AN INSECT SURVEY OF SELECT HORTICULTURE CROPS IN OKLAHOMA, EMPHASIZING POPULATION DYNAMICS IN THE SQUASH BUG/SQUASH PLANT SYSTEM

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PREFACE

This thesis is divided into two parts. Part I, entitled "An Insect Survey of Select Horticulture Crops in Oklahoma," was designed to fill a void in information on horticulture crop insect pests and their natural enemies which has gradually developed since the 1940's. Part II "Population Dynamics in the Squash Bug/Squash Plant System" was implemented to accelerate and enhance research into one biological tritrophic component of the insect/horticulture crop system. Although these studies are interrelated, it is this author's opinion that separation of this treatise into the afore mentioned parts facilitates a more systematic presentation by the author, and a clearer interpretation and understanding by the reader.

These investigations would not have become a reality without the help of several people. I would like to express my most sincere gratitude to my major adviser, Dr. W. Scott Fargo, for his continued guidance, motivation, understanding, and friendship throughout the course of this study. Dr. Fargo's assistance and expertise in working with various computer systems is especially appreciated.

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TABLE OF CONTENTS

Chapter Page

PART I

AN INSECT SURVEY OF SELECT HORTICULTURE CROPS IN OKLAHOMA 1

I. SURVEY INTRODUCTION 2

II. SURVEY LITERATURE REVIEW 5

III. MATERIALS, METHODS, AND PROCEDURES 12

IV. RESULTS AND DISCUSSION 18

V. SUMMARY AND CONCLUSIONS 39

REFERENCES CITED 42

APPENDIX A - TABLES 49

APPENDIX B - FIELD DATA FILE EXAMPLE 69

APPENDIX C - DATA FILE EXAMPLE 71

PART II

POPULATION DYNAMICS IN THE SQUASH BUG/SQUASH PLANT SYSTEM 73

I. INTRODUCTION 74

II. LITERATURE REVIEW 77

III. MATERIALS AND METHODS 87

IV. RESULTS AND DISCUSSION 90

Squash Plant Seasonal Growth and Trends 91

Squash Bug Population Dynamics 99

Chapter Page

Squash Bug Effects on the Host Squash Plant 109
Environmental Impact on the Squash Bug/Squash Plant System 121

V. SUMMARY AND CONCLUSIONS 125

REFERENCES CITED 130

APPENDIX A - MEAN GROWTH PARAMETERS DATA FILE 132

APPENDIX B - WEATHER DATA FILE EXAMPLE 134

LIST OF TABLES

Table Page

PART I

I. Insect Survey-Crops Sampled, Perkins 1983 24

II. Insect Survey-Crops Sampled, Bixby 1983 25

III. Insects Sampled on Asparagus, I>0.75-Perkins 1983 50

IV. Insects Sampled on Asparagus, I>0.75-Bixby 1983 51

V. Insects Sampled on Blackberry, I>0.75-Perkins 1983 52

VI. Insects Sampled on Blackberry, I>0.75-Bixby 1983 53

VII. Insects Sampled on Broccoli, I>0.75-Perkins 1983 54

VIII. Insects Sampled on Broccoli, I>0.75-Bixby 1983 55

IX. Insects Sampled on Cabbage, I>0.75-Perkins 1983 56

X. Insects Sampled on Cauliflower, I>0.75-Bixby 1983 57

XI. Insects Sampled on Potato, I>0.75-Perkins 1983 58

XII. Insects Sampled on Potato, I>0.75-Bixby 1983 59

XIII. Insects Sampled on Squash, I>0.75-Perkins 1983 60

XIV. Insects Sampled on Squash, I>0.75-Bixby 1983 ... 61

Table Page

XV. Insects Sampled on Sweet Potato, I>0.75-Perkins 1983 62

XVI. Insects Sampled on Sweet Potato I>0.75-Bixby 1983 64

XVII. Insects Sampled on Watermelon, I>0.75-Perkins 1983 66

XVIII. Insects Sampled on Watermelon, I>0.75-Bixby 1983 67

LIST OF FIGURES

Figure Page

PART II

1. The Mean Squash Plant Leaf Area (m^2) Sampled by Julian Date 92
2. The Mean Number of Male Flowers/Squash Plant Sampled by Julian Date 95
3. The Mean Number of Female Flowers/Squash Plant Sampled by Julian Date 96
4. The Mean Number of Immature Fruit/Squash Plant Sampled by Julian Date 98
5. The Mean Number of Mature Fruit/Squash Plant Sampled by Julian Date 100
6. The Mean Number of Squash Bugs (Adults and Nymphs)/Squash Plant Sampled by Julian Date 101
7. The Mean Number of Squash Bug Adults/Squash Plant Sampled by Julian Date 103
8. The Mean Number of Squash Bug Eggs/Squash Plant Sampled by Julian Date 105
9. The Mean Number of Squash Bug Eggs/Female/Squash Plant Sampled by Julian Date 106
10. The Mean Number of Squash Bug Nymphs (All Instars)/Squash Plant Sampled by Julian Date 108
11. The Mean Insect Density Sampled by Julian Date 111
12. Relationship of the Mean Numbers of Male Flower Buds and Squash Bugs/Squash Plant 113
13. Relationship of the Mean Numbers of Female Flower Buds and Squash Bugs/Squash Plant 114

Figure Page

14. Relationship of the Mean Numbers of Immature Fruit and Squash Bugs/Squash Plant 116

15. Relationship of the Mean Number of Mature Fruit and Squash Bugs/Squash Plant 118

16. Mean Daily Fruit Yield/Squash Plant 119

17. Mean Cumulative Fruit Yield/Squash Plant 120

18. Average Daily Temperature-Perkins 1984 122

19. Daily Photoperiod-Perkins 1984 124

20. Flowchart Diagramming the Yearly Life History of the Squash Bug 127

LIST OF SYMBOLS

PART I

cm	centimeter
CRP	crop sampled
FAM	insect family
I	incidence index value
LOC	location (1:Perkins, 2:Bixby)
mm	millimeter
OBS	observation
ORD	insect order
SD	number of sampling dates
SPECIES	insect species

PART II

g	grams
IRR	irrigation (inches)
IRRM	irrigation (centimeters)
JD	Julian date
LITE	photoperiod length (hours)
m	meters
MAX	maximum temperature (°F)
MAXM	maximum temperature (°C)
MEGGS	mean number of squash bug eggs/plant

MFA	mean number of adult squash bug females/plant
MFF	mean number of female flowers/squash plant
MFFB	mean number of female flower buds/squash plant
MIFR	mean number of immature fruit/squash plant
MIN	minimum temperature (°F)
MINM	minimum temperature (°C)
MIN1	mean number of first instar squash bug nymphs/plant
MIN2	mean number of second instar squash bug nymphs/plant
MIN3	mean number of third instar squash bug nymphs/plant
MIN4	mean number of fourth instar squash bug nymphs/plant
MIN5	mean number of fifth instar squash bug nymphs/plant
MLVS	mean number of leaves/squash plant
MMA	mean number of adult squash bug males/plant
MMASS	mean number of squash bug egg masses/plant
MMF	mean number of male flowers/squash plant
MMFB	mean number of male flower buds/squash plant
MMFR	mean number of mature fruit/squash plant
MPLA	mean squash plant leaf area (centimeters^2)
OBS	observation
PREC	rainfall (inches)
PRECM	rainfall (centimeters)
s	standard deviation
$\bar{x}$	mean
YR	year

PART I

AN INSECT SURVEY OF SELECT HORTICULTURE CROPS IN OKLAHOMA

CHAPTER I

SURVEY INTRODUCTION

Agronomic, horticultural, and forest products account for 65 percent of the gross annual agricultural product in Oklahoma. Yield and production of horticultural products produced in Oklahoma have increased in the past decades and this trend is projected to continue. Vegetable crops presently grown on 12,551 hectares with a value of $32 million could increase two-to-three-fold during the next twenty years. Nine-year projections for 1981-1990 show substantial acreage and crop-value increases for twenty-five vegetables. Asparagus acreage alone is projected to increase twenty times. Projected production potentials for 1990-2000 also show major acreage and crop-value increases for the crops (Tweeten 1982). This increase, in both commercial and private production, has prompted a renewed interest in horticultural research within the state. Associated with this renewal of interest in Horticulture has been a parallel research increase in Entomology, Plant Pathology, and associated production sciences.

In addressing entomological research needs, maximum efficiency in the production of vegetable and fruit crops in Oklahoma will depend on the survey for and identification of key insect pests and their natural enemies. Some of the important horticultural crops in Oklahoma at this time are: asparagus, broccoli, cabbage, cauliflower, potatoes, blackberries, squash, sweet potatoes, watermelon, tomatoes, sweet corn, snap beans, peaches, apples, strawberries and raspberries. All of these crops are projected to increase in acreage and economic value as described above.

A general survey was conducted on the first nine crops listed above to establish which arthropod species were present. Pest, natural enemy, and incidental insect species were of special interest. Several different sampling techniques were used to maximize detection of the insects and their different life stages. This was especially true for the pest and natural enemy species. Sampling took place throughout the growing season of each crop. Samples were collected from several different geographical locations in Oklahoma to examine differences or similarities in the insect populations. Insect species collected and identified will be used in a reference collection and as teaching aids. A photographic record of various insects and the damage done to host plants will also aid in the identification of pests. Both the reference collection and photographic record will aid in the education of growers. As a continuing study, survey work could focus on a few of the important crops, on several of the major pests, or in a specific geographical area. The specific nature of continued work would depend on future agricultural trends, insect outbreaks, and environmental conditions. Once identified, further studies of key insect pests and natural enemy species' life cycles, and corresponding host plant development will help determine proper pest management recommendations.

The overall objectives of this study were to: 1) survey the insect pests and natural enemies of several important horticultural crops in Oklahoma in terms of relative species abundance and location; 2) identify the most important insects; 3) develop a reference and teaching collection of the insects; and 4) collect a photographic record of the insects and insect damage on various crops.

CHAPTER II

SURVEY LITERATURE REVIEW

Most of the entomological research conducted on vegetables and fruits in Oklahoma is between thirty and forty years old. This work emphasized fruit crop research and primarily consisted of small scale insecticide testing. An important survey of the garden and truck crop insect pests of Oklahoma was compiled in 1912 (Sanborn 1912). The research conducted by Sanborn identified some of the insect pests of the important crops of that time and their control methods.

More recent work with fruit and vegetables was also concerned with various control methods for the major insect pests. Research with apple, peach, plum, and small fruit insect pest control methods was done between 1950-1958 (Bieberdorf et al. 1950-1953, Bieberdorf and Struble 1953-1958). Examination of insects attacking corn (Walton and Arbuthnot 1962), green crops (Walton 1950a, Walton 1954), cucurbits (Walton 1950b) and vegetables in general (Fenton 1939, Walton et al. 1952-1966) were conducted between 1950 and 1966. Again, these studies were generally concerned with the chemical control of major insect pests, although one can get a relative idea of the important pests present at that time.

A great deal of additional research has been done on vegetable and fruit insect pests in other states and in other countries. Due to differences in environmental conditions and other factors, insect pests occurring in these areas cannot be assumed to be the same as would occur in Oklahoma, even if the same crops are grown. This research does, however, present an indication of the possible insect pests and associated natural enemies which could occur in Oklahoma.

The nine crops to be surveyed in this study may be infested by an array of insect species. Only the major pests from areas with climates similar to that of Oklahoma will be addressed in this literature review.

Asparagus (*Asparagus officinalis* L.) can be attacked by several pests, but usually only a few cause serious problems. A serious and common pest of asparagus is the asparagus beetle (*Criocerus asparagi* (L.)) (Knowlton 1939). The beet armyworm or asparagus caterpillar (*Spodoptera exigua* (Hubner)) (Wilson 1934), the striped garden caterpillar (*Lacanobia legitima* (Grote)), and the cotton cutworm (*Prodenia ornithogalli* Guenee) have been problems in Oklahoma (Sanborn 1912). The asparagus fern caterpillars (*Callopistria* spp.) can be serious pests of asparagus since they may have up to six generations/year (Wilson 1940). Japanese beetles (*Popillia japonica* Newman) (Langford et al. 1941), asparagus miners (*Ophiomyia simplex* (Loew)) (Barnes 1937), tarnished plant bugs (*Lygus lineolaris* (Palisot de

Beauvois)), alfalfa plant bugs (*Adelphocoris lineolatus* (Goeze)) (Grafius and Morrow 1982, Wukasch and Sears 1981), and asparagus aphids (*Brachycolus asparagi* Mordvilko) (Halfhill et al. 1983) are a few of the other pests which may feed on asparagus.

Broccoli (*Brassica oleracea* L.) is frequently infested by three major insect pests. These pests cause great foliage damage and can extremely weaken the plant. The imported cabbageworm (= small white butterfly larvae) (*Artogeia rapae* L.) is a major pest of broccoli (Richards 1940). Cabbage aphids (*Brevicoryne brassicae* (L.)) (Moore 1937), and the corn earworm (*Heliothis zea* (Boddie)) (Walker and Anderson 1941) are the two other major broccoli pests. The cabbage looper (*Trichoplusia ni* (Hubner)) can also be a serious pest of broccoli (Walker and Anderson 1934). Other aphids which may feed on broccoli are turnip aphids (*Hyadaphis erysimi* (Kaltenbach)) and green peach aphids (*Myzus persicae* (Sulzer)) (Trumble et al. 1982).

Cabbage (*Brassica oleracea* L.) is attacked by a myriad of insect pests, and infrequent outbreaks of some of these pests do occur. The survey done by Sanborn (1912) cites sixteen pests of cabbage. The cabbage root maggot or fly (*Delia radicum* (L.)) (Miles 1950), the cabbage moth or diamondback moth, (*Plutella xylostella* (L.)), the cabbage aphid (Campbell 1941), greasy or black and spotted cutworms (*Argrotis ipsilon* (Hufnagel), *Amathes c-nigrum* (L.)), the imported cabbage webworm (*Hellula rogatalis* (Hulst)), and tarnished plant bugs are some of the important pests contained in Sanborn's survey. Other important cabbage pests are cabbage flea beetles (*Phyllotreta undulata* Kutschera, *P. atra* (Fab.), *P. nigripes* (Fab.), *P. cruciferae* (Goeze)) (Petherbridge and Thomas 1935), cabbage butterfly larvae (Richards 1940), the cabbage looper, the harlequin bug (*Murgantia histrionica* (Hahn)) (Walker and Anderson 1934), and the cabbage armyworm (*Mamestra brassicae* L.) (Shimizu and Yagi 1982). Most of the broccoli pests may also damage cabbage and visa-versa. The majority of these pests cause direct damage to the foliage either by consuming the tissue or by extracting the plant fluids.

