observed May 8 - July 13, and no egg masses were observed on the main broccoli crop during the entire season.

- Mustard and broccoli were not sampled after July 25.

Table 4. Weekly mean number of harlequin bug nymphs per plant for each of the three trap crops in spring 1994[1].

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$SE	$\bar{X} \pm$ SE
June 20	0	0	0
June 28	0.46 ± 0.46	0	0
July 5	0.63 ± 0.51	0	0
July 11	0.58 ± 0.46	0	0
July 19	0.33 ± 0.13	0	0
July 25	0.21 ± 0.10	0.04 ± 0.04	0
August 4	-	1.54 ± 0.90	-
August 10	-	8.38 ± 2.96	-
August 19	-	14.63 ± 2.49	-
August 26	-	30.50 ± 9.63	-

[1]No nymphs observed May 8 - July 13, and no nymphs were observed on the main broccoli crop during the entire season.

- Mustard and broccoli were not sampled after July 25.

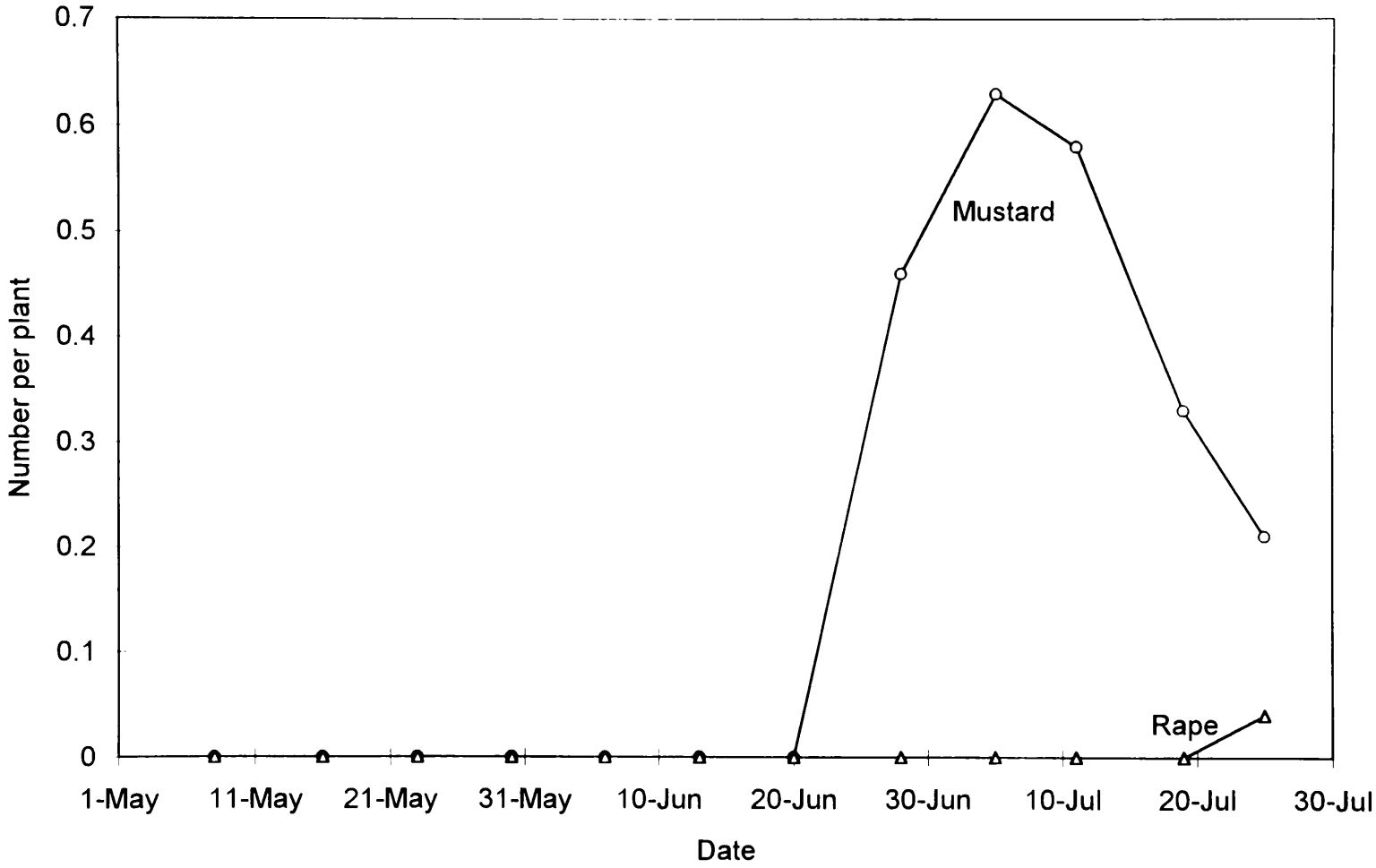

Figure 1. Seasonal abundance of harlequin bug nymphs on trap crops in spring 1994; no individuals observed on trap broccoli.

Table 5. Weekly mean number of harlequin bug adults per plant for each of the three trap crops in spring 1994[1].

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
June 20	0.04 ± 0.04	0	0
June 28	0	0	0
July 5	0	0	0
July 11	0	0.04 ± 0.04	0
July 19	0.08 ± 0.06	0.13 ± 0.09	0
July 25	0	0.88 ± 0.36	0
August 4	-	1.67 ± 0.53	-
August 10	-	3.83 ± 1.00	-
August 19	-	2.00 ± 0.62	-
August 26	-	1.04 ± 0.30	-

[1]No adults observed May 8 - July 13, and no adults were observed on the main broccoli crop during the entire season.

- Mustard and broccoli were not sampled after July 25.

Table 6. Summary of statistically significant (P<0.05) data for trap crop comparisons using Friedman's method for randomized blocks.

Time period	Trap plant interaction	Harlequin bug life stage	P value	X^2 (df=1)
Spring 1994				
6/20-7/25	Mustard vs. Broccoli	Nymph	0.041	4.17
6/20-7/25	Mustard vs. Rape	Nymph	0.041	4.17
Fall 1994				
9/30-10/28	Mustard vs. Broccoli	Nymph	0.026	5.00
9/30-10/28	Rape vs. Broccoli	Nymph	0.026	5.00
9/16-10/21	Mustard vs. Broccoli	Adult	0.014	6.00
9/16-10/21	Rape vs. Broccoli	Adult	0.014	6.00
Spring 1995				
7/25-8/18	Rape vs. Broccoli	Egg	0.046	4.00
7/25-8-18	Rape vs. Mustard	Egg	0.046	4.00
7-17-8/18	Rape vs. Broccoli	Adult	0.026	5.00
7-17-8/18	Rape vs. Mustard	Adult	0.026	5.00

Table 7. Weekly mean number of harlequin bug egg masses per plant for each of the three trap crops in fall 1994.

Date	Mustard	Rape	Broccoli[1]
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
September 3	0	0	0
September 9	0	0.04 ± 0.04	0
September 16	0	0	0
September 23	0	0.04 ± 0.04	0
September 30	0	0.04 ± 0.04	0
October 7	0	0	0
October 15	0	0	0
October 21	0	0	0
October 28	0	0	0
November 4	0	0	0

[1]One egg mass was observed on a main broccoli plant surrounded by trap broccoli on September 23, 30, and October 7.

Table 8. Weekly mean number of harlequin bug nymphs per plant for each of the three trap crops in fall 1994.

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
September 3	0	0	0
September 9	0	0	0
September 16	0	0	0
September 23	0	0	0
September 30	0.25 ± 0.21	0.25 ± 0.21	0
October 7	0.33 ± 0.33	0.13 ± 0.09	0
October 15	0.46 ± 0.38	0.50 ± 0.46	0
October 21	0.25 ± 0.21	0.63 ± 0.46	0
October 28	0.29 ± 0.29	0.04 ± 0.04	0
November 4	0.13 ± 0.09	0	0

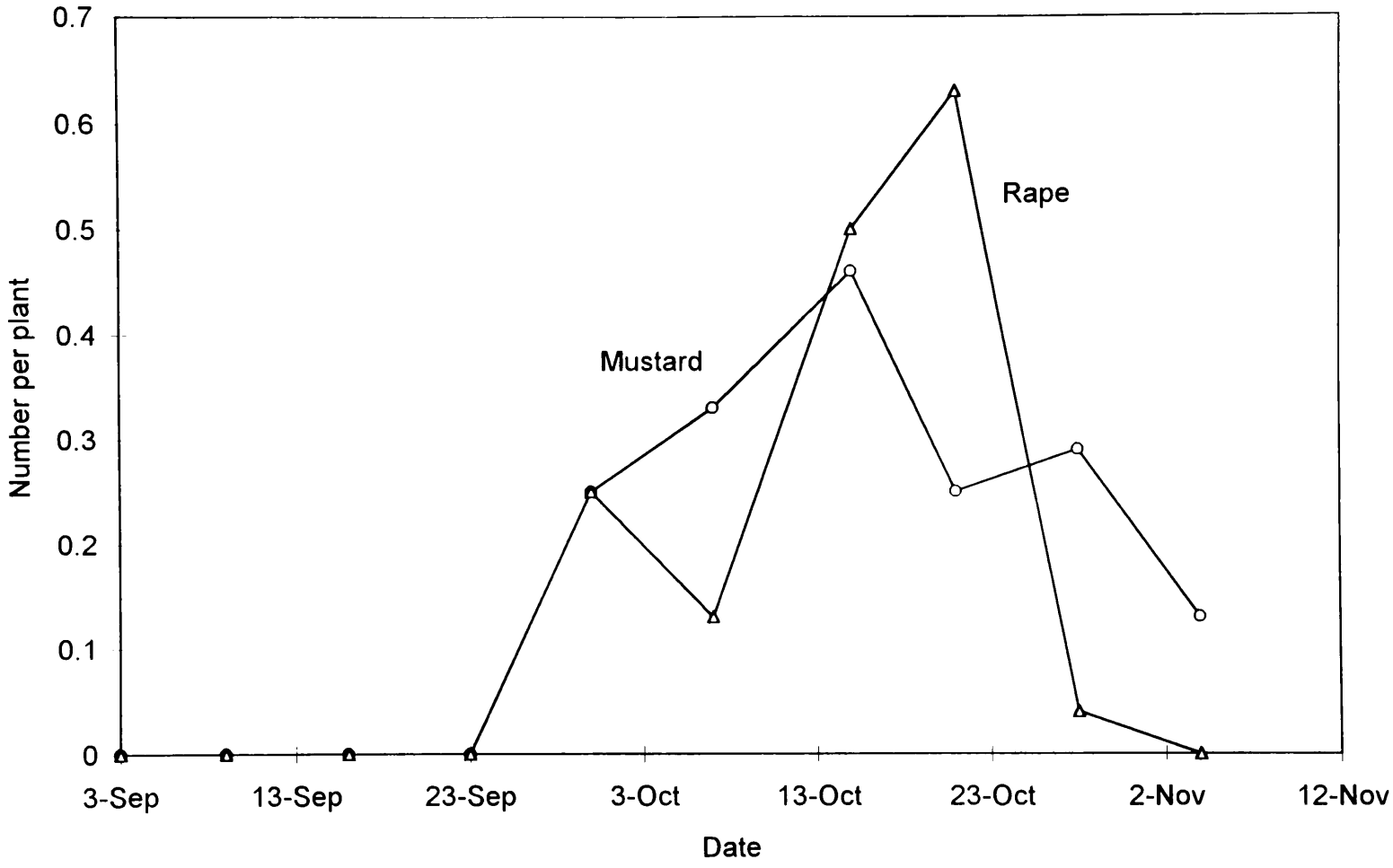

Figure 2. Seasonal abundance of harlequin bug nymphs on trap crops in fall 1995; no individuals observed on trap broccoli.

Table 9. Weekly mean number of harlequin bug adults per plant for each of the three trap crops in fall 1994.

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
3 September	0.04 ± 0.04	0	0
9 September	0.04 ± 0.04	0	0
16 September	0.08 ± 0.06	0.04 ± 0.04	0
23 September	0.17 ± 0.10	0.29 ± 0.14	0.08 ± 0.06
30 September	0.54 ± 0.22	0.79 ± 0.31[2]	0.08 ± 0.06[1]
7 October	0.63 ± 0.16	0.88 ± 0.48	0.04 ± 0.04
15 October	0.38 ± 0.12[3]	0.71 ± 0.38	0
21 October	0.17 ± 0.17	0.17 ± 0.13[2]	0
28 October	0.04 ± 0.04	0.13 ± 0.12	0
4 November	0.04 ± 0.04	0.04 ± 0.04	0

[1]One adult on main broccoli plant surrounded by trap broccoli.
[2]One adult on main broccoli plant surrounded by rape.
[3]One adult on main broccoli plant surrounded by mustard.

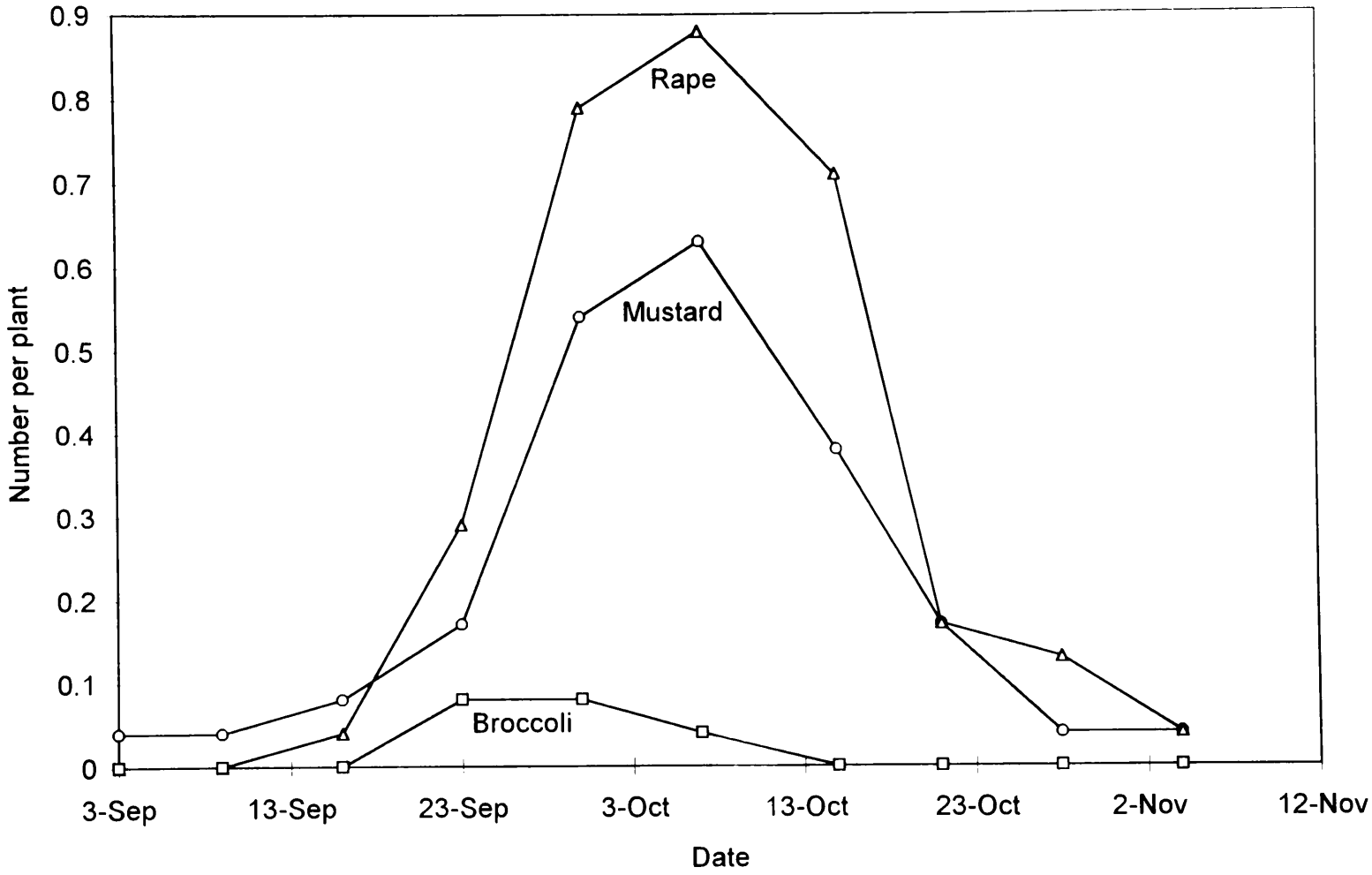

Figure 3. Seasonal abundance of harlequin bug adults on trap crops in fall 1994.