Potatoes (*Solanum tuberosum* L.) are also attacked by a great number of pests, often as a secondary food source. Again, quite a few pests were observed on potatoes by Sanborn in 1912. Some of these are the green peach aphid, black, striped, and gray blister beetles, (*Epicauta pennsylvanica* (DeGeer), *E. lemniscata* (Fab.), *E. cinerea* (Forster)), tarnished plant bugs, potato stalk borers (*Trichobaris trinotata* (Say)), and greasy and cotton cutworms (Sanborn 1912). These pests are reported by a great number of authors. Other major potato pests include the Colorado potato beetle (*Leptinotarsa decemlineata* (Say)) (Daniels 1941), the potato tuber-worm (*Phthorimaea opercullela* (Zeller)) (Hill 1948, Graf 1917), the green capsid bug (*Lygus pabulinus* L.) (Smith 1926), potato flea beetles (*Epitrix subcrinita* LeConte, *E. cucumeris* (Harris), *E. tuberis*

Gentner, *E. fuscula* Crotch) (Hanson 1933, Hill 1948, Hill and Tate 1942), potato leafhoppers (*Empoasca fabae* (Harris)) (Delong 1928), a variety of wireworms (*Agriotes mancus* (Say), *Limonius agonus* (Say)) (Greenwood 1945, Kulash 1943, McLeod 1934), the potato psyllid (*Paratrioza cockerelli* (Sulc)) (Pletsch 1947), and whiteflies (*Aleyrodes spiraeoides* Quaint) (Landis and Getzendaner 1947). Two-spotted spider mites (*Tetranychus bimaculatus* Harvey) (Landis and Davis 1947), the European corn borer (*Ostrinia nubilalis* (Hubner)) (Kennedy 1983), the potato aphid (*Macrosiphum euphorbiae* (Thomas)) (Walker et al. 1984), and the tobacco hornworm (*Manduca sexta* (L.)) (deBoer and Hanson 1984) can also damage potatoes. There are also a great many minor potato pests which may or may not occur in Oklahoma.

Sweet potato (*Ipomoea batatas* (L.)) pests can be serious, and often occur in sporatic outbreaks. Some of the pests to be expected are the sweet potato weevil (*Cylas formicarius elegantulus* (Summers)) (Anonymous 1931), the sweet potato sawfly (*Strerictiphora cellularis* (Say)) (Chapman and Gould 1929), the sweet potato leaf miner (*Bedellia orchilella* Walsingham) (Poos 1928), the imbricated snout beetle (*Epicaerus imbricatus* (Say)), and the three-lined blister beetle (*Epicauta lemniscata* (Fab.)) (Sanborn 1912). Earwigs (*Euborellia annulipes* Lucus) have also been documented as feeding on sweet potato tubers (Klostermeyer 1942).

Blackberry (*Rubus fruticosus* L.), and other small fruit insect pests are also tremendously varied and infestations are again often sporatic. The red-necked cane borer (*Agrilus ruficollis* (Fab.)) has been found in Oklahoma (Hixson 1939). Other boring pests consist of various caneborers (*Agrilus* spp.) (Mundinger 1941), the raspberry caneborer (*Oberae bimaculata* (Olivier)) (Neiswander 1948), and the raspberry crown borer (*Pennisetia marginata* (Harris)) (Headlee 1926). Additional blackberry insect pests include two-spotted spider mites (Hutson 1936), raspberry fruitworms (*Byturus unicolor* Say), and sawflies (*Monophadnoides geniculatus* (Hartig)) (Neiswander 1948), the raspberry cane midge (*Thomosia* sp.) (Barnes 1926), blackberry mites (*Eriophyes essigi* Hassan), rose leafhoppers (*Empoa rosae* L.) (Hanson and Webster 1938), and blackberry psyllids (*Trioza tripunctata* (Fitch)) (Mead 1966, Peterson 1923).

Squash (*Cucurbita* spp.) and watermelon (*Citrullus lanatus* (Thunb.) Mansf.) insect pests will be considered together because they are both in the plant family Cucurbitaceae. Many of these pests are generally not specific to either squash or watermelon, but to the cucurbits. There are four chief pests which can be expected to occur on cucurbits. These are: the squash bug (*Anasa tristis* (DeGeer)) (Beard 1940, Gould 1943, Howe and Rhodes 1973, Howe and Rhodes 1976), striped (Bach 1980) and spotted cucumber beetles (*Acalymma vittatum* (Fab.), *Diabrotica undecimpunctata howardi* Barber) (Gould 1943, Howe and Rhodes 1973, Howe et al. 1972, Sanborn 1912), and the squash vine borer (*Melittia cucurbitae* (Harris)) (Howe 1950). Other pests include the melon aphid

(*Aphis gossypii* Glover) (Fenton 1939, Goff and Tissot 1932, Howe and Rhodes 1976), cutworms, especially the greasy cutworm, pickleworms (*Diaphania nitidalis* (Stoll)), garden springtails (*Bourletiella hortensis* (Fitch)) (Gould 1943), and a variety of leaf miners (*Liriomyza* spp.) (Hill and Taylor 1951). Cucurbits are also damaged by melon leafhoppers (*Empoasca abrupta* DeLong), and a variety of mites, particularly the two-spotted spider mite (Michelbacher et al. 1955). The vast majority of these are contained in the Britton (1919) reference. And again, there are also numerous pests which may or may not appear in Oklahoma. Most of these are contained in the Sanborn (1912) and Gould (1943) references.

Natural enemies occur in association with many insect pests. The presence and abundance of natural enemy species depend on the pests occurring throughout the growing season. Natural enemies which may be associated with specific insect pests, are well documented (Clausen 1940, Dunn 1949, Poos 1928, Sanderson 1913, Smith 1948, and Thompson 1943). The general texts cited above will serve as references in identifying parasite or predator species surveyed. In addition, the presence of specific pest species raises the possibility of finding its usual associates, including natural enemies.

CHAPTER III

MATERIALS, METHODS, AND PROCEDURES

Sampling for insect pests and their natural enemies, was completed in several areas within Oklahoma during the spring and summer of 1983. The Oklahoma State University Horticulture Research Station in Bixby, Tulsa County, Oklahoma, and the O.S.U. Horticulture/Agronomy Research Station near Perkins, Payne County, Oklahoma, were the two primary locations sampled. In addition, sampling was conducted in a large private garden in Perkins, Payne County, Oklahoma, where five of the nine sampled vegetable crops were present. Two of the vegetable crops were sampled in cooperation with an organic farmer three miles east of Tonkawa, Kay County, Oklahoma.

Samples were taken during all growth stages (seedling, pre-flower, flower, and fruit) of the crops examined. This schedule amounted to approximately one sampling date every two weeks per crop, per location. This routine ensured sampling of those pests which may only attack one growth stage of the crop examined, while also sampling continous pests of certain crops.

The sampling techniques employed maximized the capture of arthropod species, especially insect pests and their natural enemies. A sufficient number of replications per sample were taken to ensure that a proper representation of the insect populations present was captured. Six major sampling methods were used where appropriate. Descriptions of these methods and their applications are outlined below.

Direct observation of the plant was the first method employed. Rating the plant damage and examining the plant for insect eggs, emergence holes, larval damage, and other evidence of insect activity was completed. Often this was the best method of examining plants which were difficult to sample mechanically. An aspirator was used to collect insects which were observed. This examination also included dissection of the roots and stems. This was especially true for some potato pests, which may attack all the plant parts, the most important of which develop underground. Direct observations were also important in the examination of broccoli, cabbage, and cauliflower heads. Whole plant samplings and inspections were routinely conducted on broccoli, cabbage, cauliflower and potatoes. Rearing larvae or other immature insect forms sampled was often necessary and useful. This was especially true for parasitized insect pests (Poos 1928), and insect pupae. Direct plant observations were always completed before other sampling methods disturbed the insects present. Specimens collected were stored in 95% ethyl alcohol until laboratory processing occurred.

A second method of sampling, and probably the most important for sampling foliage insects, was the use of a D-Vac® vacuum sampling unit (Dietrick et al. 1959). Whole plants or several leaves and stems may be sampled quite efficiently with this method (Southwood 1966). Individual samples were easily gathered in the field by changing the sample bags before each sample. The samples were taken quickly and without disturbing the plant prematurely, allowing the sampling of fast flying insects and large larvae. D-Vac samples were taken on all crops, except broccoli, cabbage, and cauliflower, throughout the sampling season. Approximately twenty-five random suctions were taken per sample. Individual bagged samples were subjected to ethyl acetate.

Foliage inhabiting insects were also sampled with a sweep net. Exchangeable bags were designed to simplify field sampling and reduce the chance of insect escapes. Small, removable bags were attached to the open end of a regular sweep net bag using velcro strips. Following sampling, string ties immediately closed off these small bags, and the placement of a new bag in position allowed another sample to be taken quickly and efficiently. This system was manufactured as described by Dambach (1939). Sweep net samples were not taken on thick-stemmed plants such as broccoli, cabbage, cauliflower and the cucurbits.

The use of a beat cloth was also available as a sampling technique. The beat cloth was used in the event of an infestation of large beetles or caterpillars on a plant which was difficult to sample any other way. A cloth was positioned under the desired plant and the plant was simply jarred or shaken and insects falling to the cloth were collected (Bieberdorf and Struble 1953). Again, collected specimens were stored in alcohol and returned to the laboratory for processing. This technique was not very reliable and was used only when necessary.

Pitfall traps were used to sample substrate insects. These traps consisted of a 1 gallon capacity, 6.0 inches (15.24 cm) in diameter x 6 15/16 inches (17.62 cm) deep, tin can dropped into the ground up to the lip of the can. A funnel, slightly smaller in diameter than the can, fit tightly inside the lip of the can. A plastic container, filled with ethylene glycol, held any trapped insects until the traps could be checked and emptied. Trap contents were removed using an aquarium net, placed in alcohol, and returned to the laboratory. All debris was removed from the trap and fresh ethylene glycol was added after each sampling routine. Traps were randomly placed between plants within a single crop area. Ground beetles and other large terrestrial insects were trapped in this manner.

Soil sampling was the sixth major sampling technique utilized. A soil auger was used to extract a specific amount of soil. The auger bucket measured 2 7/8 inches (7.30 cm) in diameter x 7.0 inches (17.78 cm) deep. The soil sample, one per crop per location per date, consisted of two auger buckets of soil taken to a depth of twice the length of the bucket. Sampled soil was seived to extract any insects which were present. Any insects found were preserved in alcohol. This method was of great importance when insects were a pest on plant roots, such as potatoes, sweet potatoes, and cabbage. Soil samples were also used to examine pupation and overwintering sites of some insects. Other sampling methods, such as floating the insects off of a plant (Daniels 1933), were available but unnecessary in this study.

Additional sampling techniques may prove useful if the results of this survey lead to further sampling. Sampling could be increased on specific crops or insect groups. Airfall traps, such as Malaise traps, light traps, and pheromone traps may be used. These traps usually sample a specific group of insects, and once the presence of these insects is determined from this survey or otherwise, these traps could be very useful (Bacon et al. 1976). Pheromone traps are often employed in commercial vegetable and fruit production. Pest species populations can be monitored or controlled using various pheromone traps.

All field samples, qualitative insect activity and abundance observations, and weather records were taken to the laboratory. All insect species were initially separated from remaining sample debris. The "cleaned" samples were stored individually in alcohol by date, location, and crop. Further sorting and identification of the specimens were completed during the remainder of the study. All insect specimens were initially identified to insect family, and separate species were numbered within a family. The data was labelled and coded to facilitate computer cataloguing. An example of this is presented in Appendix B. Species abundance was qualitatively rated as: low (1-3 individuals), medium (4-10 individuals), high (11-100 individuals), and very high (> 100 individuals). A qualitative measure of individual species abundance, for a given date, location, and crop, was designed using these abundance measures, and is discussed in the next chapter.

Separate aphid and soft-bodied larval specimens remain in alcohol. All other specimens were pinned and placed in Cornell collection drawers. A reference collection of the insect pests and their natural enemies will be maintained for future reference and for teaching purposes. Expertise in identification of the insects was solicited from experts on the staff of the Entomology Department at Oklahoma State University, and from the literature (Borror et al. 1964, Dillon and Dillon 1972, Poos 1928, and Thompson 1943). In addition, general field condition observations were also noted. These included soil moisture, air temperature, light intensity, wind velocity, irrigation, and pesticide application records. Plant development through the various growth stages was noted. Peculiar insect activity and/or behaviour was also recorded. A Canon AE-1 35mm camera, equipped with a Canon FD 50mm 1:3.5 macro lens and Agfa Agfachrome 200 (135-36) film, was used in obtaining the photographic record.

CHAPTER IV

RESULTS AND DISCUSSION

Sampling began initially at all four locations described in the previous chapter. Sampling first occurred on May 11, 1983 at the Oklahoma State University Horticulture/Agronomy Research Station in Perkins, Oklahoma. This will be referred to as the Perkins location. Asparagus, blackberry, broccoli, cabbage, head lettuce, and potato were sampled for insects on this date. Sampling was started on squash (six varieties), sweet potato, and watermelon as they emerged later in the season.

Sampling was initiated at the O.S.U. Horticulture Research Station in Bixby, Oklahoma on May 12. Henceforth this will be referred to as the Bixby location. Asparagus, blackberry, broccoli, cauliflower, and potato were the crops initially sampled for insects at the Bixby location. Squash, sweet potato, and watermelon were added to the sampling regime as the season progressed.

The two other locations initially sampled for insects included a private garden site in Perkins, Oklahoma, and an organic farm near Tonkawa, Oklahoma. Sampling began on May 13 at the private garden site. Asparagus, cabbage, potato, and squash insects were surveyed at this time. Watermelon insects were also sampled upon emergence of the plants. Sampling at the Tonkawa location did not begin until June 7. Asparagus, potato, and tomato insects were initially sampled, and cucumbers were added to the sampling routine later in the season.

Sampling techniques at all locations throughout the season were employed as uniformly as possible. The survey was completed by the same individuals and an efficient routine was established. All suitable sampling techniques were utilized on each crop to maximize insect detection. Initially, direct observation of insects was important on all crop seedlings, and continued until plant growth allowed the additional sampling methods to be used.

Asparagus insect sampling was achieved through the use of pitfall traps, soil samples, the D-Vac suction machine, and direct observations. Direct observation insect samples were taken until spear harvesting ended and fern growth dictated the use of the D-Vac. Blackberry insects were surveyed with the D-Vac, pitfall traps, and soil samples. The cole crop (broccoli, cabbage, and cauliflower) insects were sampled by direct observations, soil samples, and pitfall traps. Direct observations were of utmost importance in examining the developing leaf layers and heads of these vegetables. Whole plants were sacrificed, dissected, and examined for root and boring insect pests. Potato insects were sampled with the D-Vac, soil samples, and pitfall traps. Direct observation was also crucial in the detection of tuber insect pests.

Sweet potato insects were sampled in much the same way as the white potatoes. Soil samples, pitfall traps, and the D-Vac were the primary sampling techniques used. Direct observations on tubers were important up to harvest. Cucurbit insect sampling was also completed with the use of soil samples, pitfall traps, and the D-Vac. Late season examinations of squash and watermelon vines and fruit for insect pests were essential.

Sampling conditions throughout the season remained relatively uniform at all locations. As the sampling process became routine, it could be completed at all locations within a three day period. Travel and sampling time involved in the routine accounted for the sampling date differences. Samples at the Perkins location were taken during mid-morning hours, and were generally followed by sampling at the private garden location. All of these samples were completed by noon of the same day. Samples at both the Bixby and Tonkawa locations were also taken in the morning, but on consecutive days, and completed by noon.

Environmental conditions, qualitatively recorded on all sampling dates and at all locations, were generally consistent among locations throughout the season. Since sampling at all locations occurred within a three day period, average temperatures and rainfall were fairly consistent. An exception to this occurred at the Perkins and private garden sites on July 1. These areas had received heavy rainfall and were extremely wet. In comparison, the other two locations were much drier. Rainfall not only filled the pitfall traps but also made D-Vac sampling difficult. The private garden location was also heavily shaded and so remained wet for a longer time period than did the other locations. The garden site was also protected from windy conditions by trees and shrubs. Conversely, the Perkins, Bixby, and Tonkawa locations became extremely windy on several occasions. Windy conditions often made sampling difficult. D-Vac sampling was especially a problem under windy conditions. July and August of 1983 were very dry, and the use of irrigation was mandatory. Irrigation at Perkins and Bixby was monitored. The Bixby location received regular irrigation and was generally more moist than the other locations. Irrigation levels at the private garden and Tonkawa sites could not be consistently monitored.

The private garden location was sampled only five times and then dropped from the study for the following reasons. Only five of the nine desired crops were grown, the individual crop areas were small and overlapped after several weeks of growth. Due to this overlap in crop area, insects generally specific to one crop might have been sampled on another crop. Sampled insects could not be determined to occur only on one or several plant hosts. Also, insecticides were used at this location several times and drastically altered the insect species composition. The Perkins location and the private garden location were only a few miles apart and so were assumed to have similar insect species present.

July 1 was the last day the private garden site was sampled.

The Tonkawa location was rejected after being sampled four times. Only two of the preferred crops were grown throughout the described sampling period. The crops were surrounded by weeds at this organic farm. For example, the asparagus was strangled with field bindweed and almost completely hidden by other weeds. Travel expenses and time constraints also added to the problems which led to the rejection of the Tonkawa location. Sampling at Tonkawa ended on July 20.

General observations of significance were made at the private garden and Tonkawa sites before sampling ended. It appeared that the private garden and Tonkawa locations were inhabited by more soil-borne arthropod species than the other two sites. Isopods, Collembola (Entombryidae spp. and Sminthuridae spp.), centipedes, snails, cockroaches, various mite species, and an abundance of spider species were present throughout the sampling period. Isopods were particularly abundant at the private garden location, while Collembola were sampled in large numbers, often greater than one hundred insects per sampling date, at the Tonkawa site. Carabid beetles were also trapped in large numbers at the Tonkawa location when compared to the other sites. Insect larvae in the families Scarabaeidae and Curculionidae were also present at these two locations, but were not observed damaging plant parts. Soil nematodes were also frequently observed in the soil samples. Few of these animals occurred at the Perkins and Bixby sites in such great numbers.

The apparent reasons for the above differences varied for each location. Sampling at the Tonkawa location occurred on an organic farm. Pesticides were not used and had not been used for several years. Insect diversity and abundance, particularly in the soil, may increase when pesticides are not used. The private garden location was heavily shaded. This site also bordered an alfalfa field, which in addition to the woody habitat, helped alter the insect composition. General use insecticides were used only when necessary.

Sampling results of the Perkins and Bixby locations will be addressed in greater detail. Both sites produced the same crops, with the exception of cabbage at Perkins and cauliflower at Bixby. Since these cole crops, Brassica oleracea L., are very similar in production and development, insects sampled on them will be grouped. Sampling occurred within a two day period at these two locations. Sampling was timed to occur during each of the various plant growth stages. The exact sampling dates and crops sampled for each location are contained in Tables I and II. Laboratory processing did not occur on those samples which were taken from repeated sampling on the same plant growth stages. Samples taken late in the season from asparagus, blackberry, squash, sweet potato, and watermelon were not processed (Tables I and II). These crops, except for sweet potato, were well beyond harvest and the concern for insect damage. Sweet potatoes were near harvest, and further foliage damage

TABLE I

INSECT SURVEY-CROPS SAMPLED, PERKINS 1983

CROP\DATE	5/11	5/23	6/6	6/20	7/1	7/19	8/1	8/16	9/2	9/15
ASPARAGUS	X	X	X	X	X	X	X	X[1]	X[1]	
BLACKBERRY	X	X	X	X	X	X	X	X[1]	X[1]	
BROCCOLI	X	X	X	X	X					
CABBAGE	X	X	X	X	X					
POTATO	X	X	X	X	X	X	X			
SQUASH			X	X	X	X	X	X	X[1]	X[1]
SWEET POTATO				X	X	X	X	X	X	X[1]
WATERMELON			X	X	X	X	X	X	X	X[1]

X[1] - Crops were sampled but not laboratory processed.

TABLE II

INSECT SURVEY-CROPS SAMPLED, BIXBY 1983

CROPS/DATE	5/12	5/25	6/8	6/22	7/5	7/21	8/3	8/18	9/3	9/16
ASPARAGUS	X	X	X	X	X	X	X	X^1	X^1	
BLACKBERRY	X	X	X	X	X	X	X	X^1	X^1	
BROCCOLI	X	X	X	X	X					
CAULIFLOWER	X	X	X	X	X					
POTATO	X	X	X	X	X	X				
SQUASH		X	X	X	X	X	X	X	X^1	
SWEET POTATO				X	X	X	X	X	X	X^1
WATERMELON				X	X	X	X	X	X	X^1

X^1 - Crops were sampled but not laboratory processed.

by insects late in the season would not have affected the mature tubers.

Although cultivation and care of these horticultural crops were similar at the two Research Stations, there were two major differences. The Bixby location is concerned with horticultural research and insecticide usage was high. These conditions have existed for several years. On the other hand, the crops grown at the Perkins location were present for entomological research and no insecticides were used. Horticultural production was also relatively new to this heavily biased agronomic Research Station. The insect species sampled at these two locations, due in part to the contrasts of insecticide use versus non-use, and the degree of horticultural crop exposure, proved to be interesting.

A total of 1929 insect species were sorted from the samples and have been preserved. Eight insect orders and one hundred insect families comprise the collection. Over six hundred species, unidentified even to family, are also present, along with ninety-eight larval species. These numbers include specimens from all four locations, although only the Perkins and Bixby specimens will be addressed in detail.

All major insect pests sampled on the different crops have been tabulated in Tables III-XVIII and are contained in Appendix A. In order to prioritize additional species identification and further investigate survey results, an incidence index was formulated. The index, I, was calculated for each species in the following manner:

$$I = \Sigma(\text{frequency X abundance})/(\text{no. sampling dates})$$

where frequency equals the number of times a species occurred at a particular abundance over the entire season, and abundance equals the qualitative measure of a species, either low (1), medium (2), high (3), or very high (4) on a particular crop and sampling date. The denominator equals the total number of dates a certain crop was sampled. An example will clarify this calculation. Assume a carabid species occurs once with an abundance measure of three, twice with an abundance measure of two, and three times with an abundance measure of one on potatoes at Bixby. The index for this species would be:

$$I = \Sigma((1x3)+(2x2)+(3x1))/6 = 1.67$$

All species having $I>0.75$ on any of the crops at either Perkins or Bixby were determined to be of relative importance. A data-file example of I values and associated locations, crops, insect orders, insect families, insect species, and number of sampling dates is contained in Appendix C. Insects considered to be pests of man, either directly or indirectly, account for only 1% of all insect species (Freeman 1979). Approximately 4.5% of the insect species surveyed in this study had $I>0.75$. Major and minor insect pests, along with prominent insect natural enemy species, were theorized to be included in this 4.5% measure. These selected insect species are also listed in Tables III-XVIII by crop and location. Insect scientific names are presented when known, along with accepted common names (Anonymous 1982). Letter designations of P-pest, B-beneficial (predatory or parasitic), or I-incidental (saprophytic or randomly occurring) denote general life histories of the species.

The overall results of the Perkins and Bixby sampling routines were unexpectedly similar, considering the differences in insecticide use and crop history. The Bixby location had a greater number of total insect families on four of the eight sets of crops sampled for insects. The four crops included blackberry, the cole crops (either cabbage or cauliflower), potato, and watermelon. The Perkins location had a greater number of insect families on asparagus, broccoli, and squash. Both locations had the same number of total insect families sampled on sweet potato. It should be clarified that several hundred Diptera and Hymenoptera species, which were rarely sampled, were unidentified even to family.

The total number of insect families sampled within an insect order, on a particular crop, were also compared. Within the order Coleoptera, the Bixby location had a greater number of insect families on asparagus (13 families sampled at Bixby to 12 at Perkins; a Bixby:Perkins ratio will be followed throughout this chapter), blackberry (19:18), cabbage/cauliflower (15:11), potato (14:12), and sweet potato (19:16). More coleopteran insect families were sampled on squash (12:17) at Perkins than at Bixby. Fourteen beetle families were sampled on watermelon, and ten families were sampled on broccoli at both locations. The trend of a greater number of insect families sampled at Bixby continued in the orders Hemiptera and Lepidoptera. More hemipteran insect families were sampled at Bixby than at Perkins on five of the crops: asparagus (9:8), blackberry (12:9), broccoli (5:4), cabbage/cauliflower (4:2), and squash (8:7). Only sweet potato had more true bug families (7:10) sampled at Perkins than at Bixby. Potato and watermelon had eight and seven hemipteran families, respectively, sampled at both locations. Within the Lepidoptera, more insect families were sampled at Bixby than at Perkins on broccoli (1:0), potato (1:0), squash (1:0), and watermelon (1:0). Blackberry at Perkins had more lepidopteran families (1:2) sampled than at Bixby. No adult lepidopterans were sampled on asparagus and sweet potatoes, and only one family was sampled on the cole crops at each location.

The remaining insect orders sampled were similar in the number of insect families represented at both the Perkins and Bixby locations. More Diptera insect families were sampled from asparagus (4:6), blackberry (6:7), broccoli (3:6), and the cole crops (3:4) at Perkins than at Bixby. Four dipteran families were sampled from each location on potato. The Bixby location had a greater number of fly families on squash (3:2), sweet potato (7:4), and watermelon (5:4) than did the Perkins location. Within Homoptera, the Bixby location had a greater number of families on blackberry (7:6), potato (6:3), and watermelon (6:4). There were an equal number of homopteran families on asparagus (4:4), broccoli (2:2), squash (4:4), and sweet potato (6:6). Perkins had more homopteran families on the cole crops (2:4) than did the Bixby location.

The number of insect families sampled in the order Hymenoptera were relatively the same. Equal numbers of hymenopteran families were taken from broccoli (1:1), the cole crops (1:1), and potato (2:2) at both locations. The Perkins location had more hymenopteran families on asparagus (1:4), squash (2:3), and sweet potato (1:5); while the Bixby location had more families on blackberry (5:3), and watermelon (5:3). Within the order Neuroptera, equal numbers of families were collected on asparagus (2:2), blackberry (2:2), and potato (1:1) at both locations. More neuropteran families were sampled on squash (1:0), sweet potato (2:1), and watermelon (2:1) at Bixby than at Perkins; while more families were sampled on the cole crops (1:2) at Perkins. Equal numbers of insect families in the order Orthoptera were sampled on asparagus (1:1), broccoli (0:0), the cole crops (0:0), squash (1:1), sweet potato (1:1), and watermelon (1:1) at both locations. Finally, more orthopteran insect families were sampled from blackberry (1:0) and potato (1:0) at Bixby than at Perkins.

The number of insect larval specimens sampled at Perkins and Bixby were similar. More larvae were sampled on asparagus (5:10), broccoli (5:9), the cole crops (5:10), and watermelon (7:11) at Perkins than at Bixby. Larval species were more abundant on potato (14:13), squash (8:7), and sweet potato (14:10) at Bixby than at Perkins. Eight larval species were sampled on blackberry at both locations.

In summary, there were more insect families collected overall at Bixby than at Perkins. More insect families were also sampled at Bixby than at Perkins when considering all the insect orders and all the crops sampled. Finally, considering the insect order-crop combinations, 9 orders x 8 crop sets at both locations, Bixby had more insect families represented in 35 of the 72 combinations (48.6%), while Perkins had more families 27/72 times (37.5%). Both locations had an equal number of insect families sampled in 10 of the 72 combinations (13.9%). Individual species numbers paralleled the insect family numbers and trends across the range of the different crops for both locations.

Tables III-XVIII provide a more detailed account of the significant insects sampled at Perkins and Bixby. Differences between the locations and common insects sampled are of greater significance than the general observations already discussed.

Asparagus insects sampled were similar at both locations (Tables III and IV). Two carabid species (_Tachys_ sp. and _Cratacanthus dubius_) were prominent at Perkins, but none had an I>0.75 at Bixby. The asparagus beetle (_Crioceris asparagi_), flea beetles (_Epitrix_ spp.), and leafhoppers (_Empoasca_ spp.) were the major pests sampled at both locations. Short-horned grasshoppers (Acrididae spp.) damaged fern growth late in the season at both sites. In addition to the carabid predators, a tiger beetle (Megacephala virginica) was important at Perkins, and minute pirate bugs (Orius sp.) were common at both locations.