Table 10. Weekly mean number of harlequin bug egg masses per plant for each of the three trap crops in spring 1995.

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
June 20	0	0	0
June 27	0	0	0
July 4	0	0	0
July 12	0.08 ± 0.08	0	0
July 17	0	0.04 ± 0.04	0
July 25	0.13 ± 0.09	0.71 ± 0.27	0.42 ± 0.30
August 2	0.13 ± 0.13	1.38 ± 0.38	0.50 ± 0.23
August 9	0.38 ± 0.16	1.33 ± 0.49	0.46 ± 0.21
August 18	0.29 ± 0.15	2.63 ± 0.60	0.25 ± 0.14

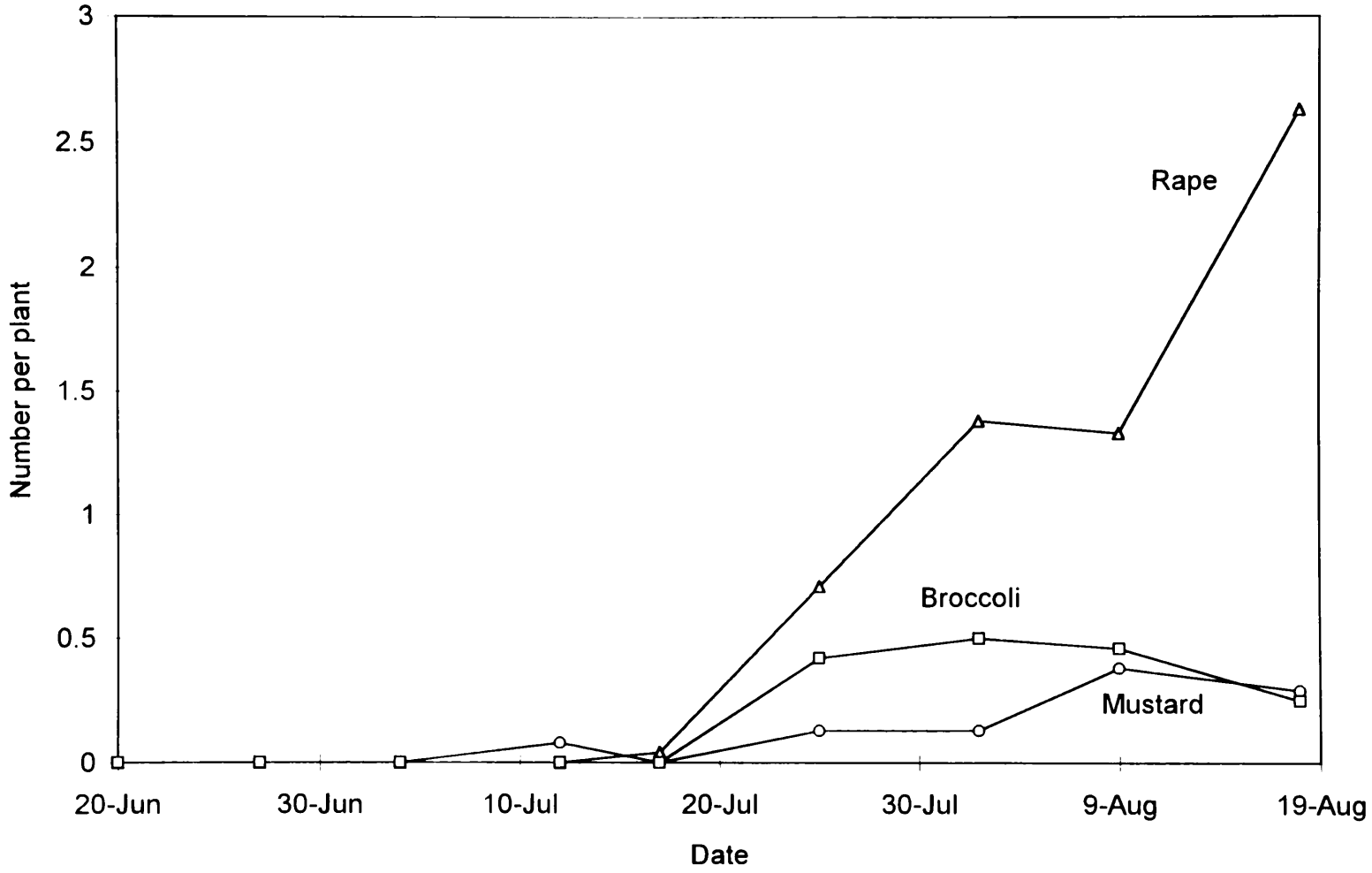

Figure 4. Seasonal abundance of harlequin bug egg masses on trap crops in spring 1995.

Table 11. Weekly mean number of harlequin bug nymphs per plant for each of the three trap crops in spring 1995.

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
June 20	0	0	0
June 27	0	0	0
July 4	0	0	0
July 12	0	0	0
July 17	0.25 ± 0.25	0	0.50 ± 0.50
July 25	0.50 ± 0.50	0.33 ± 0.29	0.25 ± 0.25
August 2	1.71 ± 1.25	7.21 ± 3.27	2.04 ± 1.10
August 9	1.50 ± 0.68	21.38 ± 7.10	3.88 ± 2.17
August 18	2.88 ± 1.25	15.46 ± 5.20	2.46 ± 1.32

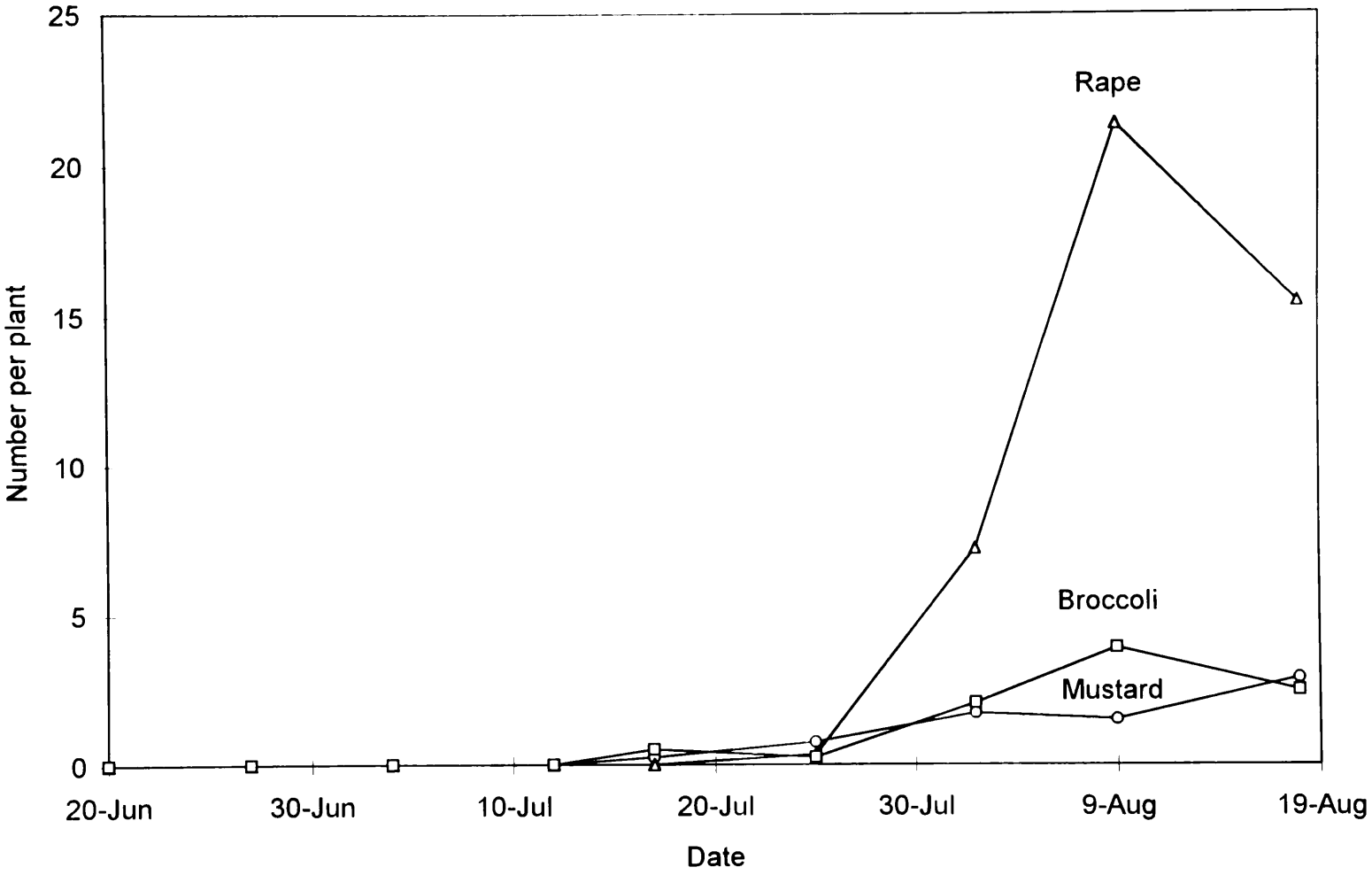

Figure 5. Seasonal abundance of harlequin bug nymphs on trap crops in spring 1995.

Table 12. Weekly mean number of harlequin bug adults per plant for each of the three trap crops in spring 1995.

Date	Mustard	Rape	Broccoli
	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
June 20	0	0	0
June 27	0	0	0
July 4	0	0	0
July 12	0.13 ± 0.09	0	0.08 ± 0.06
July 17	0.04 ± 0.04	0.25 ± 0.12	0.21 ± 0.17
July 25	0.29 ± 0.14	1.33 ± 0.60	0.04 ± 0.04
August 2	0.92 ± 0.27	1.33 ± 0.63	0.38 ± 0.22
August 9	1.04 ± 0.38	1.75 ± 0.63	0.08 ± 0.08
August 18	1.00 ± 0.32	2.46 ± 0.81	0.17 ± 0.10

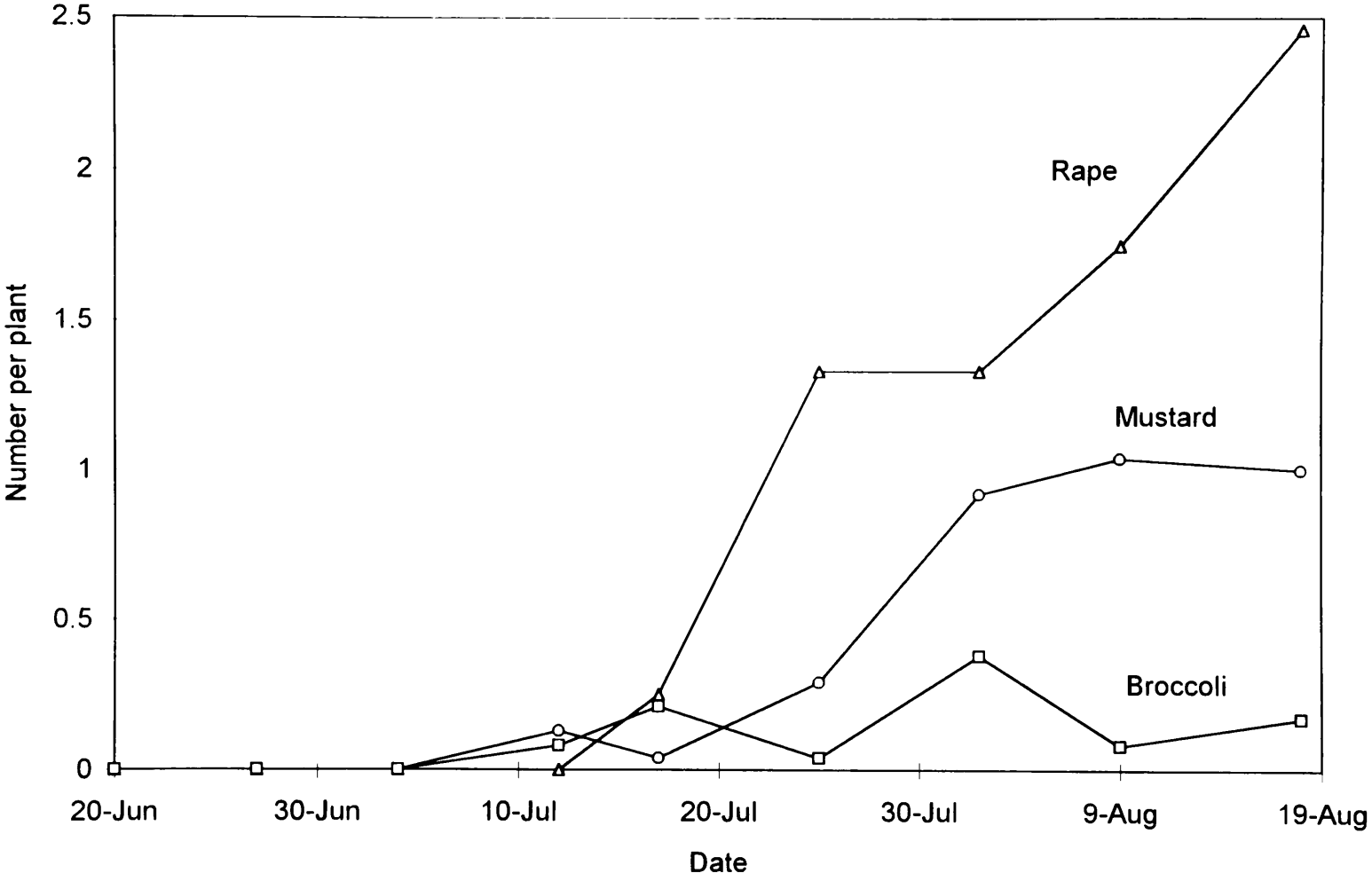

Figure 6. Seasonal abundance of harlequin bug adults on trap crops in spring 1995.

Table 13. Weekly mean number of harlequin bug egg masses, nymphs, and adults per plant for the main broccoli surrounded by trap crops[1] in spring 1995.

	Broccoli surrounded by		
	Mustard	Rape	Broccoli
Date	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE	$\bar{X} \pm$ SE
Eggs			
August 2	0.13 ± 0.07	0	0
August 9	0.04 ± 0.04	0.08 ± 0.06	0.08 ± 0.06
August 18	0.58 ± 0.25	0.08 ± 0.08	0.04 ± 0.04
Nymphs			
August 2	0	0	0
August 9	1.00 ± 0.69	0	0.04 ± 0.04
August 18	1.79 ± 0.87	0.50 ± 0.50	0.67 ± 0.31
Adults			
August 2	0.04 ± 0.04	0	0.04 ± 0.04
August 9	0.08 ± 0.06	0.08 ± 0.06	0
August 18	0.13 ± 0.07	0.04 ± 0.04	0.08 ± 0.08

[1] No egg masses, nymphs, or adults observed June 20 - July 25.

Table 14. Summary of statistically significant data ($P<0.05$) using Friedman's method for randomized blocks for comparisons of trap crops and their main broccoli.

Time period	Trap plant	Harlequin bug life stage	P value	X^2 (df=1)
Spring 1994				
6/20-7/25	Mustard	Nymphs	0.041	4.17
Fall 1994				
9/30-10/28	Rape	Nymph	0.026	5.00
9/30-10/28	Mustard	Nymph	0.026	5.00
9/16-10/21	Rape	Adult	0.014	6.00
9/16-10/21	Mustard	Adult	0.014	6.00
Spring 1995				
7/25-9/18	Broccoli	Egg	0.046	4.00
7/25-9/18	Rape	Egg	0.046	4.00
7/17-8/18	Broccoli	Nymph	0.026	5.00
7/17-8/18	Rape	Nymph	0.026	5.00
7/17-8/18	Broccoli	Adult	0.026	5.00
7/17-8/18	Mustard	Adult	0.026	5.00
7/17-8/18	Rape	Adult	0.026	5.00

Chapter 3

Effect of Host Plants on Harlequin Bug Development and Effect of Sex Ratio on Egg Production and Viability

INTRODUCTION

Numerous studies (Canerday 1965, Paddock 1918, Streams and Pimentel 1963) have been conducted to investigate harlequin bug development on cabbage (Table 1), the major Cole crop at the time these studies were undertaken (Proulx 1981). We do not know how broccoli or other host plants affect the harlequin bug's biology. The goal of this experiment is to compare the effects of broccoli, mustard, and rape on its development.

MATERIAL AND METHODS

Nymphal Development

Broccoli (*Brassica oleracea* 'Packman hybrid'), mustard (*B. kabar* 'southern giant curled'), and rape (*B. napus* 'dwarf essex') were evaluated as harlequin bug host plants. Egg masses were collected from laboratory reared harlequin bugs and individually placed in 100 mm x 15 mm petri dishes. Nymphal development was conducted using two cohorts of nymphs from the same parental generation. The initiation of each cohort was separated by seven weeks. At eclosion, a damp paper towel was added to the petri dishes to supply the first instars with water and placed in a growth chamber (14L:10D, 25°C). No leaves were placed in the containers since first instars do not feed (Streams & Pimentel 1963). Second instars were divided into three groups and placed in petri dishes containing a leaf section from one of the three host plants. In the

two cohorts, 110 and 120 second instars, respectively, were observed. Nymphs were checked every 24 hours to put in fresh leaves and to monitor molting. Third instars were reared using the same techniques as the previous instar, but the fourth and fifth instars were reared in 1 L plastic containers. The containers were inverted and the top replaced with 40 mesh per cm^2 screen. The leaf petiole was pushed through a hole in the lid of the container into a jar of water.

The developmental time for each instar reared on mustard, rape, or broccoli was recorded and compared using Tukey's HSD (Sokal & Rohlf 1995). The developmental time for male and female fifth instars on each host plant was also compared using Tukey's HSD. Total developmental time was determined by the sum of the average development time for each instar on each host plant.

Adult Longevity

Seventeen pairs of adults from each host plant were paired and placed in 1 L plastic containers with a leaf from the host plant they were reared on and stored in a growth chamber (15L:9D, 25°C). Adults were checked daily to determine preoviposition period and longevity. Adults fed on mustard were only reared until their preovipositional period was determined due to difficulties with growing mustard in the greenhouse. Broccoli and rape fed adults were reared for 113 days.

Sex Ratio Effect on Egg Production and Viability

Seven sex ratios, 4:1, 3:1, 2:1,1:1, 1:2, 1:3, and 1:4, were evaluated to determine if sex ratio affects egg production and viability under laboratory conditions. Fifteen day old virgin adults were placed in 1 L plastic containers. The containers were inverted and the top replaced with 40 mesh per cm^2 screen. A broccoli leaf petiole was inserted through a hole in the lid of the container into a jar of water. Containers were stored in a growth chamber (14L:10D, 25°C) and checked daily for leaf replacement and egg removal. Eggs were placed in petri dishes to hatch. Each treatment was replicated five times. The average number of eggs per female per replicate was compared using Tukey's HSD.

RESULTS AND DISCUSSION

Nymphal Development

Although the nymphs from each cohort were from the same parental generation and reared under the same conditions, the second cohort took longer to develop than the first generation. As a consequence, the two cohorts were analyzed independently.

The developmental rate of first instars was determined from the second cohort only. The average developmental time was 4.92 days, (n=316). This was over a day longer than the 3.58 days recorded by Canerday (1965) at the same temperature.

Cohort 1 Second instars reared on broccoli developed slower than those reared on rape ($P<0.05$, Tukey's HSD) (Table 15). Third, fourth, and fifth instars developed faster on broccoli or rape than mustard ($P<0.05$, Tukey's HSD). There was a significant difference ($P<0.05$, Tukey's HSD) in developmental time of the two sexes when reared on broccoli; females took 0.9 days longer to develop than males (Table 16). Developmental time from second instar to adult was 31.5 days for broccoli and rape and 34.0 days for mustard.

Cohort 2 Developmental times of second instars reared on each of the three host plants were different (Table 15). Broccoli had the longest development time followed by mustard and then rape ($P<0.05$, Tukey's HSD). Third instars reared on broccoli took longer to develop than those reared on rape ($P<0.05$, Tukey's HSD). Fourth instars developed faster on rape than broccoli or mustard ($P<0.05$, Tukey's HSD) and fifth instars developed slower on mustard than broccoli or rape ($P<0.05$, Tukey's HSD). The developmental time of male fifth instars was 1.9 days slower than the same stage females reared on mustard ($P<0.05$, Tukey's HSD) (Table 16). The average development time from second instar to adult was 40.5 days on rape, 44.6 days on broccoli, and 46.4 days on mustard.

Adult Longevity The preovipositional times for harlequin bugs reared on broccoli, mustard, and rape were 21.8 days, 24.6 days, and 19.5 days respectively. Harlequin bugs reared on mustard and rape had significantly

different preovipositional times. The longer development time for the mustard-reared individuals before oviposition may indicate that mustard lacks nutrients needed by the harlequin bug to initiate egg production. All of the mustard-reared adults survived a minimum of 35 days. Seventy-five percent of the broccoli-reared adults and 59% of the rape-reared adults survived 113 days.

Discussion Although the two cohorts demonstrated different developmental rates, two trends can be inferred. First, rape-reared nymphs had the shortest developmental time. Second, mustard-reared nymphs had the longest developmental time.

In the first cohort the shortest developmental times were found in rape and broccoli in the last three instars. In the second cohort nymphs feeding on rape had the shortest development time in the second to fourth instars, but had a similar developmental rate on broccoli during the fifth instar. Nymphs on mustard generally had the longest development time. In the first cohort, broccoli reared nymphs had the same total development time as rape, but in the second cohort broccoli reared nymphs developed four days slower than rape and two days faster than mustard.

Although there is a difference in harlequin bug developmental time between rape and mustard-reared nymphs, the difference is not large enough to affect the recommendation of one trap crop over another. An ideal situation would be to have a trap plant that is more attractive than broccoli and that

significantly delayed harlequin bug development. The pants tested did not exhibit such an effect.

Although there were two cases where the development times of the sexes differed, I believe that this was an aberration due to the small sample size as the two occurrences corresponded to the two lowest sample sizes. Results from the larger sample sizes indicate no difference in the developmental rates of the two sexes.

Sex Ratio Effect on Egg Production and Viability

Sex ratio had no effect on the number of eggs laid, hatched, or unhatched (Figs. 7-8) ($P>0.05$, Tukey's HSD). Since no significant differences among sex ratios were observed, the average number of eggs for the three categories was determined by averaging all the sex ratios. Female harlequin bugs laid an average of 149 eggs, of which 106 eggs were viable, giving a 71% hatch rate.

These results indicate that egg production is not related to the number of males present. Male and female harlequin bugs were observed to mate multiple times. Canerday (1965) reported that after one mating, female harlequin bugs are able to produce five fertile egg masses (approximately 60 eggs). The above observations confirm that males are capable of mating with a minimum of four females. Multiple mating, together with a relatively high reproductive rate may explain the capability of the harlequin bug to increase rapidly.

CONCLUSION

This study shows that host plants do have an effect on harlequin bug development. Nymphs develop faster when reared on rape than on mustard. In the first cohort, nymphs reared on broccoli developed at the same rate as those reared on rape. In the second cohort broccoli-reared nymphs developed at an intermediate rate between those reared on rape and mustard. The number of eggs produced or hatched was not affected by sex ratio.

Table 15. Developmental time in days of harlequin bug nymphs reared on three host plants.

Host Plant	2nd	3rd	4th	5th	Total (2nd - 5th)
	$\bar{X}$ ±SD (n)	$\bar{X}$ ±SD (n)	$\bar{X}$ ±SD (n)	$\bar{X}$ ±SD (n)	
1st Cohort					
Broccoli	6.23±0.66 (101) a	5.90±1.00 (92) b	7.28±0.89 (85) b	12.09±.93 (88) b	31.50
Mustard	6.07±0.90 (95) ab	6.56±1.23 (84) a	8.15±0.99 (78) a	13.20± 1.75 (76) a	33.98
Rape	5.96±0.71 (96) b	5.89±0.85 (91) b	7.41±0.69 (87) b	12.21±1.00 (84) b	31.47
2nd Cohort					
Broccoli	8.42±1.61 (93) a	8.36±1.66(83)a	12.16±3.64 (74) a	15.61±1.99 (72) b	44.55
Mustard	7.77±0.88(85) b	8.18±1.82 (78)ab	13.17±2.87 (48) a	17.61±2.76 (44) a	46.73
Rape	7.18±0.85(103) c	7.72±1.19 (97)b	9.91±1.83 (87) b	15.71±2.28 (79) b	40.52

Means in columns within cohorts followed by the same letter are not significantly different (P>0.05, Tukey's HSD).

Table 16. Developmental time in days of female and male fifth instars reared on three host plants.

Host Plant	Female	Male
	$\bar{X}$ ±SD (n)	$\bar{X}$ ±SD (n)
1st Cohort		
Broccoli	12.4 days ± 0.9 (30)a	11.5 days ± 0.8 (29)b
Mustard	13.3 days ± 1.8 (29)a	13.2 days ± 1.9 (41)a
Rape	12.4 days ± 1.0 (30)a	12.1 days ± 0.9 (31)a
2nd Cohort		
Broccoli	15.7 ±2.2 (68)a	15.6 ±1.9 (39)a
Mustard	16.9 ± 2.5 (27)b	18.8 ± 2.8 (17)a
Rape	15.8 ± 2.5 (30)a	15.6 ± 2.1 (48)a

Means in rows followed by the same letter are not significantly different (P>0.05, Tukey's HSD)

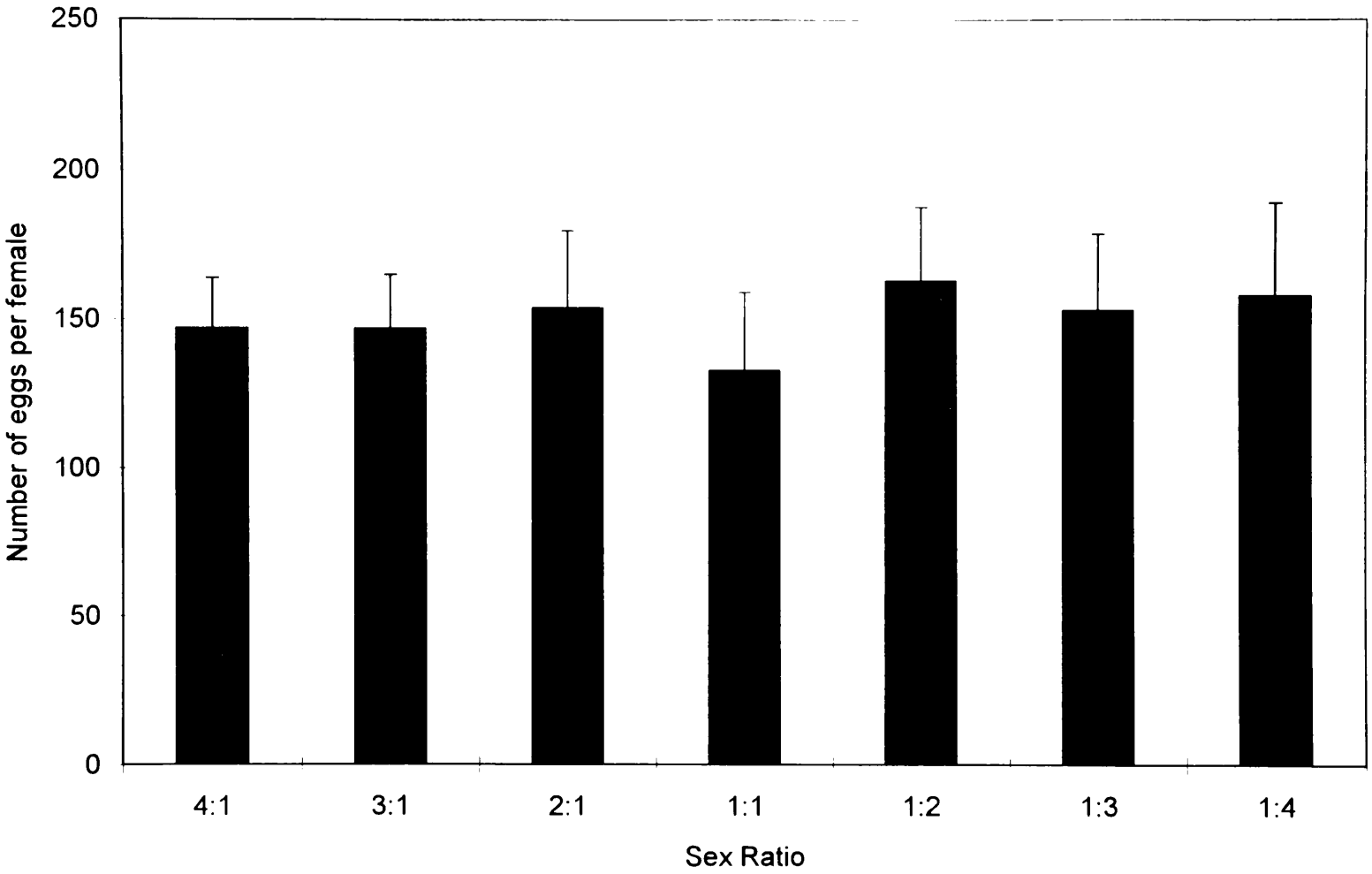

Figure 7. Fecundity of harlequin bugs reared at different sex (F:M) ratios. There was no significant difference (P>0.05, Tukey's HSD).