Insects collected from blackberry at both Perkins and Bixby are presented in Tables V and VI. Insect predators were common on blackberry. Carabids were of greater significance at Perkins than at Bixby, but collops beetles (Collops sp.) were of greater importance at Bixby. Nabid species (Reduviolus spp.) and the goldeneye lacewing (Chrysopa oculata) were prominent at both locations. Several pest species were also common to both locations. The rednecked cane borer (Agrilus ruficollis), a leafhopper species, and the snowy tree cricket (Oecanthus fultoni) damaged blackberry at both locations. A blackberry psyllid (Trioza sp.) was damaging at Perkins, and grasshoppers were a problem at Bixby late in the season. Leaf miners in the family Anthomyiidae were sampled consistently at both places.

Tables VII and VIII display the broccoli insects sampled. Pest species present at both Perkins and Bixby included flea beetles (Chaetocnema spp.), false chinch bugs (Nysius spp.), green peach aphids (Myzus persicae), and cabbage loopers (Trichoplusia ni). In addition, diamondback moths (Plutella xylostella) were a pest at Perkins, while potato aphids (Macrosiphum euphorbiae) damaged broccoli at Bixby. Carabids in the genus Agonoderus were important at Bixby, while the genera *Selenophorus*, *Tachys*, and *Cratacanthus* were prominent at Perkins. Antlike flower beetles (Anthicidae spp.) were prominent at both locations but not as pests or predators.

Cole crop insects at Perkins and Bixby were somewhat different. The *Agonoderus* carabid genus was again prominent at Bixby, while six carabid genera were of importance at Perkins (Tables IX and X). Lady beetle larvae (Coccinellidae spp.) were prominent at Perkins alone. Pest species common to both locations included green peach aphids and cabbage loopers. Flea beetles and leaf miners (Agromyzidae spp.) were sampled at high levels at Perkins alone, while false chinch bugs were only of consequence at Bixby. Anthicids were again commonly found at both locations. The pest species differences may have occurred due to the cole crop differences.

Potato pests were of greater consequence at Perkins than at Bixby (Tables XI and XII). Flea beetles (*Chaetocnema* spp., *Epitrix* sp.), Colorado potato beetle larvae and adults (*Leptinotarsa decemlineata*), white grubs (*Phyllophaga* sp.), potato aphids, and leafhoppers were of consequence at Perkins. Colorado potato beetles were especially devastating to the potato foliage at Perkins. Only the aphids and leafhoppers were prominent at Bixby. Predatory species common to both places included various carabid species. Lady beetle larvae and nabids were important predators at Perkins, while bigeyed bugs (*Geocoris punctipes*) were important at Bixby.

Insect sampled on squash again included pest and predator species (Tables XIII and XIV). Pests sampled at both locations included the squash bug (*Anasa tristis*), spotted and striped cucumber beetles (*Diabrotica undecimpunctata howardi*, *Acalymma vittatum*), and a leafhopper species. Flea beetles (*Chaetocnema* spp.), leaf miners (Agromyzidae spp.), and the garden webworm (*Achyra rantalis*) were damaging at Perkins alone. Predatory species at both locations included carabids and nabids. Tiger beetles were also prominent in squash. *Cicindela punctulata punctulata* and *Megacephala virginica* were important at Perkins, while *Megacephala carolina* was important at Bixby. In addition, collops beetles and dance flies (Empididae spp.) were prominent at Perkins, and bigeyed bugs were prominent at Bixby.

Insect diversity and numbers were greatest on sweet potatoes at both locations (Tables XV and XVI). Major pest species at both locations included flea beetles, the mottled tortoise beetle (*Deloyala guttata*), click beetles (*Conoderus* spp.), leafhoppers, saltmarsh caterpillars (*Estigmene acrea*), and grasshoppers. An additional tortoise beetle (*Agroiconota bivittata*), white grubs, and the garden webworm were pests at Perkins. The spotted cucumber beetle was sampled consistently on sweet potatoes at Bixby. Predators common to both locations included carabids, lady beetles (*Ceratomegilla fuscilabris*), dance flies, minute pirate bugs, nabids, and brown lacewings (*Micromus* sp.). The convergent lady beetle (*Hippodamia convergens*), and another lady beetle (*Scymnus* *cinctus*) were prominent at Perkins. Additional Bixby natural enemies included the tiger beetle species *Megacephala carolina*, long-legged flies (Dolichopodidae sp.), bigeyed bugs, and a chalcid (*Eupteromalus* sp.). Incidental species sampled included chloropid, phorid, lauxaniid, and heleomyzid flies, anthicids, and stilt bugs (*Jalysus wickhami*). Rove beetles (*Anotylus* sp. and *Paederus littorarius*) were prominent at Bixby also.

There were also a great number of common insects sampled on watermelon at both locations (Tables XVII and XVIII). Various natural enemies were again significant. Carabids were present at both locations. Beetles within the genera *Selenophorus* and *Cratacanthus* were prominent at Perkins, while the genera *Agonoderus* and *Geopinus* were prominent at Bixby. Tiger beetles, collops beetles, and nabids were also important at both locations. In addition, aphid flies (Chamaemylidae sp.), minute pirate bugs, bigeyed bugs, and two hymenopteran species (*Brachymeria fonscolombei* and *Enchemicrum* sp.) were important at Bixby. Several pest species, including leaf miners and leafhoppers, were common to both locations. Squash bugs, flea beetles (*Chaetocnema* sp.), and the garden webworm were important at Perkins. Additional prominent pest species at Bixby included the spotted and striped cucumber beetles, click beetles, false chinch bugs, and whitemarked fleahoppers (*Spanagonicus albofasciatus*). And as discussed above, several incidental species, which included anthicids, lauxaniids, stilt bugs, and rove beetles were sampled.

In summary, there were several species which were sampled at both Perkins and Bixby on the same crops. Additionally, some species were distributed throughout the plots and occurred consistently on at least four of the crops. Antlike flower beetles and lauxaniid flies were universally present throughout the season but were of no apparent consequence to the crops or other insects.

Insect predators were important at both locations, although only a few were common to both. Carabids in the genera *Selenophorus* and *Harpalus* occurred consistently at Perkins and Bixby. Nabids, lacewings, and collops beetles were also common at both locations. Minute pirate bugs were sampled consistently at both locations, but seemed to be present over a longer time period at Bixby.

There were several pest species which were damaging at both Perkins and Bixby. Asparagus beetles and short-horned grasshoppers were present late in the sampling period on asparagus ferns at both sites. The rednecked cane borer occurred on blackberry, while flea beetles (*Epitrix* spp.), leafhoppers (*Empoasca* spp.), and click beetles (*Conoderus bellus*) were sampled consistently on a variety of crops at both locations.

Of special interest were those species which occurred at only one of the locations, or which occurred at both places but were of particular importance at only one of the locations. Coleopteran predator species were of greater importance at Perkins than at Bixby. Carabids in the genera *Cratacanthus*, *Calosoma*, *Tachys*, and *Bembidion* were consistently sampled at Perkins. Coccinellid larvae, along with adults in the genera *Hippodamia* and *Scymnus* were also prominent at Perkins. Two tiger beetle species, *Megacephala virginica* and *Cicindela punctulata punctulata* were also prominent only at Perkins. These predatory species were generally terrestrial, and except for the lady beetles, fed on caterpillars and other soft-bodied insects. Lady beetle larvae and adults fed consistently on aphids.

Predator species were sampled less consistently at Bixby. The carabid genera of *Agonoderus* and *Geopinus*, and the tiger beetle *Megacephala carolina* were of importance at Bixby. Non-beetle predators were of greater importance though at Bixby. In addition to the predator species described above, bigeyed bugs, aphid flies, and two hymenopteran species (*Enchemicrum* sp. and *Eupteromalus* sp.) were important at Bixby alone. The intensive insecticide use at Bixby may account for these differences between locations. Ground and tiger beetle populations may be reduced by insecticide applications, while flying insects may be able to migrate back into an area more rapidly after chemicals are used.

Several pest species were of consequence only at Perkins. Potato pests, especially Colorado potato beetle larvae and adults and white grubs, were of consequence only at Perkins. *Trioza* sp. heavily damaged blackberry at Perkins. Garden webworms and diamondback moths were of consequence at Perkins also. In contrast, the false chinch bug was the only insect pest of real consequence at Bixby alone. Again, insecticide use may have reduced pest populations at Bixby.

Many other insect pests did occur at both locations, or at only one location, but were of little consequence at the time of this study. In addition, several of the insects described above, whether a pest, predator, or incidental species, may have occurred at both locations sometime throughout the growing season, but were only of consequence at one location.

CHAPTER V

SUMMARY AND CONCLUSIONS

Insect sampling was conducted on nine economically important horticultural crops in Oklahoma during the spring and summer of 1983. The insect survey was initiated at four locations. Sampling began at an organic farm near Tonkawa, Oklahoma; at a private garden in Perkins, Oklahoma; and at the two O.S.U. Research Stations in Perkins and Bixby, Oklahoma. Sampling was conducted throughout the growing season and detailed results have been compiled for the latter two locations.

Insects were sampled with all sampling methods available to maximize detection of insect species. Insects were collected from asparagus, blackberry, broccoli, cabbage, cauliflower, potato, squash, sweet potato, and watermelon. Sampling on these crops occurred at least once during each of the various plant growth stages. Direct observation, pitfall traps, soil samples, and the D-Vac suction machine were the major sampling methods utilized. A photographic record of the insects and insect damage was completed as available.

Major insect pests of the crops sampled at Perkins and Bixby were identified and are listed in Tables III-XVIII. An incidence index, I, was formulated to determine the relative importance of additional insects sampled. Additional commonly sampled insects are also tabulated.

There were several insect species, some pests and some predators, which occurred consistently at both Perkins and Bixby. Of special interest though were those species which were important at only one of the locations, and the reasons for this occurrence. Some predatory beetle species and major insect species which were important at Perkins were not of consequence at Bixby. The heavy use of insecticides at Bixby may account for this difference. On the other hand, the Bixby location did have a greater diversity of insect families overall than did the Perkins location. The horticulture crop history at Bixby may account for this difference in overall family numbers or insect diversity.

Additional survey work on asparagus, blackberry, broccoli, cabbage, cauliflower, potato, squash, sweet potato, and watermelon insects could continuously monitor insect populations, and possibly predict pest outbreaks and/or predator or parasite increases which might help control the pests. Additional insect species and insect relationships contained within this study could be investigated by decreasing the level of the incidence index, eg. $0.50<I<0.75$. Decreasing the index, I, would increase the number of insects considered to be of relative importance. Further investigations into some of these less common insects and their interactions with specific host crops and other insects are important. These studies could lead to better control of insect pests and protection of valuable natural enemies.

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APPENDIX A

TABLES

TABLE III

INSECTS SAMPLED ON ASPARAGUS, I>0.75-PERKINS 1983

COLEOPTERA		
Carabidae		
Tachys sp.	B	ground beetle
Cratacanthus dubius (Beauvois)	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata (Illiger)	P	flea beetle
Crioceris asparagi (L.)	P	asparagus beetle
Epitrix sp.	P	flea beetle
Cicindelidae		
Megacephala virginica (L.)	B	tiger beetle
DIPTERA		
Lauxaniidae sp.	I	
HEMIPTERA		
Anthocoridae		
Orius sp.	B	minute pirate bug
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
Norvellina seminuda (Say)	P	leafhopper
ORTHOPTERA		
Acrididae spp.	P	short-horned grasshoppers
Melanoplus sp.	P	short-horned grasshoppers

TABLE IV

INSECTS SAMPLED ON ASPARAGUS, I>0.75-BIXBY 1983

COLEOPTERA		
Chrysomelidae		
Crioceris asparagi	P	asparagus beetle
Epitrix sp.	P	flea beetle
DIPTERA		
Lauxaniidae sp.	I	
HEMIPTERA		
Anthocoridae		
Orius sp.	B	minute pirate bug
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
ORTHOPTERA		
Acrididae spp.	P	short-horned grasshoppers

TABLE V

INSECTS SAMPLED ON BLACKBERRY, I>0.75-PERKINS 1983

COLEOPTERA		
Buprestidae		
Agrilus ruficollis (Fab.)	P	rednecked cane borer
Carabidae		
Selenophorus sp.	B	ground beetle
Bembidion intermedium (Kirby)	B	ground beetle
Tachys sp.	B	ground beetle
Harpalus compar Leconte	B	ground beetle
Elateridae		
Conoderus bellus (Say)	P	click beetle
DIPTERA		
Anthomyiidae sp.	P	leaf miner
HEMIPTERA		
Cydnidae		
Pangaeus bilineatus (Say)	I,P	burrowing bug
Nabidae		
Reduviolus spp.	B	damsel bugs
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
Psyllidae		
Trioza sp.	P	psyllid
NEUROPTERA		
Chrysopidae		
Chrysopa oculata Say	B	goldeneye lacewing
ORTHOPTERA		
Gryllidae		
Oecanthus fultoni Walker	P	snowy tree cricket

TABLE VI

INSECTS SAMPLED ON BLACKBERRY, I>0.75-BIXBY 1983

COLEOPTERA		
Buprestidae		
Agrilus ruficollis	P	rednecked cane borer
Carabidae sp. (larva)	B	ground beetle larva
Selenophorus sp.	B	ground beetle
Harpalus compar	B	ground beetle
Elateridae		
Conoderus bellus	P	click beetle
Melyridae		
Collops sp.	B	collops beetle
DIPTERA		
Anthomyiidae sp.	P	leaf miner
HEMIPTERA		
Cydnidae		
Pangaeus bilineatus	I,P	burrowing bug
Nabidae		
Reduviolus sp.	B	damsel bug
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
NEUROPTERA		
Chrysopidae		
Chrysopa oculata	B	goldeneye lacewing
ORTHOPTERA		
Acrididae spp.	P	short-horned grasshoppers
Gryllidae		
Oecanthus fultoni	P	snowy tree cricket

TABLE VII

INSECTS SAMPLED ON BROCCOLI, I>0.75-PERKINS 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae sp. (larva)	B	ground beetle larva
Selenophorus sp.	B	ground beetle
Tachys sp.	B	ground beetle
Cratacanthus dubius	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata	P	flea beetle
C. sp.	P	flea beetle
Cicindelidae		
Cicindela punctulata punctulata Olivier	B	tiger beetle
Scarabaeidae		
Ataenius sp.	I,P	
HEMIPTERA		
Lygaeidae		
Nysius spp.	P	false chinch bugs
HOMOPTERA		
Aphididae		
Myzus persicae (Sulzer)	P	green peach aphid
LEPIDOPTERA		
Noctuidae		
Trichoplusia ni (Hubner)	P	cabbage looper
Plutellidae		
Plutella xylostella (L.)	P	diamondback moth