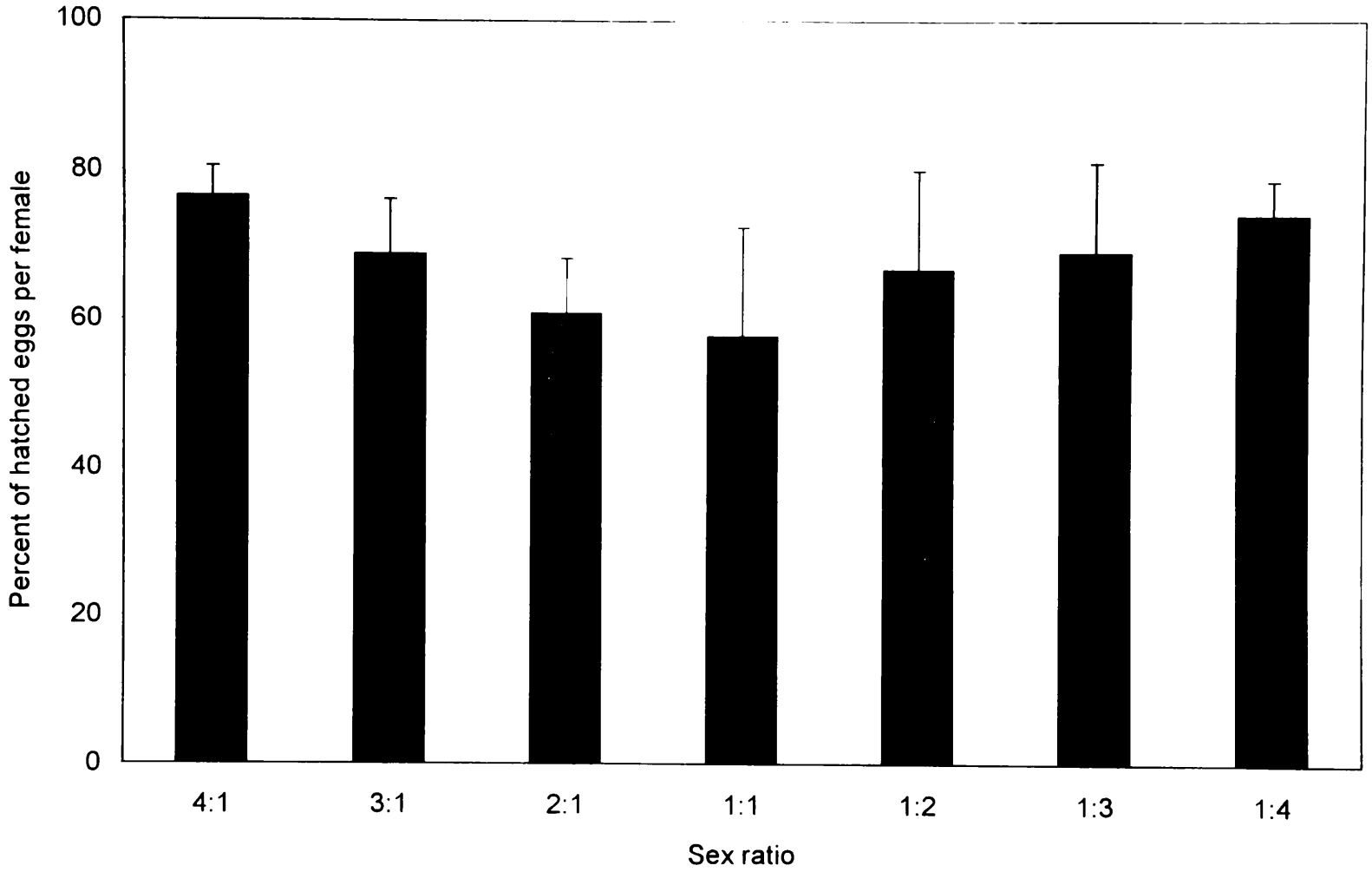

Figure 8. Viability of eggs from harlequin bugs reared at different sex (F:M) ratios. Hatch rates were not significantly different (P>0.05, Tukey's HSD).

Chapter 4

Seasonal Occurrence of Harlequin Bugs in Southwestern Virginia

INTRODUCTION

Harlequin bug host plants include both cultivated and uncultivated species (Appendix 1), allowing it to have host plants available nearly year round. As with most stink bugs, harlequin bug adults and nymphs feed on the same host plants, enabling the study of both life stages together.

Harlequin bugs have an average preoviposition period of 20.5 days (Streams and Pimentel 1963). A typical egg mass consists of 12 eggs, which at 22.5° C takes an average of 7.1 days to hatch (Streams and Pimentel 1963). Each nymphal stadium is different (Table 1); at 25° C it takes an average of 41 days to develop through all five stages (Canerday 1965). Adults have been the only stage shown to overwinter (Chittenden 1908).

Climate plays a role in the number of harlequin bug generations per year. Chittenden (1908) speculated that there is the possibility of four or five generations in the South and two generations in the North. Brett and Sullivan (1974) reported three and a partial fourth generation a year in North Carolina. Although the harlequin bug was once a major pest of cruciferous crops, its life history in Virginia is not known. The goal of this study is to determine the phenology of the harlequin bug in Montgomery County, Virginia.

MATERIALS AND METHODS

In 1994 and 1995, broccoli (*Brassica oleracea* 'Packman Hybrid'), mustard (*B. kabar* 'Southern Giant Curled'), and rape (*B. napus* 'Dwarf Essex') were planted at Kentland Farm (VPI&SU) in Montgomery County to evaluate their effectiveness as trap crops for harlequin bug control (see Chapter 2). The field design consisted of four replicates each containing three plots, mustard & broccoli, rape & broccoli, and broccoli & broccoli. Each plot contained broccoli surrounded by double rows of the trap crop. Plots measured 8 m x 9 m. In 1994, the spring and fall plantings were 50 m apart. In 1995, the spring replicates were spaced 17 m apart with the fall replicates being placed between the spring replicates. The trap plant data from both years were used to determine harlequin bug population phenology in the spring and fall plantings.

In 1995, wild turnip, *Brassica rapa*, was sampled weekly from April 3 to May 18 to determine the harlequin bug's phenology when field crops are not available. Six sites along a 0.5 km transect at the Kentland Farm were selected and four plants per site were selected each week and sampled for eggs, nymphs, and adults. Sampling was discontinued when the turnips senesced.

RESULTS AND DISCUSSION

In 1994, two harlequin bug generations were identified. The first harlequin bug adults appeared at the end of June and their population peaked at

the beginning of August (Fig. 9). The second generation of adults peaked at the beginning of October. Nymphs were recorded from mid-June through mid-October. Most of these nymphs were progeny from the first generation of adults, although some may have been from second generation adults.

One distinct oviposition peak was recorded in 1994 (Fig. 9). Eggs were first detected at the end of June in low numbers and as the adult population increased in August so did the number of egg masses. In September, a few eggs were laid. These could have been from newly emerged adults or from first generation adults. I doubt that the nymphs that emerged in late September would have been capable of reaching the adult stage before winter. These data indicate that there is at least one generation of harlequin bugs in Montgomery County, with the possibility of a partial second generation.

In 1995, three peaks in the adult population were observed (Fig. 10). In mid-April the first peak occurred on the wild turnips. These were overwintered adults. The next two peaks occurred at the beginning of August and at the end of September. The first peak in the nymph population occurred in mid-May and the second occurred at the beginning of August. When these data were analyzed on the basis of the percentage of nymphs or adults in the population, the above peaks are also confirmed (Fig. 11).

Two distinct harlequin bug oviposition peaks were observed in 1995 (Fig. 12). The first peak occurred in mid-April, resulting from eggs laid by the

overwintered adults. The second oviposition peak occurred in mid-August, showing the same trend as in 1994.

Two distinct generations were identified in 1995. The additional peak was from wild turnips, which were not sampled the first year. Adults were shown to emerge at about the beginning of April, beginning of July, and mid-September. The resulting egg masses showed peaks occurring in mid-April and mid- August. It is possible that adults in the last generation, which reached reproductive maturity early, may have oviposited. Nymphs from these eggs would account for a partial generation since they would not have a chance to develop to adult stage before overwintering.

The harlequin bug shows the same trend in host plant switching as the green stink bug. In South Carolina, the green stink bug, *Acrosternum hilare* (Say), undergoes two generations. In April, overwintering adults aggregate and oviposit on fruiting black cherry trees and elderberry bushes where the first generation develops. First generation adults then move to soybean plants where the second generation is completed. By eliminating black cherry trees and elderberry bushes located in fence rows surrounding soybean fields, the number of stink bugs entering soybean field would be substantially reduced (Jones and Sullivan 1982).

The first generation of both species occurs on wild host plants, while the second generation moves to cultivated crops. With a better understanding of

harlequin bug phenology, growers should be better able to cope with the harlequin bug as a Cole crop pest as has occurred with the green stink bug in soybeans.

CONCLUSION

In 1994, harlequin bugs were observed to have at least one and a partial second generation a year, but sampling was started after a first generation may have started to develop. The second year's data indicate harlequin bugs have two and possibly a partial third generation a year in Montgomery County.

Overwintered adults oviposited on wild turnips where the first generation completed development. The subsequent generation then migrated to field plants in June and July. The second generation completed development on field crops producing the adults which overwinter. In both years few eggs were laid by these overwintering adults, and the resulting nymphs probably did not develop to the adult stage before winter.

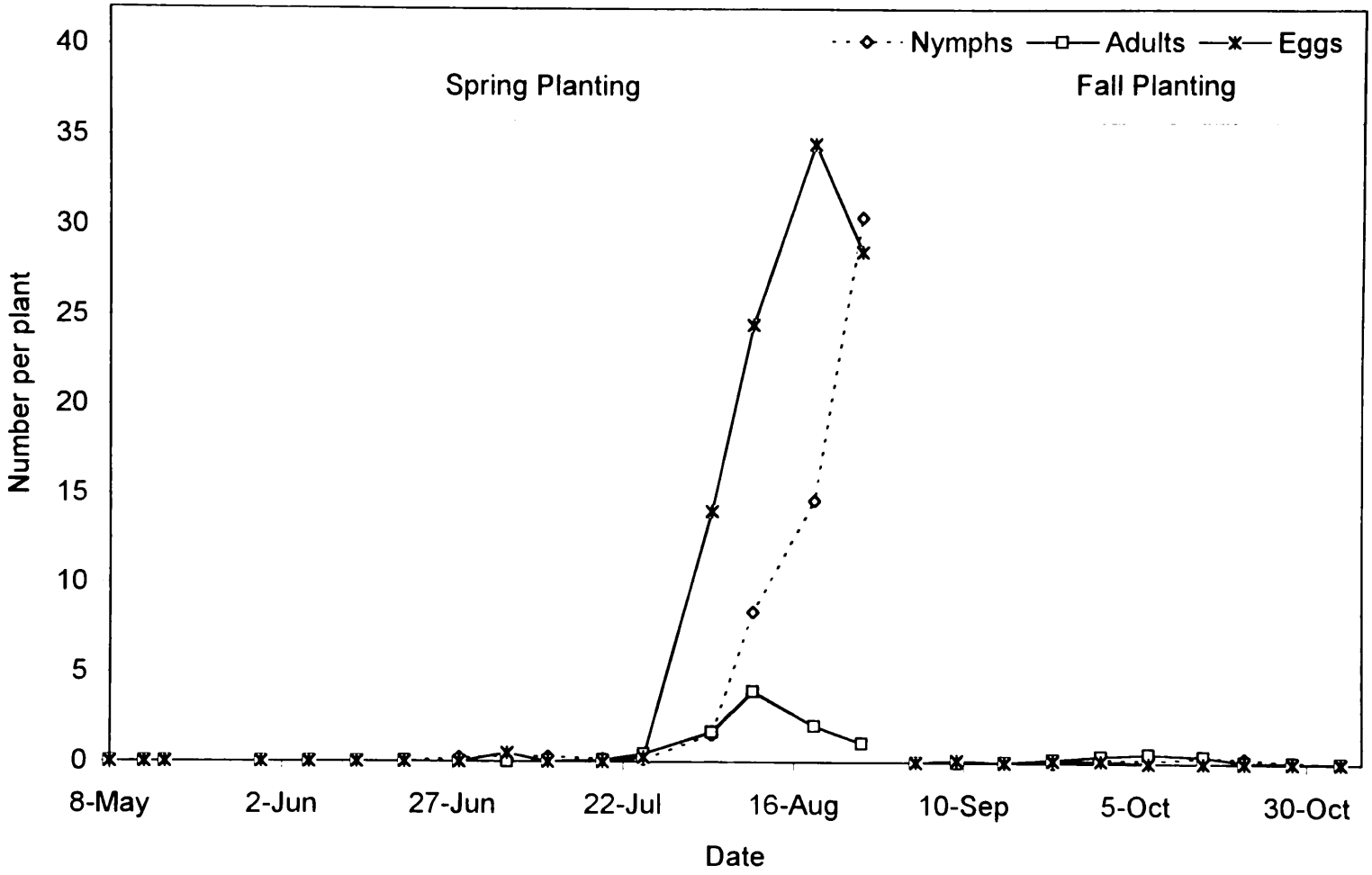

Figure 10. Seasonality of harlequin bug eggs, nymphs, and adults in 1994.

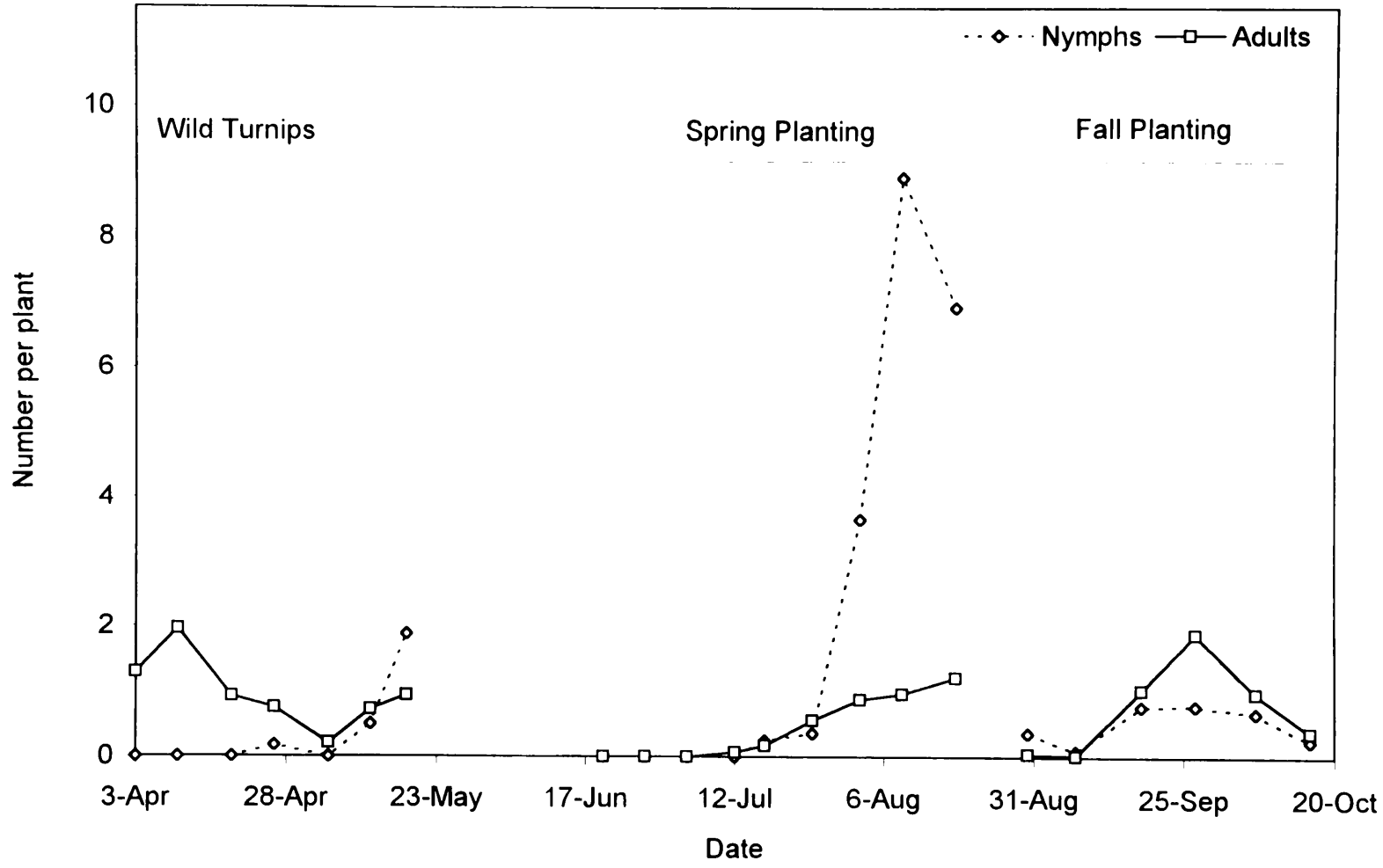

Figure 11. Seasonality of harlequin bug nymphs and adults in 1995.

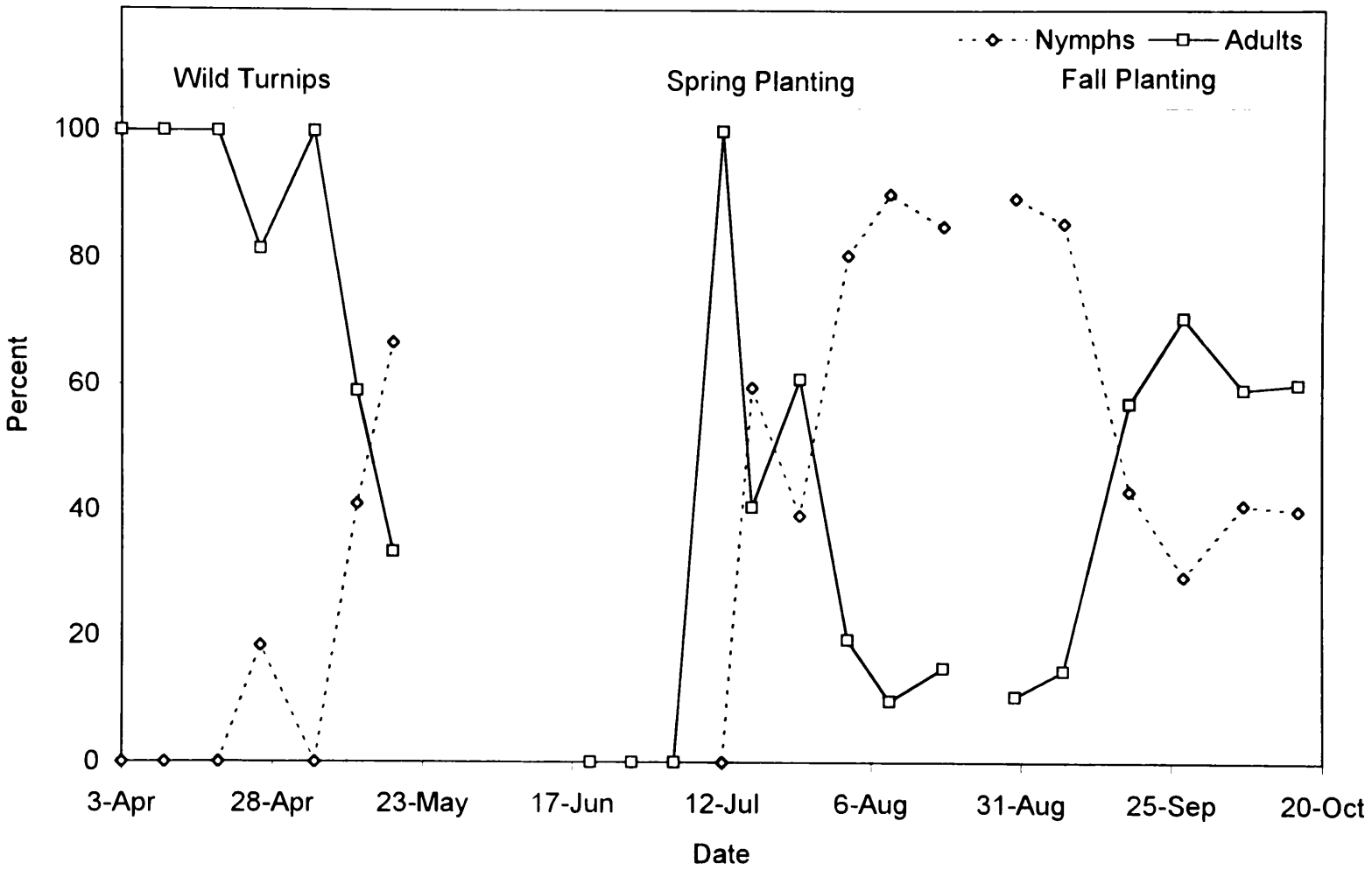

Figure 12. Percentage of harlequin bug adults and nymphs in the population in 1995.

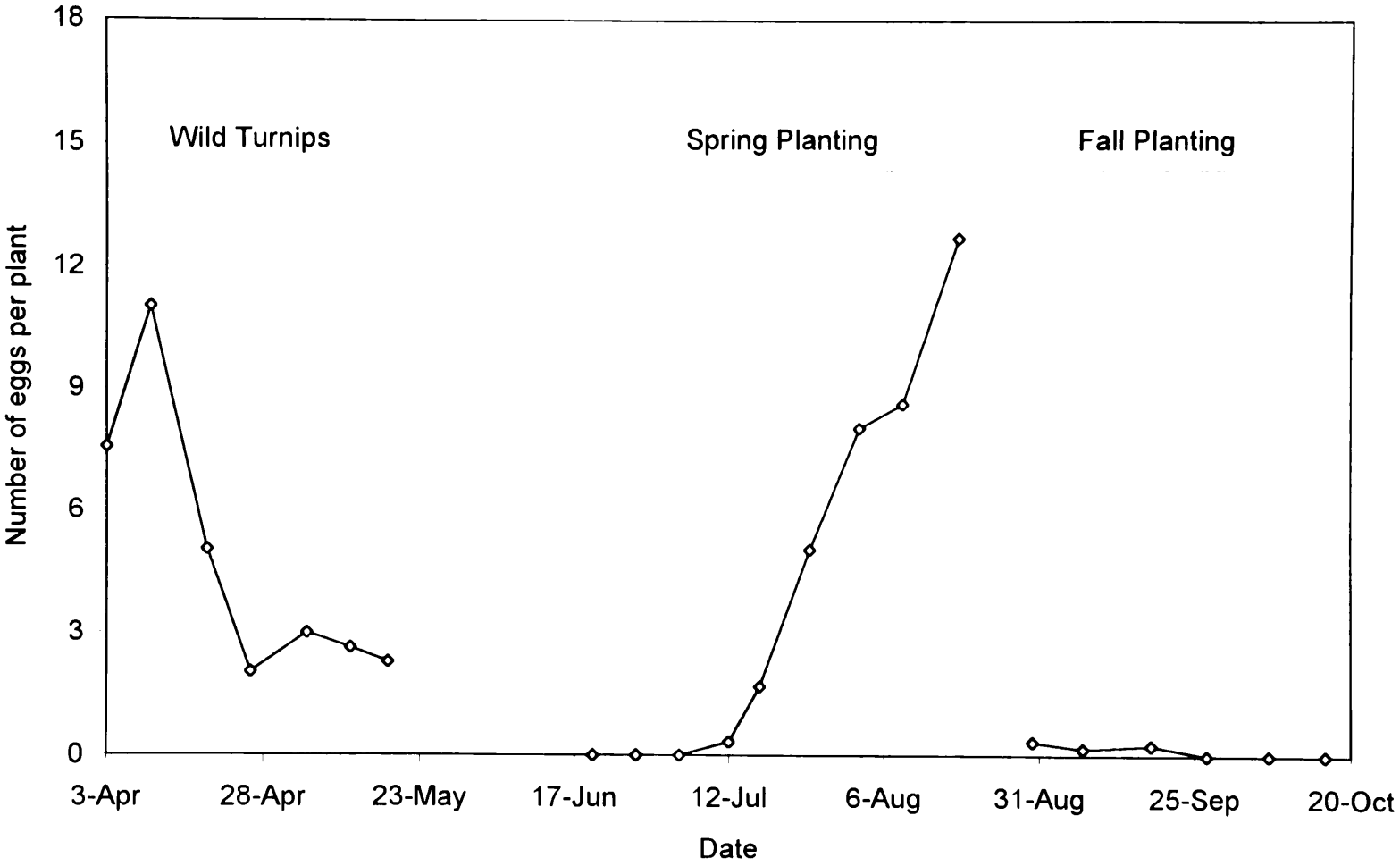

Figure 13. Seasonality of harlequin bug eggs in 1995.

Chapter 5

Parasitoids of Harlequin Bug Eggs

INTRODUCTION

There are two dominant species of harlequin bug egg parasitoids found in the United States, *Ooencyrtus johnsoni* Howard (Hymenoptera: Encyrtidae) and *Trissolcus murgantiae* Ashmead (Hymenoptera: Scelionidae) (Huffaker 1941). Other known parasitoids are *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae) (Buschman and Whitcomb 1980), *T. podisi* Ashmead (Chittenden 1908), *T. utahensis* (Ashmead), *T. euschisti* (Ashmead), and *O. californicus* Girault (Hymenoptera: Encyrtidae) (Hoffmann et al. 1991). In Virginia, *O. johnsoni* was reported to parasitize 35% to 55% of the eggs collected during August and September of 1932 (Walker and Anderson 1933). No reports of *Trissolcus murgantiae* in Virginia have been documented.

MATERIALS AND METHODS

To monitor harlequin bug egg parasitoids, eight egg masses were removed weekly from rape plants in each of the four replicates over a six week period (July 26 to Sept. 3) in 1994. In 1995, eight egg masses per replicate were removed weekly between August 3 and August 29 from rape plants in three replicates. Each egg mass was placed in a 29 mL cup and stored in a growth chamber [15L:9D (1994), 14L:10D (1995) and 25°C] and monitored for hatch. In 1995 a photoperiod of 14:10 was used due to limited growth chamber space. Harlequin bug nymphs were removed as they emerged. Egg parasitoids that

emerged were collected and sent for identification at the Systematic Entomology Laboratory, Taxonomic Services Unit in Beltsville, Maryland. Eggs from which no emergence had occurred were checked for signs of being preyed upon by a piercing-sucking predator. If not, the eggs were considered dead and were dissected to determine if they were parasitized, infertile, or that the harlequin bug nymph died before emergence. Both years, the study was concluded once the adult populations had dispersed because of senescing host plants.

RESULTS AND DISCUSSION

Egg collection was started July 26, 1994 and August 3, 1995 on rape which was the only plant on which eggs were laid at high levels. No eggs were collected during the fall plantings due to extremely low number of eggs. Two species of egg parasitoids, *Trissolcus murgantiae* and *Ooencyrtus johnsoni*, were recovered.

1994 The parasitization rate was below 1% for three of the first four weeks (Figures 13-14). The parasitoid populations were increasing towards the end of the sampling periods as parasitization rates were 21% and 27% for August 26 and September 3, respectively. Of all the eggs collected, 77% hatched, 8% were parasitized, and 15% that did not hatch were not parasitized.

Trissolcus murgantiae, collected on August 26 and September 3, caused 19% and 22% mortality, respectively. This was the first recorded occurrence of

T. murgantiae in Virginia. *O. johnsoni* was collected every week except August 10, but caused less than 7% egg mortality. In an earlier study in Virginia, Walker and Anderson (1933) recovered the latter species, but not *T. murgantiae*.

To exit the host, *T. murgantiae* chewed a hole through the top of the egg, whereas *O. johnsoni* exited by chewing a hole in the side of the egg. *T. murgantiae* is larger than *O. johnsoni* and only one adult developed per host egg. Sixty *O. johnsoni* adults were collected from 37 host eggs for a ratio of 1.6 adults per egg. This was slightly lower than that observed by Maple (1937) who reported 2.05 *O. johnsoni* adults emerged per host egg under laboratory conditions.