TABLE VIII

INSECTS SAMPLED ON BROCCOLI, I>0.75-BIXBY 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae sp. (larva)	B	ground beetle larva
Agonoderus lineola (Fab.)	B	ground beetle
A. comma (Fab.)	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata	P	flea beetle
C. sp.	P	flea beetle
Elateridae		
Conoderus bellus	P	click beetle
Scarabaeidae		
Ataenius sp.	I,P	
HEMIPTERA		
Lygaeidae		
Nysius sp.	P	false chinch bug
HOMOPTERA		
Aphididae		
Myzus persicae	P	green peach aphid
Macrosiphum euphorbiae (Thomas)	P	potato aphid
LEPIDOPTERA		
Noctuidae		
Trichoplusia ni	P	cabbage looper

TABLE IX

INSECTS SAMPLED ON CABBAGE, I>0.75-PERKINS 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae spp. (larvae)	B	ground beetle larvae
Selenophorus sp.	B	ground beetle
Agonoderus lineola	B	ground beetle
Bembidion intermedium	B	ground beetle
Tachys sp.	B	ground beetle
Calosoma sp.	B	ground beetle
Cratacanthus dubuis	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata	P	flea beetle
C. sp.	P	flea beetle
Coccinellidae spp. (larvae)	B	lady beetle larvae
Scarabaeidae		
Ataenius sp.	I,P	
DIPTERA		
Agromyzidae spp.	P	leaf miners
HOMOPTERA		
Aphididae		
Myzus persicae	P	green peach aphid
LEPIDOPTERA		
Noctuidae		
Trichoplusia ni	P	cabbage looper
Plutellidae		
Plutella xylostella	P	diamondback moth

TABLE X

INSECTS SAMPLED ON CAULIFLOWER, I>0.75-BIXBY 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae sp. (larva)	B	ground beetle larva
Agonoderus lineola	B	ground beetle
A. comma	B	ground beetle
Scarabaeidae		
Ataenius sp.	I,P	
HEMIPTERA		
Lygaeidae		
Nysius spp.	P	false chinch bugs
HOMOPTERA		
Aphididae		
Myzus persicae	P	green peach aphid
LEPIDOPTERA		
Noctuidae		
Trichoplusia ni	P	cabbage looper

TABLE XI

INSECTS SAMPLED ON POTATO, I>0.75-PERKINS 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae sp. (larva)	B	ground beetle larva
Selenophorus sp.	B	ground beetle
Tachys sp.	B	ground beetle
Cratacanthus dubius	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata	P	flea beetle
Leptinotarsa decemlineata (Say)	P	Colorado potato beetle larvae and adults
Epitrix sp.	P	flea beetle
Coccinellidae spp. (larvae)	B	lady beetle larvae
Scarabaeidae		
Phyllophaga sp.	P	white grub (larva)
HEMIPTERA		
Nabidae		
Reduviolus sp.	B	damsel bug
HOMOPTERA		
Aphididae		
Macrosiphum euphorbiae	P	potato aphid
Cicadellidae		
Empoasca sp.	P	leafhopper

TABLE XII

INSECTS SAMPLED ON POTATO, I>0.75-BIXBY 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae		
Tachys sp.	B	ground beetle
Scarabaeidae		
Ataenius sp.	I,P	
HEMIPTERA		
Lygaeidae		
Geocoris punctipes (Say)	B	bigeyed bug
HOMOPTERA		
Aphididae		
Macrosiphum euphorbiae	P	potato aphid
Cicadellidae		
Empoasca sp.	P	leafhopper

TABLE XIII

INSECTS SAMPLED ON SQUASH, I>0.75-PERKINS 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae spp. (larvae)	B	ground beetle larvae
Selenophorus sp.	B	ground beetle
Tachys sp.	B	ground beetle
Cratacanthus dubius	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata	P	flea beetle
C. sp.	P	flea beetle
Diabrotica undecimpunctata howardi Barber	P	spotted cucumber beetle
Acalymma vittatum (Fab.)	P	striped cucumber beetle
Cicindelidae		
Cicindela punctulata punctulata	B	tiger beetle
Megacephala virginica	B	tiger beetle
Melyridae		
Collops spp.	B	collops beetles
Staphylinidae		
Oxyporus sp.	I	rove beetle
DIPTERA		
Agromyzidae spp.	P	leaf miners
Empididae spp.	I,B	dance flies
Lauxaniidae sp.	I	
HEMIPTERA		
Coreidae		
Anasa tristis (DeGeer)	P	squash bug
Nabidae		
Reduviolus sp.	B	damsel bug
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
LEPIDOPTERA		
Pyralidae		
Achyra rantalis (Guenee)	P	garden webworm

TABLE XIV

INSECTS SAMPLED ON SQUASH, I>0.75-BIXBY 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae		
Agonoderus lineola	B	ground beetle
A. comma	B	ground beetle
Chrysomelidae		
Diabrotica undecimpunctata howardi	P	spotted cucumber beetle
Acalymma vittatum	P	striped cucumber beetle
Cicindelidae		
Megacephala carolina (L.)	B	tiger beetle
Scarabaeidae		
Ataenius sp.	I,P	
DIPTERA		
Lauxaniidae spp.	I	
HEMIPTERA		
Coreidae		
Anasa tristis	P	squash bug
Lygaeidae		
Geocoris punctipes	B	bigeyed bug
Nabidae		
Reduviolus sp.	B	damsel bug
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper

TABLE XV

INSECTS SAMPLED ON SWEET POTATO, I>0.75-PERKINS 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae		
Platynus sp.	B	ground beetle
Tachys sp.	B	ground beetle
Cratacanthus dubius	B	ground beetle
Chrysomelidae		
Chaetocnema sp.	P	flea beetle
Agroiconota bivittata (Say)	P	tortoise beetle
Deloyala guttata (Olivier)	P	mottled tortoise beetle
Coccinellidae		
Hippodamia convergens Guerin-Meneville	B	convergent lady beetle
Ceratomegilla fuscilabris (Mulsant)	B	lady beetle
Scymnus cinctus Leconte	B	lady beetle
Elateridae		
Conoderus vespertinus (Fab.)	P	click beetle
Scarabaeidae		
Phyllophaga sp.	P	white grub (larva)
DIPTERA		
Empididae spp.	I,B	dance flies
Chloropidae sp.	I,P	
Phoridae sp.	I	humpbacked fly
Heleomyzidae sp.	I	
HEMIPTERA		
Anthocoridae		
Orius sp.	B	minute pirate bug
Berytidae		
Jalysus wickhami VanDuzee	I,P	stilt bug
Nabidae		
Reduviolus spp.	B	damsel bugs
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper

TABLE XV (Continued)

LEPIDOPTERA		
Arctiidae		
Estigmene acrea (Drury)	P	saltmarsh caterpillar
Pyralidae		
Achyra rantalis	P	garden webworm
NEUROPTERA		
Hemerobiidae		
Micromus sp.	B	brown lacewing
ORTHOPTERA		
Acrididae spp.	P	short-horned grasshoppers

TABLE XVI

INSECTS SAMPLED ON SWEET POTATO, I>0.75-BIXBY 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae		
Platynus sp.	B	ground beetle
Bembidion intermedium	B	ground beetle
Tachys sp.	B	ground beetle
Chrysomelidae		
Chaetocnema sp.	P	flea beetle
Diabrotica undecimpunctata howardi	P	spotted cucumber beetle
Deloyala guttata	P	mottled tortoise beetle
Cicindelidae		
Megacephala carolina	B	tiger beetle
Coccinellidae		
Ceratomegilla fuscilabris	B	lady beetle
Elateridae		
Conoderus bellus	P	click beetle
C. vespertinus	P	click beetle
Scarabaeidae		
Ataenius sp.	I,P	
Staphylinidae		
Anotylus sp.	I	rove beetle
Paederus littorarius Gravenhorst	I	rove beetle
DIPTERA		
Chloropidae sp.	I,P	
Empididae spp.	I,B	dance flies
Phoridae sp.	I	humpbacked fly
Lauxaniidae spp.	I	
Dolichopodidae sp.	B	long-legged fly
Heleomyzidae sp.	I	
HEMIPTERA		
Anthocoridae		
Orius sp.	B	minute pirate bug
Lygaeidae		
Geocoris punctipes	B	bigeyed bug
Nabidae		
Reduviolus spp.	B	damsel bugs

TABLE XVI (Continued)

HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
Macrosteles sp.	P	leafhopper
HYMENOPTERA		
Pteromalidae		
Eupteromalus sp.	B	chalcid
LEPIDOPTERA		
Arctiidae		
Estigmene acrea	P	saltmarsh caterpillar
NEUROPTERA		
Hemerobiidae		
Micromus sp.	B	brown lacewing
ORTHOPTERA		
Acrididae spp.	P	short-horned grasshoppers

TABLE XVII

INSECTS SAMPLED ON WATERMELON, I>0.75-PERKINS 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae sp. (larva)	B	ground beetle larva
Selenophorus sp.	B	ground beetle
Cratacanthus dubius	B	ground beetle
Chrysomelidae		
Chaetocnema denticulata	P	flea beetle
Cicindelidae		
Cicindela punctulata punctulata	B	tiger beetle
Megacephala virginica	B	tiger beetle
Melyridae		
Collops sp.	B	collops beetle
DIPTERA		
Agromyzidae spp.	P	leaf miners
Lauxaniidae spp.	I	
HEMIPTERA		
Coreidae		
Anasa tristis	P	squash bug
Nabidae		
Reduviolus sp.	B	damsel bug
HOMOPTERA		
Cicadellidae		
Empoasca sp.	P	leafhopper
HYMENOPTERA		
Chalcididae		
Brachymeria fonscolombei (Dufour)	B	chalcids
LEPIDOPTERA		
Pyralidae		
Achyra rantalis	P	garden webworm

TABLE XVIII

INSECTS SAMPLED ON WATERMELON, I>0.75-BIXBY 1983

COLEOPTERA		
Anthicidae		
Anthicus spp.	I	antlike flower beetles
Carabidae		
Agonoderus lineola	B	ground beetle
Geopinus incrassatus (Dejean)	B	ground beetle
Chrysomelidae		
Acalymma vittatum	P	striped cucumber beetle
Diabrotica undecimpunctata howardi	P	spotted cucumber beetle
Cicindelidae		
Megacephala carolina	B	tiger beetle
Elateridae		
Conoderus vespertinus	P	click beetle
Melyridae		
Collops sp.	B	collops beetle
Scarabaeidae		
Ataenius sp.	I,P	
Staphylinidae		
Philonthus sp.	I	rove beetle
DIPTERA		
Agromyzidae sp.	P	leaf miner
Chamaemylidae sp.	B	aphid fly
Lauxaniidae spp.	I	
Chloropidae sp.	I,P	
HEMIPTERA		
Anthocoridae		
Orius sp.	B	minute pirate bug
Berytidae		
Jalysus wickhami	I,P	stilt bug
Lygaeidae		
Geocoris punctipes	B	bigeyed bug
Nysius spp.	P	false chinch bugs
Miridae		
Spanagonicus albofasciatus (Reuter)	P	whitemarked fleahopper
Nabidae		
Reduviolus sp.	B	damsel bug

TABLE XVIII (Continued)

HOMOPTERA		
Cicadellidae sp.	P	leafhopper
Empoasca sp.	P	leafhopper
HYMENOPTERA		
Chalcididae		
Brachymeria fonscolombei	B	chalcid
Crabronidae		
Enchemicrum sp.	B	sphecid

APPENDIX B

FIELD DATA FILE EXAMPLE

```
----------------------------------- LOC=2    CRP=POT    ORD=LAR    FAM=XXXXXXXXXX -----------------------------------

 O   C                                     S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S
 B   N  J     S   S   S   S   S    S S S S 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4
 S   T  D     1   2   3   4   5    6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3

1472 1 132   11   .   .   .   .    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1473 2 145   12 231   .   .   .    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1474 1 159   11   .   .   .   .    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1475 5 173  303 531 151 541 551    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1476 6 186  721 711 731 511 741  751 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1477 1 202  871   .   .   .   .    . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

----------------------------------- LOC=2    CRP=POT    ORD=LEP    FAM=NOCTUIDAEX -----------------------------------

        O    C                         S S S S S S S S S 6 S S S S S S S S S S S S S S S S S S S S S S S S
        B    N   J  S  S S S S S S S S 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4
        S    T   D  1  2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3

        1478 1 173 21  . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

----------------------------------- LOC=2    CRP=POT    ORD=NEU    FAM=CHRYSOPIDA -----------------------------------

        O    C                         S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S
        B    N   J  S  S S S S S S S S 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4
        S    T   D  1  2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3

        1479 1 159 11  . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
        1480 1 173 11  . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
        1481 1 186 11  . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

----------------------------------- LOC=2    CRP=POT    ORD=ORT    FAM=ACRIDIDAEX -----------------------------------

        O    C                          S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S
        B    N   J   S  S S S S S S S S 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4
        S    T   D   1  2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3

        1482 1 186 221  . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

----------------------------------- LOC=2    CRP=SQU    ORD=COL    FAM=CARABIDAEX -----------------------------------

 O   C                                    S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S S
 B   N  J   S   S   S   S   S   S   S S S 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3 3 3 3 3 3 4 4 4 4
 S   T  D   1   2   3   4   5   6   7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3

1483 5 159 31  61 142 161 221   .   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1484 8 173 31 101 142 162 221 311 581 831 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1485 8 186 31  61  71 141 161 261 411 571 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1486 2 202 32 251   .   .   .   .   .   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1487 6 215 21  32 142 411 551 571   .   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
1488 6 230 22  32  51  81 411 591   .   . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
```