1995 Parasites played a more important role in egg mortality in 1995 than they did in 1994 (Figs. 15-16). The number of parasitized eggs was higher in all four weeks compared with the unhatched eggs (Fig. 15). Of the total, 55% of the eggs hatched, 8% did not hatch (unparasitized), and 37% were parasitized. Thirty-two *O. johnsoni* were collected from 17 host eggs for an adult per egg ratio of 1.9. This was consistent with the level observed the previous year.

Both *T. murgantiae* and *O. johnsoni* were collected each week. *T. murgantiae's* parasitization rates increased from 8% to 80% over the sample period. *O. johnsoni* was also present during the entire period, but caused only 1%-2% mortality.

The 1994 and 1995 results suggest that the egg parasitoids did not significantly reduce the harlequin bug populations. In 1994, the number of eggs parasitized was higher than the number unhatched only once. In 1995, the number of parasitized eggs was greater than the unhatched eggs all four weeks, with the parasitization rate exceeding 80% by August 29. Unfortunately, this high rate of parasitization occurred towards the end of harlequin bug egg laying and had little effect on the population. Thus, timing is important as the parasites are capable of parasitizing a large number of eggs (Fig 15). If parasites were released at the start of harlequin bug ovipostiton they could reduce the harlequin bug population.

Adults and nymphs were not collected regularly to determine if they were parasitized. The adults that were collected and reared in the lab at various times to strengthen the lab colony showed no signs of parasitism. In the field no predation was observed on nymphs or adults.

CONCLUSION

The level of parasitization varied greatly between years. In 1994 the parasitization rate was 8% compared with 37% for 1995. Only once over the two year period was the parasitization rate over 50% (August 29, 1994). *Trissolcus murgantiae* was the dominant parasite both years. It was responsible for 87% and 96% of the eggs parasitized in 1994 and 1995. This was the first record of *T. murgantiae* in Virginia. Over the two year period the adult parasite per egg

ratio was 1.0 for *T. murgantiae* and 1.7 for *O. johnsoni*.

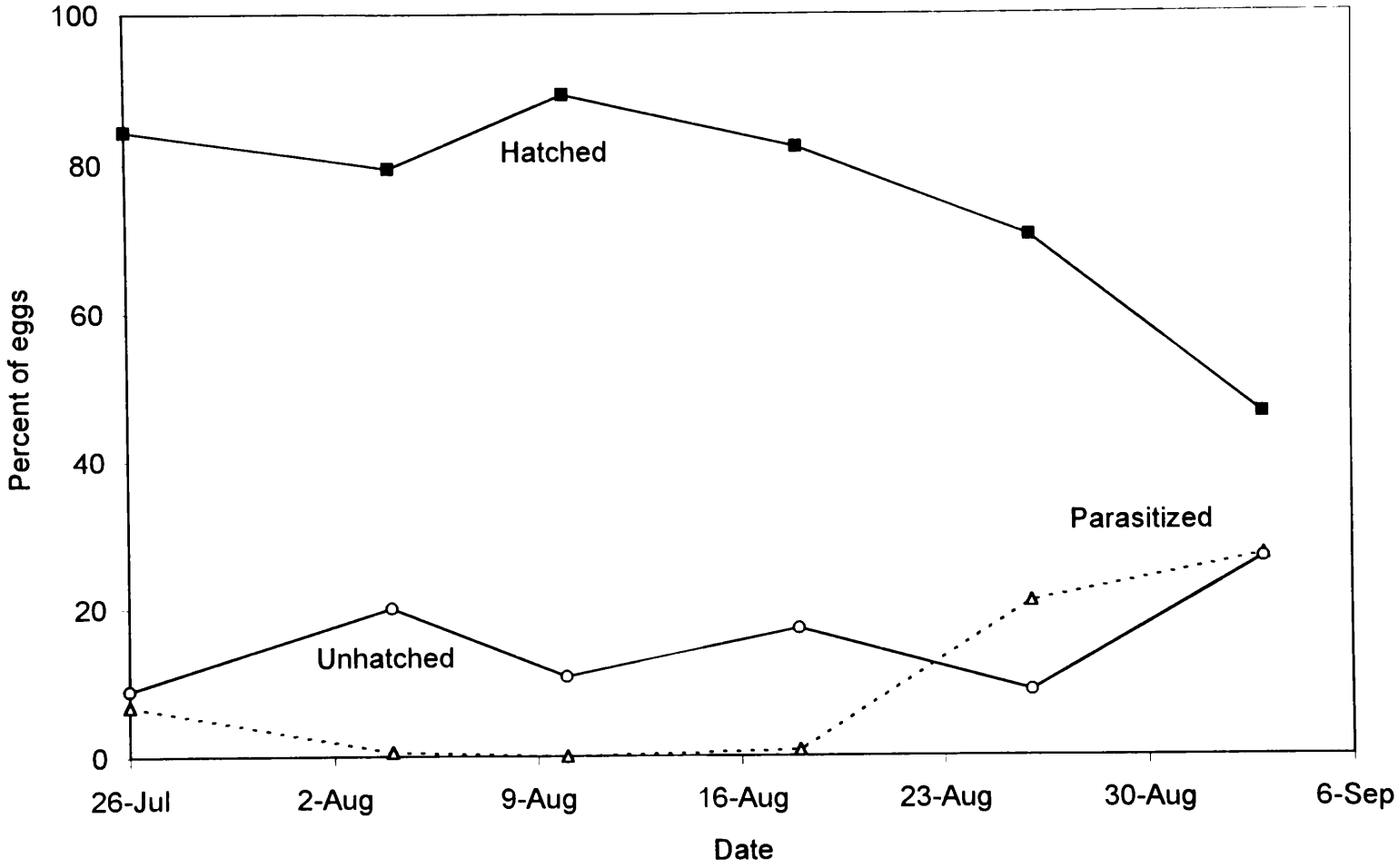

Figure 13. Fate of harlequin bug eggs in 1994.

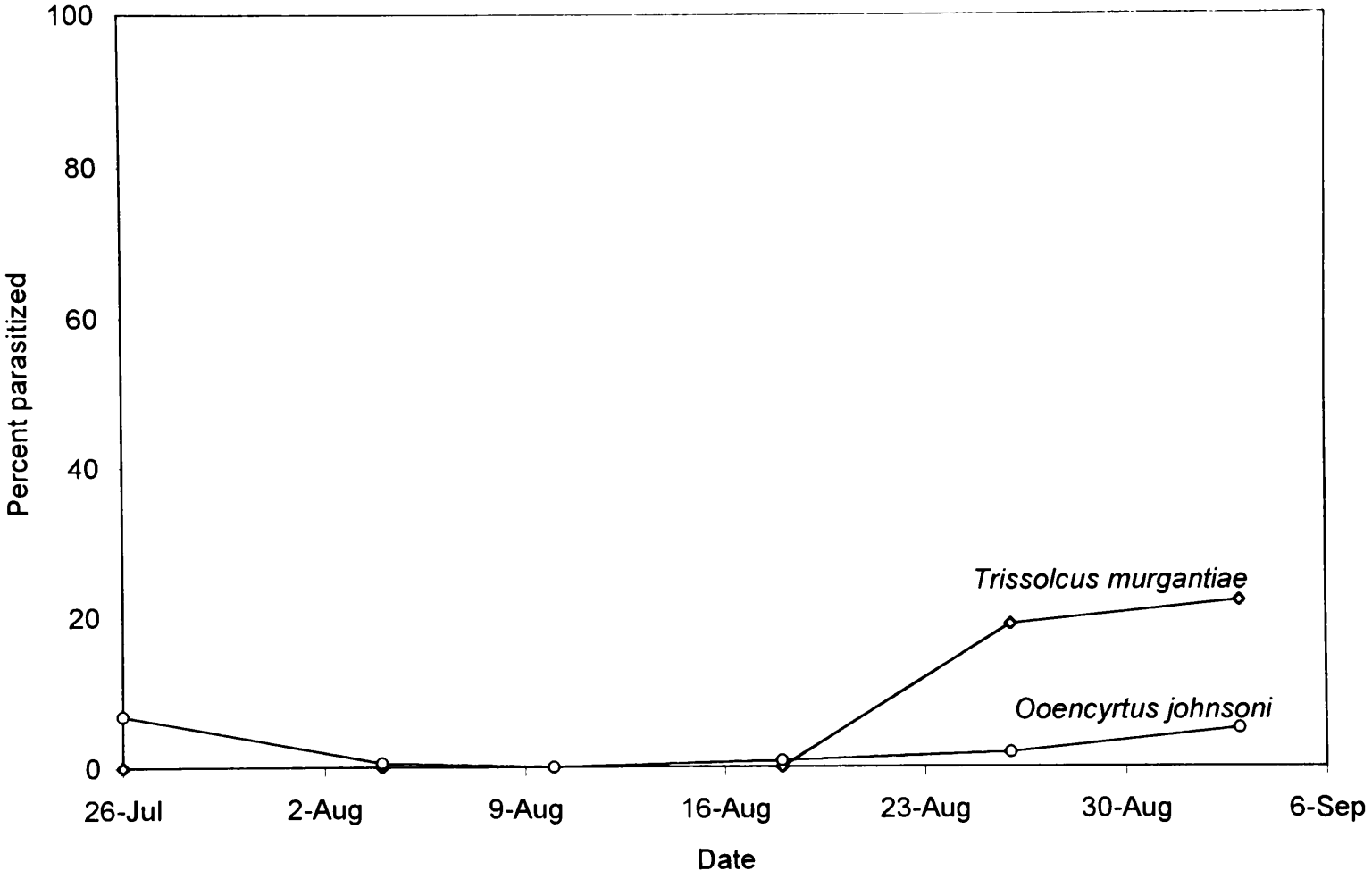

Figure 14. Percent parasitization of harlequin bug eggs by *Trissolcus murgantiae* and *Ooencyrtus johnsoni* in 1994.

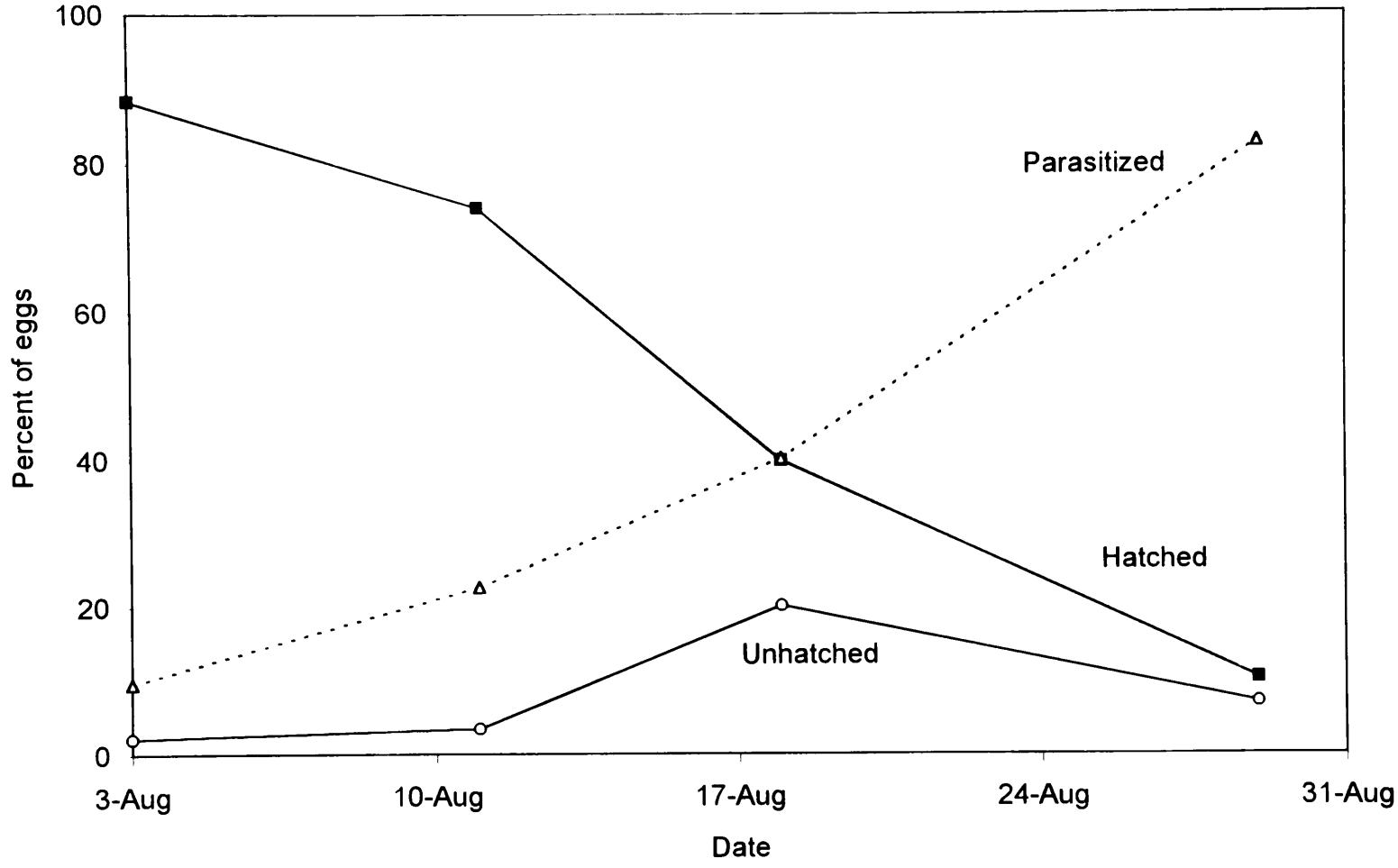

Figure 15. Fate of harlequin bug eggs in 1995.

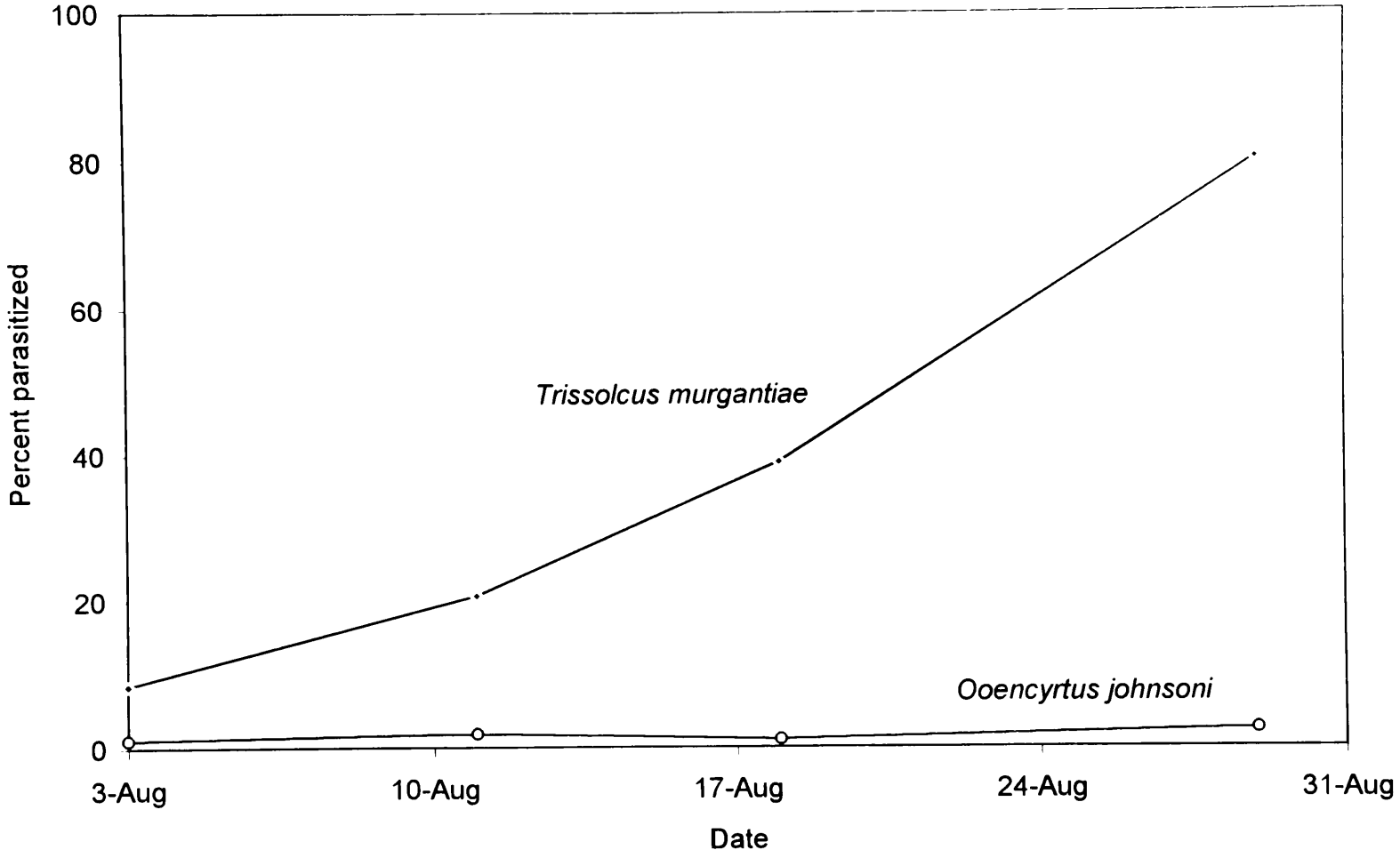

Figure 16. Percent parasitization of harlequin bug eggs by *Trissolcus murgantiae* and *Ooencyrtus johnsoni* in 1995.

Chapter 6

Broccoli Response to Varying Densities of Harlequin Bugs

INTRODUCTION

Most of the impact studies on pests of Cole crops have focused on Lepidoptera. For example, studies on cabbage looper feeding and artificial defoliation of broccoli indicated that plant yield was reduced when 50% or more of the plant was defoliated (Vail 1988). Although harlequin bugs have long been known as pests of Cole crops, no information is available on how their feeding affects broccoli development. Such information would allow growers to know when harlequin bugs need to be controlled. This information will aid in the overall understanding of pest management in Broccoli.

MATERIALS AND METHODS

Two series of tests were undertaken to determine how broccoli 'Packman Hybrid' responds to harlequin bug feeding. In the first series, two plant sizes were exposed to five harlequin bug densities. Plants were exposed to 0, 3, 6, 9, and 12 harlequin bugs per plant. Plant height was measured from the soil to the top of the plant stem. The number of leaves was determined by counting both the leaves present and the leaf scars, as it was common for the plants to be missing the first pair of leaves. The first two pairs of leaves are usually small in comparison with the larger leaves at the top of the plant.

Plants were individually placed in 46 cm x 46 cm x 61 cm wooden framed cages surrounded by 40 mesh per cm^2 screen and adult harlequin bugs added.

There were three replicates. Plants were monitored daily to determine when all the leaves were wilted or 'crisp,' and the plant was considered dead. Egg masses were removed daily to eliminate the effect of increased densities from the emerging nymphs. Durations of time to plant death at the various insect densities were calculated.

Based on the results of the first test, I conducted a second test to verify the results obtained from the small plants in the first series. As the highest density (12 insect/plant) caused mortality in less than 10 days, lower insect densities, 0, 2, 4, 6, and 8 harlequin bugs per plant, were used to enable a better understanding of how small plants respond to low insect densities. The same method was used as in the first series of tests.

Harlequin bug densities were plotted against plant response to obtain a trend line and regression analysis performed. Kruskal-Wallis one-way analysis of variance was used to determine significance of densities for each plant size.

RESULTS AND DISCUSSION

Series 1 Plants with 7 pairs of leaves averaged 19.6 ± 0.6 cm and those with 6 pairs of leaves were 12.6 ± 0.7 cm. Plant mortality occurred at all harlequin bug densities evaluated, indicating that even low densities of 3 insects per plant are capable of causing plant death (Table 17). The difference in

duration of plant mortality between highest and lowest densities was 2 days for the smaller plants and 20 days for the 19.6 cm plants.

Regression analyses showed only the 19.6 cm plants to be negatively correlated with insect density ($y = 38.88 - 2.32x$, $r^2 = 0.95$) (Fig. 17). This correlation allows a prediction of plant death to be made given any harlequin bug density. For example, it would take for 10 insects 14.8 days to kill a plant. There were significant differences in time of death between insect densities ($P<0.05$, Kruskal-Wallis).

For the 12.6 cm plants, linear analysis indicated a weak correlation between insect density and plant death ($y = 12.00 - 0.22x$, $r^2 = 0.59$) (Fig. 18). When analyzed with Kruskal-Wallis one-way analysis of variance no significant difference occurred in plant death between densities ($P>0.05$).

Both plant sizes had similar results at the 12 harlequin bugs per plant level. The difference in time of death between plant sizes decreased as insect density increased, 18.0, 16.3, 6.3 and 0.3 days, respectively. There was significant difference in plant mortality rates between plant sizes at density levels of 3, 6, and 9 insects per plant ($P<0.05$, Kruskal-Wallis). No difference was observed at the 12 insects per plant level ($P>0.05$, Kruskal-Wallis). This indicates that when levels reach 12 harlequin bugs per plant, broccoli is not able to withstand harlequin bug feeding.

Series 2 To gain a better understanding of the effects of harlequin bug feeding on small plants, broccoli plants averaging 11.9 ± 0.3 cm, with 5 pairs of leaves were exposed to lower insect densities than those used in the first series of tests.

The same trends were observed in these plants as with the with the 12.6 cm plants in the first series of tests. The difference in duration of plant mortality between highest and lower densities was 7 days. There was no significant difference in plant response between insect densities ($P>0.05$, Kruskal-Wallis). Linear regression analysis indicated a strong correlation between harlequin bug density and time to plant death ($y = 22.17 - 1.17x$, $r^2 = 0.99$)(Fig. 19). This confirms that low densities of harlequin bugs are as damaging as high densities on small plants.

The data indicate that small plants appear to respond equally to all harlequin bug densities. This suggests that for small sized plants, the presence of harlequin bug feeding is a more important factor in plant death than the number of insects that are feeding.

CONCLUSION

This study indicates that young plants appear to be highly susceptible to low harlequin bug densities. The impact increases with harlequin bug density on large plants. While larger plants can withstand feeding for a longer period, they are also susceptible. This would indicate that sampling for harlequin bugs is

more important on newly planted plants than plants that are ready to be harvested.

Table 17. Summary of broccoli mortality at varying harlequin bug densities.

Number of leaves per plant & harlequin bug density (# per plant)	Days till plant death $\bar{X} \pm SE$	P-value and levels of significance[1]
Series 1		
12.6 cm plants		P>0.05
3	11.0 ± 2.0	
6	10.7 ± 0.9	
8	11.0 ± 1.5	
12	8.7 ± 2.2	
19.6 cm plants		P<0.05
3	29.0 ± 0.0	a
6	27.0 ± 4.16	b
8	17.3 ± 1.2	c
12	9.0 ± 2.0	d
Series 2		
11.9 cm plants		P>0.05
2	20.0 ± 3.1	
4	17.3 ± 2.9	
6	15.0 ± 1.5	
8	13.0 ± 2.7	

[1] Mean densities within plant size followed by different letters are significantly different (P<0.05, Kruskal-Wallis).

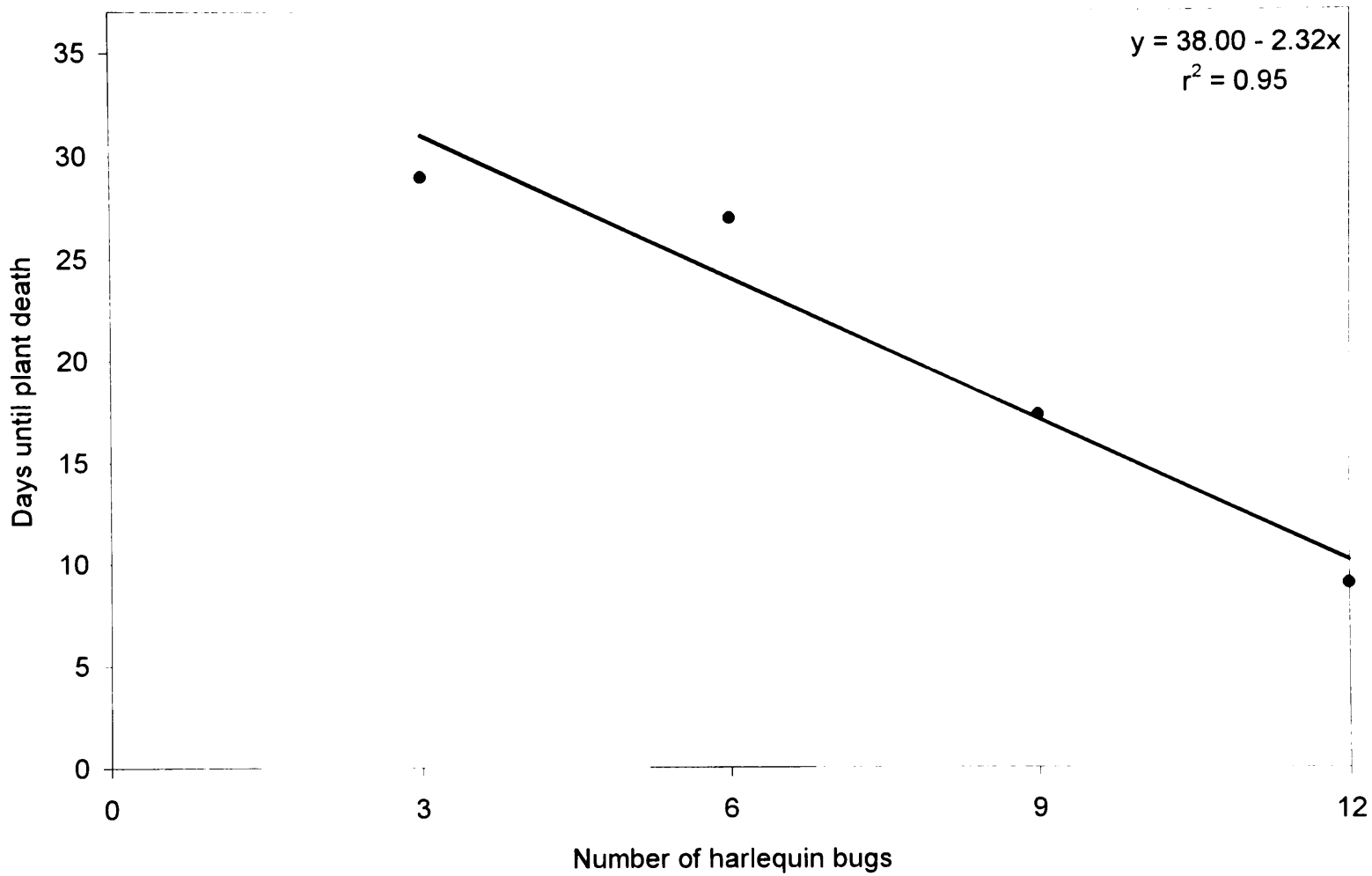

Figure 17. Response of broccoli plants (19.6 cm tall) to four harlequin bug densities, no death in control plants (0 harlequin bugs).

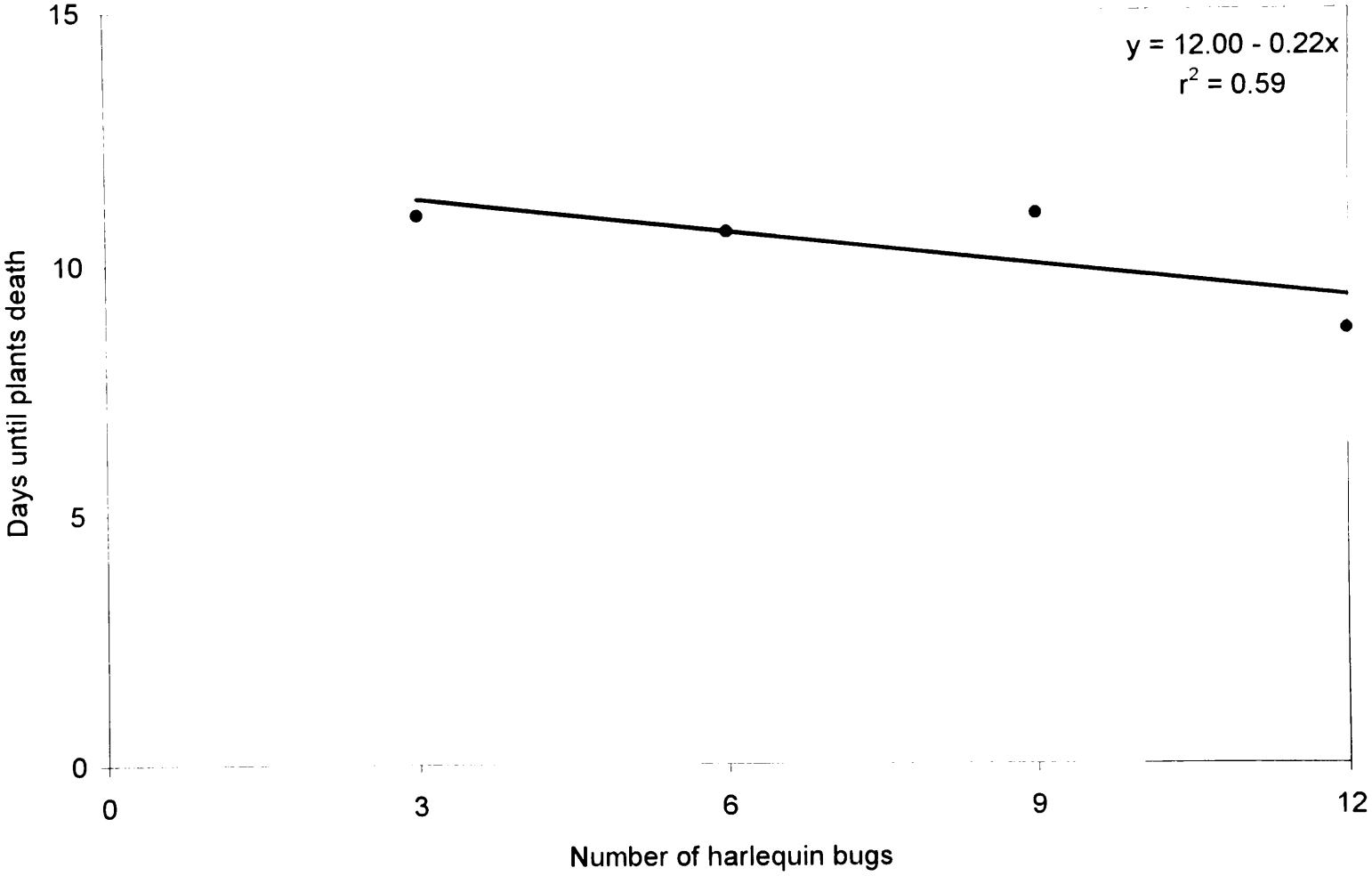

Figure 18. Response of broccoli plants (12.6 cm tall) to four harlequin bug densities, no death in control plants (0 harlequin bugs).