APPENDIX C

DATA FILE EXAMPLE

```
 OBS    LOC    CRP    ORD       FAM        SPECIES     SD        I

  57     1     SWE    COL    ELATERIDAE       26        6     0.83333
  58     1     SWE    COL    UNKNOWNXXX        2        6     1.00000
  59     1     SWE    DIP    UNKNOWNXXX      210        6     0.83333
  60     1     SWE    DIP    UNKNOWNXXX      184        6     1.00000
  61     1     SWE    DIP    UNKNOWNXXX      144        6     1.66667
  62     1     SWE    HEM    BERYTIDAEX        1        6     1.16667
  63     1     SWE    HOM    CICADELLID        6        6     2.00000
  64     1     WAT    COL    CARABIDAEX        1        7     1.14286
  65     1     WAT    COL    CARABIDAEX       15        7     2.28571
  66     1     WAT    COL    CHRYSOMELI        1        7     1.71429
  67     1     WAT    COL    CICINDELID        7        7     1.00000
  68     1     WAT    COL    CICINDELID        5        7     1.14286
  69     1     WAT    COL    UNKNOWNXXX        2        7     1.28571
  70     1     WAT    DIP    UNKNOWNXXX      193        7     1.00000
  71     1     WAT    HYM    UNKNOWNXXX      193        7     0.85714
  72     2     ASP    COL    CHRYSOMELI       96        7     1.00000
  73     2     ASP    DIP    UNKNOWNXXX      187        7     1.14286
  74     2     ASP    HEM    ANTHOCORID        1        7     1.28571
  75     2     ASP    HOM    CICADELLID        6        7     1.00000
  76     2     BLA    COL    CARABIDAEX       41        7     0.85714
  77     2     BLA    COL    CARABIDAEX        1        7     1.00000
  78     2     BLA    COL    ELATERIDAE        1        7     0.85714
  79     2     BLA    DIP    UNKNOWNXXX       47        7     1.14286
  80     2     BLA    HEM    CYDNIDAEXX        1        7     1.28571
  81     2     BLA    HOM    CICADELLID        6        7     1.28571
  82     2     BLA    NEU    CHRYSOPIDA        1        7     0.85714
  83     2     BRO    COL    CARABIDAEX        3        5     1.20000
  84     2     BRO    COL    CARABIDAEX       14        5     1.80000
  85     2     BRO    COL    CHRYSOMELI        2        5     0.80000
  86     2     BRO    COL    ELATERIDAE        1        5     0.80000
  87     2     BRO    COL    SCARABAEID        4        5     1.20000
  88     2     BRO    COL    UNKNOWNXXX        2        5     2.60000
  89     2     BRO    HEM    LYGAEIDAEX       15        5     0.80000
  90     2     BRO    HOM    APHIDIDAEX        2        5     0.80000
  91     2     BRO    LAR    XXXXXXXXXX       30        5     0.80000
  92     2     BRO    LAR    XXXXXXXXXX        1        5     1.40000
  93     2     CAU    COL    CARABIDAEX        3        5     1.20000
  94     2     CAU    COL    CARABIDAEX       14        5     1.60000
  95     2     CAU    COL    SCARABAEID        4        5     0.80000
  96     2     CAU    COL    UNKNOWNXXX        2        5     1.60000
  97     2     CAU    HEM    LYGAEIDAEX        8        5     0.80000
  98     2     CAU    HEM    LYGAEIDAEX       15        5     0.80000
  99     2     CAU    LAR    XXXXXXXXXX       30        5     1.00000
 100     2     CAU    LAR    XXXXXXXXXX        1        5     1.20000
 101     2     POT    COL    CARABIDAEX        7        6     1.00000
 102     2     POT    COL    SCARABAEID        4        6     0.83333
 103     2     POT    COL    UNKNOWNXXX        2        6     1.83333
 104     2     POT    HEM    LYGAEIDAEX        3        6     0.83333
 105     2     POT    HOM    CICADELLID        6        6     1.16667
 106     2     SQU    COL    CARABIDAEX       14        7     1.00000
 107     2     SQU    COL    CARABIDAEX        3        7     1.28571
 108     2     SQU    COL    CHRYSOMELI        8        7     1.00000
 109     2     SQU    COL    CHRYSOMELI       28        7     1.00000
 110     2     SQU    COL    CICINDELID        8        7     1.14286
 111     2     SQU    COL    SCARABAEID        4        7     1.00000
 112     2     SQU    COL    UNKNOWNXXX        2        7     2.28571
```

PART II

POPULATION DYNAMICS IN THE SQUASH BUG/SQUASH PLANT SYSTEM

CHAPTER I

INTRODUCTION

A wide variety of insects feed on plants in the family Cucurbitaceae. Of special concern are those insects which damage the economically important cucurbit crops. Growers of cantaloupes, cucumbers, gourds, pumpkins, summer and winter squash, and watermelons have battled insect pests for years. Some of the more destructive cucurbit pests include: the squash bug (*Anasa tristis* (DeGeer)) (Beard 1940, Britton 1919, Chittenden 1899, Gould 1943, Wadley 1920), striped (Bach 1980, Britton 1919, Chittenden 1899) and spotted cucumber beetles (*Acalymma vittatum* (Fab.), *Diabrotica undecimpunctata howardi* Barber) (Gould 1943, Sanborn 1912), the squash vine borer (*Melittia cucurbitae* (Harris)) (Britton 1919, Chittenden 1899, Gould 1943, Howe 1950), melon and squash aphids (*Aphis gossypii* Glover, *Macrosiphum cucurbitae* Middleton) (Britton 1919, Fenton 1939, Goff and Tissot 1932), cutworms (Lepidoptera:Noctuidae) (Britton 1919, Gould 1943), and cucumber flea beetles (*Epitrix cucumeris* (Harris)) (Britton 1919). Other cucurbit pests include various pickleworms (Lepidoptera:Pyralidae) (Chittenden 1899, Gould 1943), garden springtails (*Bourletiella hortensis* (Fitch)) (Britton 1919, Gould 1943), the squash lady-beetle (*Epilachna* borealis (Fab.)) (Britton 1919, Chittenden 1899), the horned squash bug (Anasa armigera (Say)), various leaffooted bugs (Hemiptera:Coreidae) (Chittenden 1899), and numerous mites (Acari:Tetranychidae) (Michelbacher et al. 1955).

The squash bug is a devastating pest wherever cucurbits are grown. Control of the squash bug has been difficult and is often impossible. Relatively ineffective chemical control procedures for the squash bug have increased the importance of cultural and mechanical control methods. These methods are usually time and labor intensive and therefore are difficult for the commercial grower to practice. A more reliable and cost efficient means of control is needed.

Recent increases in production of economically important cucurbits at the commercial and private levels in Oklahoma (Tweeten 1982) have renewed interest in squash bug research. The basic biology, description, and life history of the squash bug is well documented (Beard 1940, Chittenden 1899, 1908, Elliott 1935, Knowlton 1933, and Wadley 1920). However, to develop an integrated management strategy for the squash bug an understanding of population changes and trends is necessary. Coulson (1981) wrote that the foundation of integrated pest management (IPM) is a thorough understanding of the ecologies of both plant and insect. With such a management strategy in mind, an initial investigation into the seasonal squash bug population trends in relation to its host plant development was implemented.

An understanding of squash bug and squash plant populations and their interactions, while considering environmental factors, will make an integrated control management plan a reality. This study will initiate the field research into this insect/plant system.

The main objectives of this study were as follows. The first objective was to monitor squash bug population dynamics by recording the daily number of egg masses, total eggs, total nymphs in each of five instars, and male and female adults. Second, monitor squash plant, Cucurbita pepo L. variety Hyrific, seasonal development by estimating daily plant leaf area, counting reproductive structures and monitoring yield. Third, investigate seasonal squash bug population trends and changes in relation to host plant development. And fourth, record daily temperature, precipitation, irrigation, and photoperiod for future correlation to the squash bug and plant developmental components.

CHAPTER II

LITERATURE REVIEW

Of the many insect pests known to damage plants in the family Cucurbitaceae, the squash bug, Anasa tristis (DeGeer), is universally agreed upon as being the largest cause of yield reduction and plant death (Chittenden 1908, Weed and Conradi 1902). Within the Cucurbitaceae, summer and winter squash, and pumpkins seem to be preferred by the squash bug (Elliott 1935, Hoerner 1938, Knowlton 1933). A native North American insect pest, the squash bug is distributed throughout the Western Hemisphere from Canada to South America (Beard 1940, Britton 1919). It is especially a devastating pest east of the Rocky Mountains in the United States (Chittenden 1908).

Cucurbit seedlings are most vulnerable to squash bug damage due to the voracious feeding of overwintering adults and newly hatched nymphs. As the plants become larger, damage begins on a single leaf and progresses through a particular branch, and finally throughout the entire plant. The typical dried and burned appearance of the leaves (Beard 1935) leads to the wilting of branches and possibly death. There has also been speculation regarding squash bug transmission of cucurbit wilt disease (Beard 1940, Britton

1919), or the injection of a toxin during feeding (Chittenden 1908, Eichmann 1945). These theories have never been substantiated. Yield losses, either due to the wilting and death of plant parts, or to the direct feeding on fruit can be devastating. Control of the squash bug is necessary at the commercial level, and a reliable, efficient control method has yet to be discovered.

The biology, life history, and description of the squash bug is well documented. Much of this work has been completed in Connecticut, Massachusetts, Utah, Kansas and Iowa (Beard 1940, Britton 1919, Chittenden 1908, Elliott 1935, Knowlton 1933, Wadley 1920, Weed and Conradi 1902, and Worthley 1923). The following description is accumulated largely from these sources.

Overwintered, unmated adults are first found on plants in late May to late June, depending on geographical location. The bugs are believed to randomly locate plants, but may be attracted to them by olfaction (Balduf 1950, Weed and Conradi 1902). After mating, oviposition occurs for up to eight weeks. Eggs are usually laid in masses of fifteen to thirty eggs. The eggs are generally laid on the underside of leaves within leaf vein angles. The eggs, which are 1.05 mm long and 1.02 mm wide, are a creamy white color at oviposition but turn yellow and finally bronze just before hatching. Eggs hatch within nine to twelve days, depending on location and environmental conditions. First instar nymphs begin as conspicuous 2.5 mm long bugs. The nymphs' crimson colored antennae, heads, legs, and thoraces are offset by a green abdomen. After a short time the red turns to the usual black color. This instar is also the most pubescent. First instar nymphs often remain congregated around the oviposition site, and so cause increased damage by gregarious feeding. First instar nymphs molt after about three days. Second instar nymphs are a more greenish-gray color, generally 3 mm in length, and molt into third instar insects after five to nine days.

Third to fifth instar nymphs are a more mottled-gray color and begin to resemble the adults. Third instar nymphs, 4-5 mm in length, begin to show wing pad development. These nymphs molt after five to eight days. Fourth instar squash bugs exhibit true rudimentary wing pads. Fourth instar nymphs are 6-8 mm in length and live six to ten days. Fifth instar insects are 9-10 mm in length, and have fully developed wing pads. The adult molt occurs after eight to fourteen days. Total squash bug development time from egg to adult ranges between thirty-four and seventy-five days in the areas studied, with an overall average being around fifty-two to fifty-four days.

Squash bug adults are 13-16 mm in length, males being slightly smaller than females. In northern areas there is usually only one generation per year (Beard 1940, Britton 1919, Knowlton 1933, Weed and Conradi 1902). These adults begin to leave the field in September for overwintering sites. In milder regions, adult mating and oviposition continues beyond this point (Eichmann 1945, Wadley 1920). A second generation often develops to completion, and a partial third generation may develop under certain conditions (Wadley 1920). The accumulation of second and third generation nymphs and adults can cause devastating losses late in the growing season.

Adults moving to overwintering sites find shelter under tree bark, in buildings, and in and around crop field debris. The overwintering of the squash bug is neither a true hibernation nor a diapause, although evidence has been brought forward indicating a reproductive diapause (Balduf 1950). Warm conditions during winter and early spring months often stir the overwintering adults and increase their activity (Wadley 1920). This quiescent state may allow winter and early spring feeding on native cucurbits, while also allowing the bugs early season access to field plots.

Cultural control methods have been used for decades on the squash bug and are often considered the best control techniques (Britton 1919, Knowlton 1933, Weed and Conradi 1902). Burning and burying crop and field debris eliminates squash bug food sources and overwintering locations. Maintaining a good plant culture through plant fertilization, cultivation, and irrigation is extremely important. The planting of excessive squash seedling numbers may dilute early season squash bug damage, while crop rotation may help reduce bug numbers. Some cucurbits may also be used as trap crops, luring the squash bugs away from desired crops

(Eichmann 1945, Weed and Conradi 1902). For example, watermelon producers may plant squash around a field. The squash bugs will attack the squash early, and control methods can be attempted before damage is done to the preferred economically important crop. The planting of resistant cucurbit varieties may also help reduce squash bug damage. In Washington, the Kentucky field pumpkin appeared resistant (Eichmann 1945). In Kansas, Butternut and Royal Acorn squash varieties were most resistant, while Pink Banana and Black Zucchini were most susceptible. Resistance appeared to be due to a lack of preference, although there was an antibiotic effect on nymphal development (Novero et al. 1962).

Several mechanical control methods are quite effective. On a small scale, hand-picking squash bug adults and eggs off of the plants early in the season can greatly reduce the population. Nets placed over cucurbit seedlings can reduce squash bug attacks. In addition, squash bugs in northern locations may seek shelter at night under boards or shingles placed around plants. These bugs can easily be destroyed the next morning.

Natural enemies have always been of special interest in the control of squash bugs. <u>Trichopoda pennipes</u> Fab., a tachinid fly, is the most referenced squash bug parasite (Beard 1940, Weed and Conradi 1902, Worthley 1923). This parasite generally completes two generations to one generation of the squash bug, but its genuine effect on bug populations is still undetermined. Third and fourth instars, and adult squash bugs are parasitized by the fly. Parasitized adult females however, are still capable of ovipositing a large number of eggs. Fly larvae and pupae are capable of passing the winter within the body of an adult squash bug. Chalcidid flies (Chittenden 1908), and several hymenopterous species (*Hadronotus anasae* Ashmead, *H. carinatifrons* Ashmead, and *H. ajax* Girault) (Beard 1935) have been reported as egg parasites. Various insect predators also occasionally feed on the squash bug. Pentatomids, nabids, lace wings, spiders, and ants are some of these predators (Beard 1940). Assorted amphibians, reptiles, and birds have also been seen feeding on squash bugs (Chittenden 1899, Weed and Conradi 1902). A pathogenic fungus and bacteria (*Bacillus entomotoxicon* Duggar) (Beard 1935), and an unidentified mite species (Hoerner 1938), have also been reported on squash bugs. There is also documentation of squash bug cannibalism (Chittenden 1899, 1908). Natural control of the squash bug by parasitism, either on eggs or adults, appears to be the most consistent natural control technique and could have management potential. However, some feel that scarcity of food and cold temperatures are the only naturally occurring methods for controlling squash bug populations (Wadley 1920).