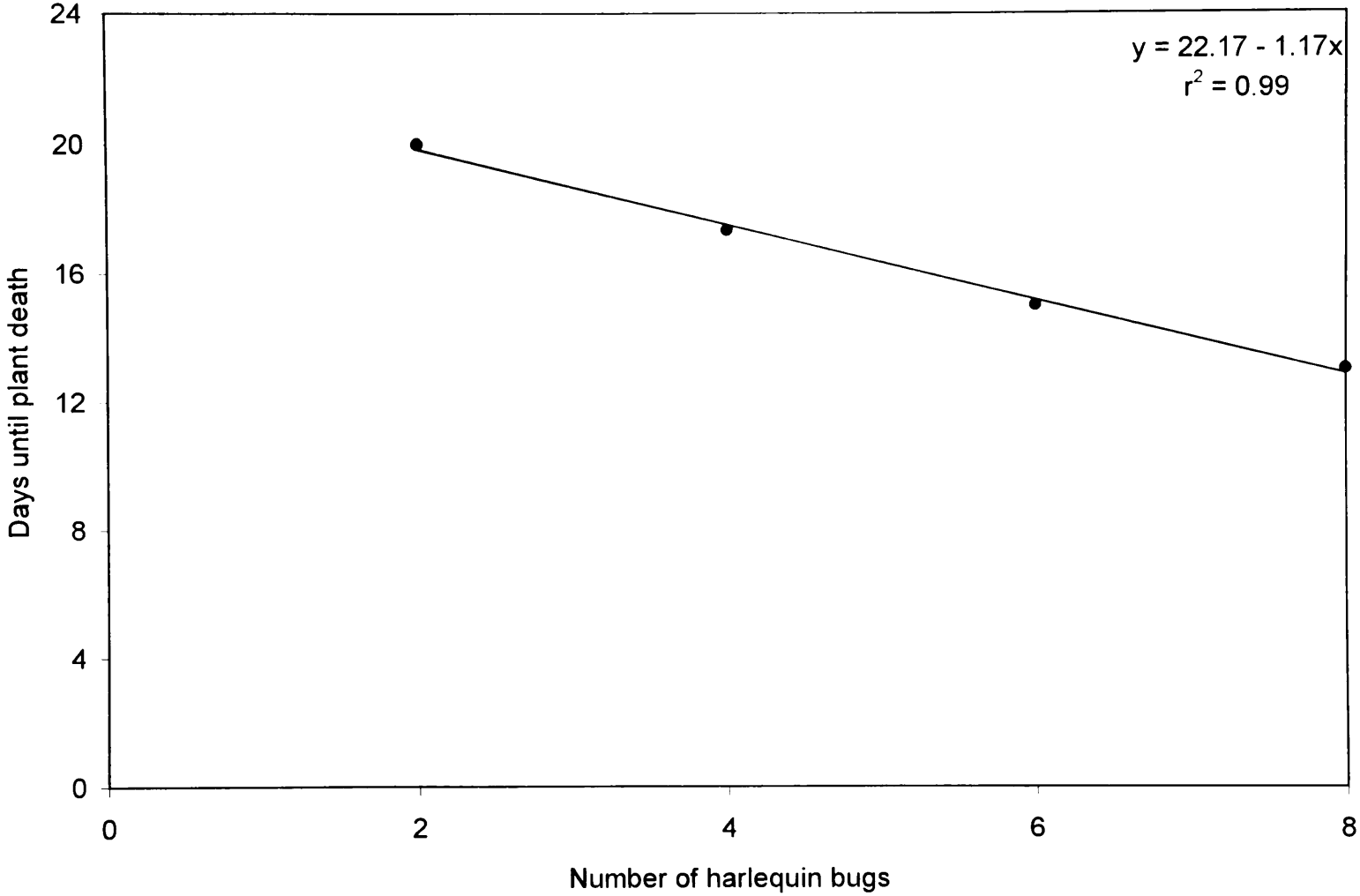

Figure 19. Response of broccoli plants (11.9 cm tall) to four harlequin bug densities, no death in control plants (0 harlequin bugs).

Summary

Broccoli (*Brassica oleracea* 'Packman Hybrid'), mustard (*B. kabar* 'Southern Giant Curled'), and rape (*B. napus* 'Dwarf Essex') were evaluated in 1994 and 1995 as trap crops to prevent harlequin bugs, *Murgantia histrionica* (Hemiptera: Pentatomidae), from reaching broccoli. When mustard and rape were planted in double rows around broccoli plots, low densities of harlequin bugs were prevented from reaching the broccoli. However, high insect densities from the trap crops moved into the main broccoli as the trap plants were not able to sustain the population. Mustard senesced earlier than rape. As a result, harlequin bugs moved off mustard when it lost its attractiveness. Rape is a longer lived plant and was capable of sustaining high harlequin bug densities for longer periods.

Harlequin bug nymphs were reared on broccoli, mustard, and rape to determine the effect of host plants on insect development. Two cohorts of individuals were used, with the second having longer development times than the first. One trend was apparent in both cohorts, nymphs reared on rape developed faster than those reared on mustard. Broccoli reared nymphs developed at the same rate as rape reared nymphs in the first cohort, but in the second cohort they developed at a rate between mustard and rape reared nymphs. Mustard reared harlequin bugs had a longer preoviposition period than

rape reared insects. The host plant effect on development is not large enough to play a role in trap plant selection. An ideal situation would be to have a host plant that is preferred by the harlequin bug and that significantly delays its development.

Virgin adults were paired at seven sex (F:M) ratios, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, and 1:4, to determine the role sex ratio plays on egg production and viability. No significant difference ($P>0.05$, Tukey's HSD) was found in the average number of eggs laid, hatched, or unhatched between treatments. This indicates, within the range tested, that egg production is independent of the number of males present and males are capable of multiple matings. Females laid an average of 149 eggs, of which 106 were viable, resulting in a 71% hatch rate. The harlequin bugs high reproductive rate and ability to mate several times may explain its ability to increase rapidly in population.

The harlequin bug was shown to have two and a partial third generation in Montgomery County, Virginia. Overwintered adults are attracted to wild turnips where they oviposit and the first generation is completed. In June and July the resulting adults moved to cultivated crops. The resulting nymphs and adults are capable of causing severe damage if not controlled. These adults then move to fall crops until they hibernate.

To determine the seasonality of harlequin bug egg parasitoids, egg masses were collected weekly when present. Two species of parasitoids were

recovered from these eggs, *Trissolcus murgantiae* Ashmead (Hymenoptera: Scelionidae) and *Ooencyrtus johnsoni* Howard (Hymenoptera: Encyrtidae). In 1994, parasitism accounted for only 8% of the egg mortality, as compared with 37% in 1995. In 1995, the parasitization level increased from 10% to 83% during a four week period. *T. murgantiae* was the dominant parasitoid accounting for 87% and 96% of the eggs parasitized during the two years. The data indicated that *T. murgantiae* could be an effective biological control organism if present early in the season. This was the first recorded occurrence of *T. murgantiae* in Virginia.

The effect of harlequin bug densities on broccoli was evaluated by exposing 19.6 cm and 12.6 cm plants to five harlequin bug densities, 0, 3, 6, 9, and 12 insects per plant. Plant mortality occurred at all densities, except the control. A negative correlation was shown in the 19.6 cm plants between insect density and plant mortality ($y = 38.00 - 2.32x$, $r^2 = 0.95$). No correlation was found in the 12.6 cm plants. Both plant sizes had nearly equal mortality rates at the 12 insects per plant level. To confirm the results of the 12.6 cm plants, an additional test was undertaken to evaluate similar sized plants (11.9 cm) at insect densities of 0, 2, 4, 6, and 8 insects per plant. A strong correlation was shown between insect density and host plant mortality ($y = 22.17 - 1.17x$, $r^2=0.99$). These tests indicate that large plants survive significantly longer at low insect densities (3 insects per plant) than at high insect densities (12 insects per

plant). Small plants showed almost no difference in mortality rates when exposed to low or high insect densities. This indicates that the presence of harlequin bug feeding is a more important mortality factor than the number of insects feeding.

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Appendix 1. Harlequin bug host plants (McPherson 1982)

Plant	Source
Bladder Pod	Van Duzee 1914
Asparagus	Chittenden 1908, 1920
Bean	Chittenden 1908, 1920; Howard 1898; White & Brannon 1933
Beet	Chittenden 1908, 1920
Bitter Cess	Chittenden 1908, 1920
Broccoli	Smith 1944; Sullivan & Brett 1974; White & Brannon 1933; Zimmerman 1948
Brussel Sprouts	Chittenden 1920; Sullivan & Brett 1974; White & Brannon 1933
Cabbage	Ashmead 1887; Banks 1903; Barber 1928; Blatchley 1926; Brimley 1938; Chittenden 1908, 1920; Forbes 1905; Furth 1974; Hart 1919; Hayslip et al. 1953; Hoffman 1971; Howard 1895; 1898; Lugger 1900; Paddock 1915, 1918; Ruckes 1937; Sanderson 1903; Smith 1944; Sullivan & Brett 1974; Summers 1891; Townsend 1894; Watson & Tissot 1942; White & Brannon 1933; Zimmerman 1948.

Appendix 1. (cont.)

Plant	Source
Capparis sandwichiana DeCandolle	Zimmerman 1948
Cauliflower	Chittenden 1908, 1920; Paddock 1918, Sullivan & Brett 1974; White & Brannon 1933; Zimmerman 1948
Cherry	Chittenden 1908, 1920
Chinese Cabbage	Sullivan & Brett 1974; White & Brannon 1933; Zimmerman 1948
Chrysanthemum	Chittenden 1908
Collard	Brett & Sullivan 1974; Brimley 1938; Chittenden 1908, 1920; Paddock 1918, Smith 1909; Sullivan & Brett 1974; Watson & Tissot 1942; White & Brannon 1933
Corn	Chittenden 1908, 1920; Paddock 1918; White & Brannon 1933
Cotton	Morrill 1910; Paddock 1918
Cow-Pea	Paddock 1918
Eggplant	Chittenden 1908, 1920; Howard 1898; Paddock 1918
Grape	Chittenden 1908, 1920; Paddock 1918

Appendix 1. (cont.)

Plant	Source
Grapefruit	Paddock 1918
Horseradish	Chittenden 1908, 1920; Howard 1898; White & Brannon 1933
Isomeris arborea Nuttall	Cockerell 1903
Jackass-Clover	Butler & Werner 1960
Kale	Chittenden 1908, 1920; Howard 1898; Paddock 1918; Smith 1944; Sullivan & Brett 1974; White & Brannon 1933
Kohl Rabi	Chittenden 1920; Paddock 1918; Sullivan & Brett 1974; White & Brannon 1933
Lamb's-Quarters	Chittenden 1908, 1920; Howard 1898
Lettuce	Chittenden 1908, 1920; Howard 1898; Paddock 1918
Loquat	Chittenden 1908, 1920; Paddock 1918
Mesquite	Ward et al. 1977

Appendix 1. (cont.)

Plant	Source
Mustard	Blatchley 1934; Brett & Sullivan 1974; Chittenden 1908, 1920; Hart 1919; Howard 1895; Paddock 1915, 1918; Sullivan & Brett 1974; Van Duzee1914; White & Brannon 1933
Nasturtium	Paddock 1918; Zimmerman 1948
Okra	Chittenden 1908, 1920; Howard 1898; Paddock 1918
Orange	Paddock 1918
Peppergrass	Chittenden 1908, 1920; Hart 1919; Paddock 1918
Pigweed	Chittenden 1908, 1920; Howard 1898
Plum	Chittenden 1908, 1920
Potato	Chittenden 1908, 1920; Howard 1898
Radish	Chittenden 1908, 1920; Howard 1895, 1898; Ruckes 1937; Sullivan & Brett 1974; White & Brannon 1933
Ragweed	Chittenden 1908, 1920; Paddock 1918
Rape	Chittenden 1908, 1920; Hart 1919; Paddock 1918; White & Brannon 1933
Rock-Cress	Chittenden 1908, 1920; Paddock 1918

Appendix 1. (cont.)

Plant	Source
Rose	Chittenden 1908
Rutabage	Paddock 1918; Sullivan & Brett 1974; White & Brannon 1933
Shepherd's Purse	Chittenden 1908, 1920
Squash	Chittenden 1908, 1920; Paddock 1918; White & Brannon 1933
Sunflower	Chittenden 1908
Thorny Amaranth	Paddock 1918
Tomato	Chittenden 1908, 1920
Turnip	Chittenden 1908, 1920; Furth 1974; Hart 1919; Lugger 1900; Paddock 1915; Sanderson 1903; Smith 1909; Sullivan & Brett 1974; White & Brannon 1933
Watercress	Chittenden 1920
Western Ragweed	Goeden & Ricker 1976
Yucca elata Engelmann	Stroud 1950

Vita

Scott William Ludwig was born December 29, 1971, in Erie, Pennsylvania. After graduating from Corry Area High School in 1990, Scott entered the University of Kentucky to work on a Bachelors of Science in Zoology. As an undergraduate, he conducted research on bluebirds, snakes, small mammals, and stinkbugs. During his final two semesters, Scott worked as a laboratory technician at the University of Kentucky Soybean Entomology Lab. The contacts made while working in the Department of Entomology helped him decide upon entomology for graduate work. He graduated with his Bachelors of Science in December of 1994, and the following January he entered Virginia Polytechnic Institute and State University to pursue his Masters of Science. Upon graduating, Scott will be attending the University of Georgia to pursue a Ph.D. in Entomology.