Chemical control has been ineffective through the years due to squash bug chemical tolerance and resistance. The problems of directing sprays onto eggs and nymphs, which are located under the leaf surface, along with chemical residues on the fruit have only made matters worse. Some of the chemicals used in the past include a kerosene extract of pyrethrum, a soap solution with sulphur, fish-oil soap, calcium-cyanide-A dust, nicotine sulfate, sodium sulfide, linseed oil emulsion, and dry pyrocide with dusting gypsum (Beard 1935, Elliott 1935, Hoerner 1938, Wadley 1920, Worthley 1923). Various repellants have also been tested with no success (Hoerner 1938). More recently, parathion, lindane, malathion, endrin, dieldrin, EPN, and aldrin have been used producing moderate squash bug control (Harries and Matsumori 1955, Wright and Decker 1955). Presently, naled, carbaryl, acephate, methomyl, and other chemicals are being used in an attempt to control squash bugs (Latheef and Ortiz 1982). Ongoing research at Oklahoma State University points to the potential of cypermethrin, fenvalerate, and methomyl for controlling squash bugs (Criswell 1985). Control of the small nymphs is essential, as larger nymphs and adults are difficult to kill with most chemicals. Research continues for a safe and reliable chemical which will adequately control squash bugs.

Present control methods can be greatly improved with basic and applied research at both the squash bug population level and throughout the entire cucurbit horticultural system. Previous research only lightly addressed squash bug population changes over time. Almost immediately upon entry into the field, overwintered females begin to oviposit. Oviposition continues for up to eight weeks. Overwintered females lay an average number of 308 (Beard 1940) to 460 eggs (Wadley 1920). The majority of egg deposition occurs during the warm daylight hours. Temperature and humidity, on a day to day basis, affect oviposition. Oviposition increases as the daily temperature increases. Conversely, inclement weather, such as heavy rainfall, drastically reduces oviposition. Day to day variations in oviposition can be best explained by weather conditions. Daily fluctuations at the population level are insignificant and so are not reflected in daily ovipositional trends. Squash bug population fluctuations over an entire season are extreme though, and will affect seasonal oviposition.

Oviposition generally reaches a peak during the second and third week of July. Almost 70% of cumulative seasonal oviposition occurs during this period (Beard 1940). Two observations point to the fact that squash bug population density appears to be the most important factor responsible for the ovipositional peaks noted throughout a season. First, documented oviposition and population density trends do correspond closely (Beard 1940). For example, an adult squash bug depletion due to heavy rainfall leads to a decrease in total oviposition. Secondly, seasonal individual fecundity trends are more uniform than the seasonal oviposition trend. Over the course of a season, fecundity rate does not increase as does the total population ovipositional trend. Considering individual fecundity alone, the number of eggs deposited is a linear function of the longevity of the bug. Again, this is not the case at the population level; population density is responsible for the observed ovipositional peaks throughout a season.

Following egg hatch, some general population trends of resulting nymphs and adults have been recorded. These observations can be fairly straightforward when there is a single generation in a season, but become more complicated if two or even three generations develop. Location and corresponding environmental conditions have a direct effect on squash bug development and so dictate the presence and/or absence of various life stages, and the extent to which they overlap.

In northern areas, where there is only one generation a year, it is quite possible for all squash bug life stages to be present in the field together. Overwintered adults lay eggs which develop into nymphs and finally become adults. Due to time intervals over which oviposition and nymphal development rates occur, overwintered adults can be present in the field with first generation adults. These first generation adults rarely oviposit, but begin to overwinter in mid-September through October (Worthley 1923). There is a period during mid-July through August when adult numbers are lowest. This period occurs after overwintered adults have completed oviposition and died, and before the new generation can complete development (Beard 1940).

In more southern areas, overwintered adults may survive in the field through August. Eggs laid in late May or June can develop into first generation adults by early July. These first generation adults begin oviposition in mid-July and continue through late September. Early second generation eggs can develop into adults by mid-August. These second generation adults may then begin ovipositing in August. It is possible then to have overwintered adults and third generation eggs in the field together, along with all life stages in between. In a long season, third generation adults may even develop and overwinter. In a shorter season most third generation nymphs will succumb to the cold. It is possible for first, second, and third generation adults to overwinter together (Wadley 1920). The above scenerio reveals the possibility of an enormous population of squash bugs feeding in a field at the same time under favorable environmental conditions. Also, a large overwintering population could lead to very high early season losses the following spring.

It is crucial to our understanding of the squash bug to know the number of generations/year and the times and lengths of occurence for the various life stages. Correlating this information with precise development parameters of the host, a particular cucurbit, will better define the host/pest relationship. Effects of the environment on all aspects of the system must also be considered, along with the resulting changes induced throughout the system.

CHAPTER III

MATERIALS AND METHODS

The population dynamics of the squash bug, *Anasa tristis*, were studied in the spring and summer months of 1984. This work was conducted on the Oklahoma State University Horticulture Research Station near Perkins, Payne County, Oklahoma. Initial ground preparation for the seeding of squash plants was completed as routinely practiced by cucurbit growers. After this initial discing and levelling, the ground was further worked with a Troy-built® tiller. A plot measuring 145'x 45' (44.2 m x 13.7 m), the larger dimension running east and west, was established. The prepared plot served as the experimental site for this study.

The plot allowed for the seeding of 252 squash plant hills. Hill spacing was five feet (1.5 m) on all sides, including a five foot border zone around the entire plot. The hills were initially seeded with four seeds of Ferry-Morse Hyrific 10120-16880 variety yellow-straightneck squash (*Cucurbita pepo* L.) on May 15 (Julian date 136). Julian date (JD) being the days of the year numbered consecutively from 1 (January 1) to 365 (December 31). A preemergence herbicide, ethalfluralin, was applied to the plot as directed by the label instructions. Upon emergence and subsequent establishment, the seedlings were thinned to one plant/hill. Cultivation of the plot was completed with a Troy-built tiller as needed. Matheson four inch irrigation pipe was permanently placed in the field and irrigation was supplied weekly or as needed to ensure proper plant growth. Measuring cups were placed throughout the plot to ensure even irrigation over the entire study area. Irrigation measurements throughout the study were taken in scaled field rain gauges. Irrigation was used when necessary to increase weekly natural rainfall to a minimum of one inch (2.54 cm). Weather data was recorded at the research station and was available to this study. Approximately four weeks after seeding, the plot was fertilized with nitrogen as directed for cucurbits.

Squash plant and squash bug sampling was completed as follows. Initially, twenty-five plants were randomly sampled daily, beginning on May 23 (JD 144). All true leaves were counted, and numbered with a permanent marker. Numbering started with the first true emerging leaf. The midrib length and tertiary width of each leaf were measured to the nearest millimeter and recorded. These measurements were used in a leaf area estimation model (Fargo and Bonjour, unpublished) to estimate total plant leaf area. As the plants matured, the male and female flower buds and flowers were counted. Later, immature fruit were also counted. Harvested fruit weights were recorded daily on all plants within the plot. A record of the total number of fruits and their weights were kept for all producing plants throughout the study.

Squash bug population parameters were also recorded daily on each sampled plant. The total number of adult male and female bugs, and the number of nymphs in each of five instars was counted and recorded for each plant. The total number of egg masses and eggs within these masses were also counted.

As the plants grew and insect numbers increased drastically, the number of plants sampled daily was reduced due to time and labor constraints. Beginning on June 28 (JD 180) only twelve or thirteen of the twenty-five plants sampled were measured as described above. All twenty-five plants were still sampled for the insect parameters. Toward the conclusion of the study, time constraints forced even fewer samples to be taken. From July 9 (JD 191) until the conclusion of the study (August 1, JD 214) only five plants were sampled every other day. In these cases, the sampled plants and all squash bugs on or near the plant were placed in large plastic bags and returned to the laboratory for processing. This procedure facilitated accurate measurements and counts due to the extreme insect numbers and plant size.

All compiled data was analyzed on an IBM 3081D computer system using the Statistical Analysis System (Ray 1982).

CHAPTER IV

RESULTS AND DISCUSSION

Daily sample means of all plant growth measurements and squash bug population parameters were calculated using the Statistical Analysis System (SAS) (Ray 1982). The mean numbers of the squash bug population estimates and the squash plant growth measurements are presented in Appendix A. This analysis allowed the data to be compared for an average plant on each of the sampling dates. For example, the mean number of adult squash bugs/plant could be compared when 25 plants were sampled or when only 5 plants were sampled. The mean number of adults/plant could then be compared for each sampling date throughout the entire growing season regardless of actual sample size. Cumulative yield for all producing plants was recorded. Data and their comparisons will be presented by Julian date. All the population data were taken from randomly selected squash plants within the study plot. Variation between plants was often high. Plant growth measurements and seasonal trends will be addressed first, followed by the squash bug population data. Finally, the possible squash bug population effects on the host plant will be discussed, as well as the impact of environmental factors on the squash bug/squash plant system.

Squash plant seasonal growth and trends

The squash plants were seeded on JD 136 (May 15, 1984). Sampling for plant leaf area began on JD 144. Although several of the plants had not yet emerged or developed true leaves by this date, all available data was collected. Leaf measurements were used in the model designed by Fargo and Bonjour (unpublished) to approximate leaf area. As stated above, mean leaf area/plant was estimated for each sampling date throughout the growing season. Mean plant leaf area increased slowly early in the season (Figure 1). An intial plant leaf area of 2.50×10^{-5} m^2 was estimated on JD 145. Mean plant leaf area increased to 3.91×10^{-4} m^2 on JD 151, 3.29×10^{-3} m^2 on JD 155, and 1.04×10^{-2} m^2 on JD 165. The scale of the y-axis in Figure 1 hides these early season mean plant leaf areas. As more true leaves were produced, and the leaves began to expand, the plant leaf area increased drastically. A sharp linear increase began about JD 170. Leaf area increased over a month long period, but began to slow about JD 206 (July 24). The maximum mean leaf area/plant reached approximately 23 m^2. The resulting sigmoid-shaped growth curve is typical of many plant growth systems. The late season decrease in plant leaf area was due to a combination of fruit growth onset, leaf senescence, and squash bug damage.

The average number of leaves/plant paralleled the seasonal trends of the mean leaf area/plant as expected. The

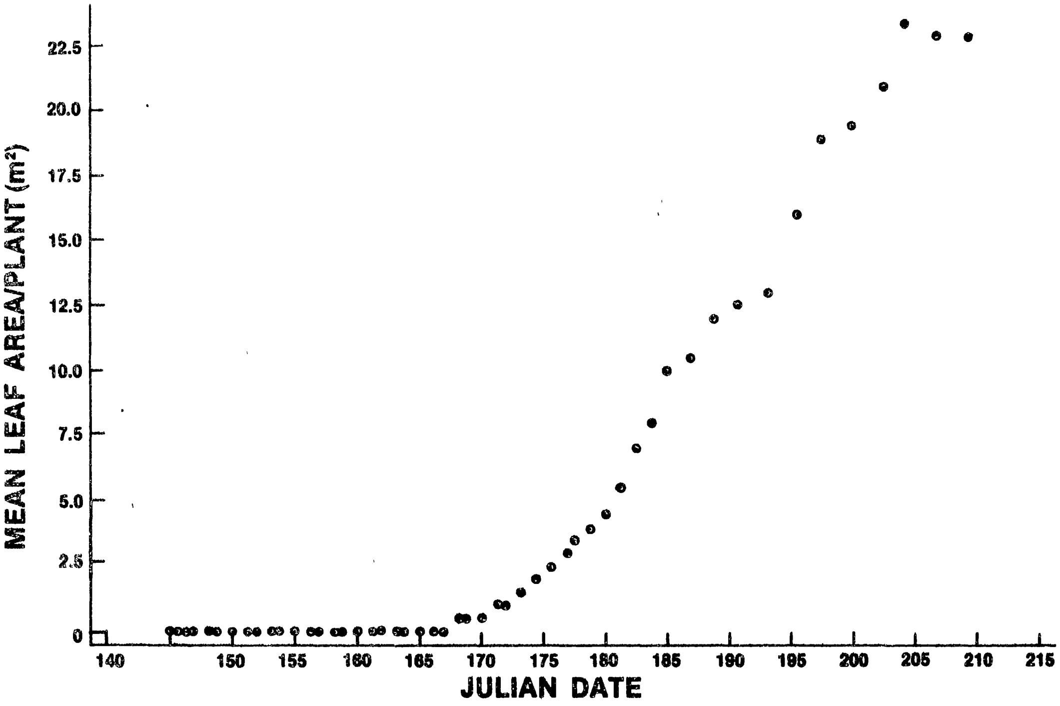

Figure 1. The Mean Squash Plant Leaf Area (m^2) Sampled by Julian Date

mean number of leaves/plant also increased sharply in a linear manner. The increase began about JD 149, earlier than the beginning of the dramatic mean plant leaf area increase. A maximum average of just over 50 leaves/plant was reached on JD 208 and 212. The mean number of leaves/plant fell to 42 leaves/plant on JD 214 (August 1), due primarily to leaf senescence and squash bug damage. The resulting curve is similar to Figure 1 with the linear increase beginning earlier in the season. The mean plant leaf area and the mean number of leaves/plant were highly correlated, r=0.92.

The development of plant reproductive structures exhibited the following trends. The mean number of male and female flower buds/plant increased slowly early in the season. Male flower buds first appeared on JD 156, while female flower buds developed later, about JD 163. The mean number of flower buds/plant also exhibited a linear increase during the growing season. The male flower buds reached a maximum mean of 212/plant on JD 202, while the female flower buds reached a peak value of 148 on JD 209. The number of male and female flower buds/plant decreased beyond this point in the season. The season long growth curves for the mean numbers of male and female flower buds is similar to that of the mean number of leaves and the mean plant leaf area. The only difference between male and female flower bud development was a seven day lag period in female bud development. The mean numbers of male and female flower buds were also highly correlated to the mean plant leaf area, r=0.95 and 0.98 respectively. This correlation is logical since the plant leaves are the primary location of photosynthesis. Increased vegetative growth increases photosynthesis and subsequent reproductive plant growth.

The male and female flower buds developed into male and female flowers which first appeared in the samples on JD 173 and 176 respectively (Figures 2 and 3). The y-axis scale hides small sample means early in the season. Development time from the first observed male flower bud to the first male flower was 17 days, while 13 days elapsed between initial female flower bud and female flower development. This resulted in the near simultaneous occurrence of both flower sexes in the plot. A season long ratio of 6.73:1 male flowers to female flowers was observed (s=3.29). The mean number of male and female flowers increased throughout the season in a linear manner. The mean number of male flowers (Figure 2) appears sigmoid, reaching a peak of 61/plant on JD 209, but decreasing to 59 on JD 214. In contrast, the mean number of female flowers was highest on JD 214, numbering 10.5 flowers/plant. Sampling did not occur beyond JD 214, so the peak mean number of female flowers may not have been reached. The curve of the mean number of female flowers (Figure 3) was more erratic with decreases having occurred on Julian dates 193 and 209. Again, these are mean numbers sampled from randomly selected squash plants and variation from plant to plant was often high. The mean numbers of male and female flowers were also highly correlated to the mean

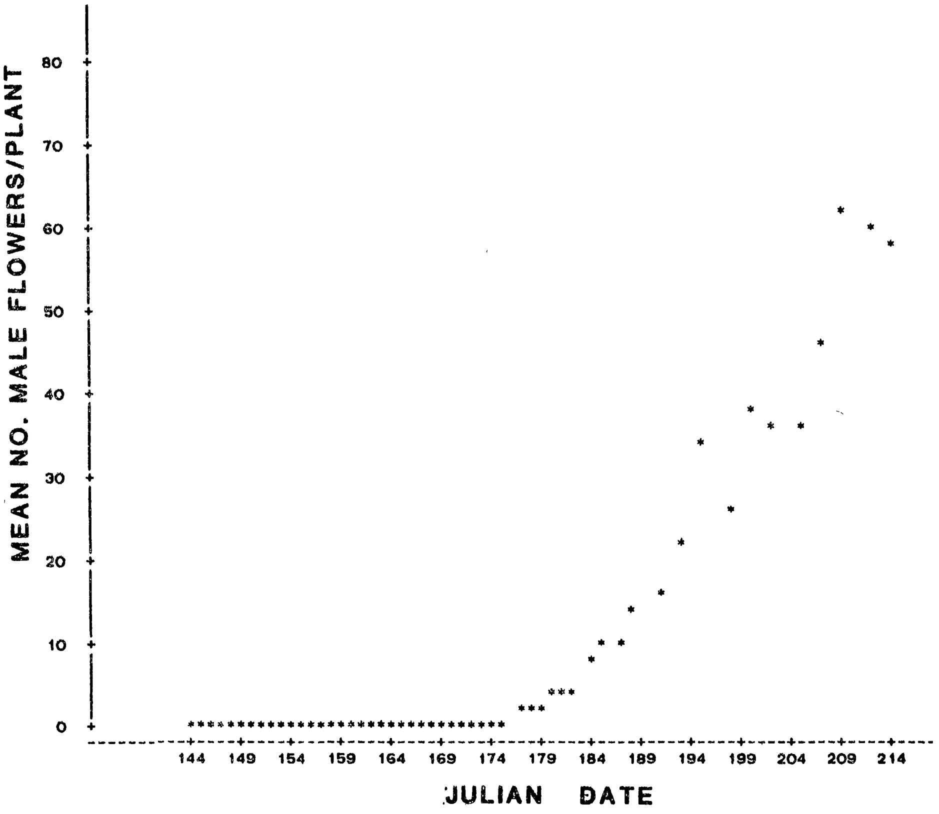

Figure 2. The Mean Number of Male Flowers/Squash Plant Sampled by Julian Date

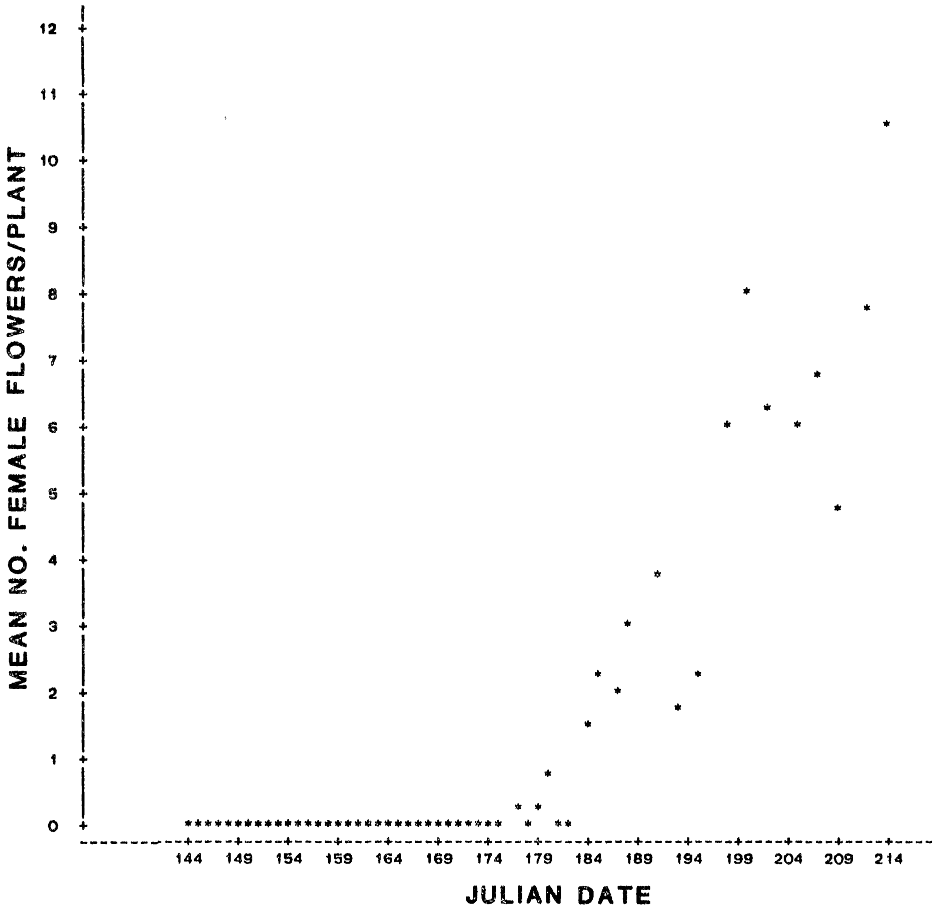

Figure 3. The Mean Number of Female Flowers/ Squash Plant Sampled by Julian Date

plant leaf area, r=0.95 and 0.92 respectively.

The appearance of immature squash fruit over the course of the season is plotted in Figure 4. A mean of 0.25 immature fruit/plant was recorded on JD 177. The mean number of immature fruit/plant rose and fell throughout the season. A peak mean number of 2.62 immature fruit occurred on JD 188. The mean numbers beyond JD 189 were less, but did fluctuate from just under 2.25 to about 0.80 immature fruit/plant. Variation between plants was expected, and these results substantiated the variation. A late season decrease in plant growth, as described previously for plant leaf area, the number of leaves, and the number of flower buds and flowers, may have also slowed fruit production. The squash bug population increased late in the season and may have affected immature fruit growth. Other problems, such as end rot, drought, and other possible disease conditions may have contributed to the decrease in immature fruit numbers late in the season. The mean number of immature fruit/plant was correlated to the mean plant leaf area, r=0.78.

Mature fruit were harvested daily from all plants remaining in the study plot. Fruit which measured approximately eight inches long and which appeared fully developed were picked. The majority of these mature fruits weighed between 200 and 400 grams ($\bar{x}$=302.00g and s=82.52g). Total seasonal yield/plant was not obtained due to plant death by disease and destructive sampling for the squash bug data late in the season. The first squash fruit were

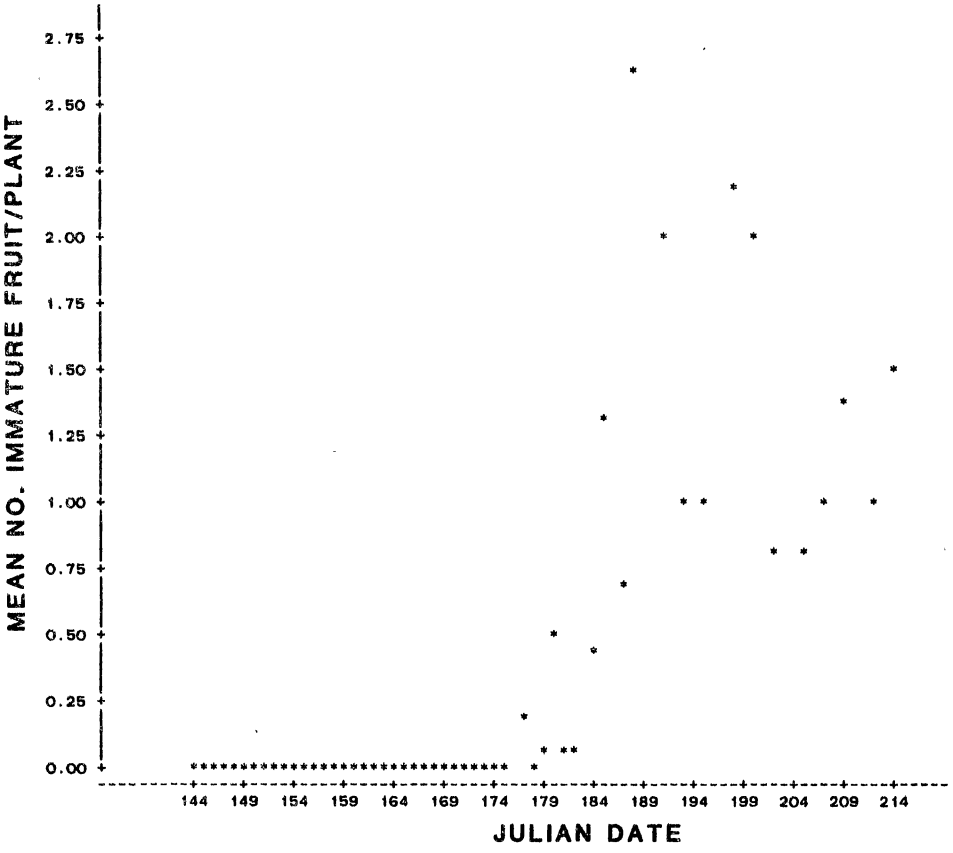

Figure 4. The Mean Number of Immature Fruit/ Squash Plant Sampled by Julian Date

harvested on JD 179 (Figure 5) when a mean of 0.01 fruit/plant was harvested. The mean number of fruit/plant reached a maximum on JD 205. Approximately 0.67 fruit/plant was sampled on this date. An earlier season peak of 0.47 fruit/plant was recorded on JD 194. A ten day decline in the mean number of fruit/plant occurred until the maximum was reached on JD 205. A decrease in the mean number of fruit/plant occurred after JD 205 until the end of sampling, JD 214. The squash bug population may not have adversely affected the plants and fruit development until after the initial peak (JD 194). Insect populations increased drastically beyond this date and may have decreased fruit production. The mean number of mature fruit/plant and mean plant leaf area were also correlated, r=0.72. Squash plant/squash bug interactions are addressed below.

Squash bug population dynamics

The squash bug population estimates were also calculated on a mean number/plant basis. The mean number of insects, including adults and nymphs within each of the five instars, is plotted in Figure 6. Total squash bug numbers/plant increased slowly at the beginning of the season. The scale of the y-axis in Figure 6 hides the fact that adults were first sampled in the field on JD 158, and first instar nymphs were initially sampled on JD 170. The mean number of insects does not appear to increase appreciably until JD 177 and 180. An apparent exponential growth in the mean number of squash

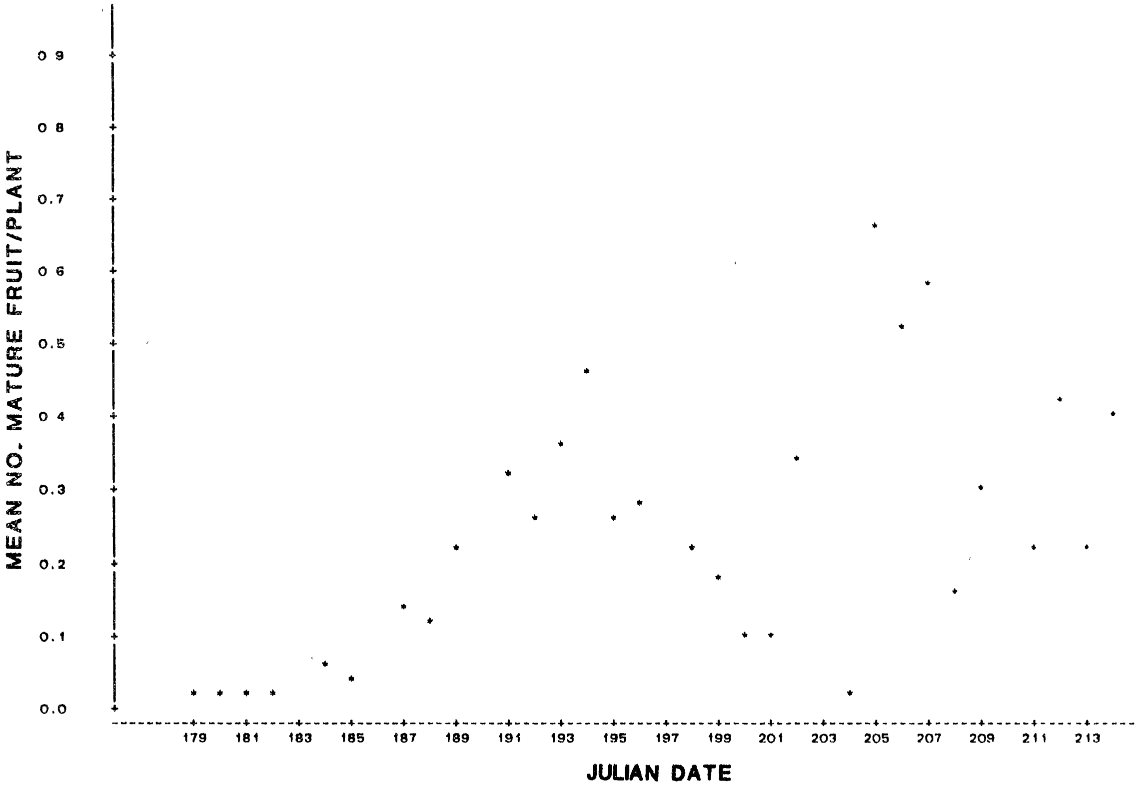

Figure 5. The Mean Number of Mature Fruit/ Squash Plant Sampled by Julian Date

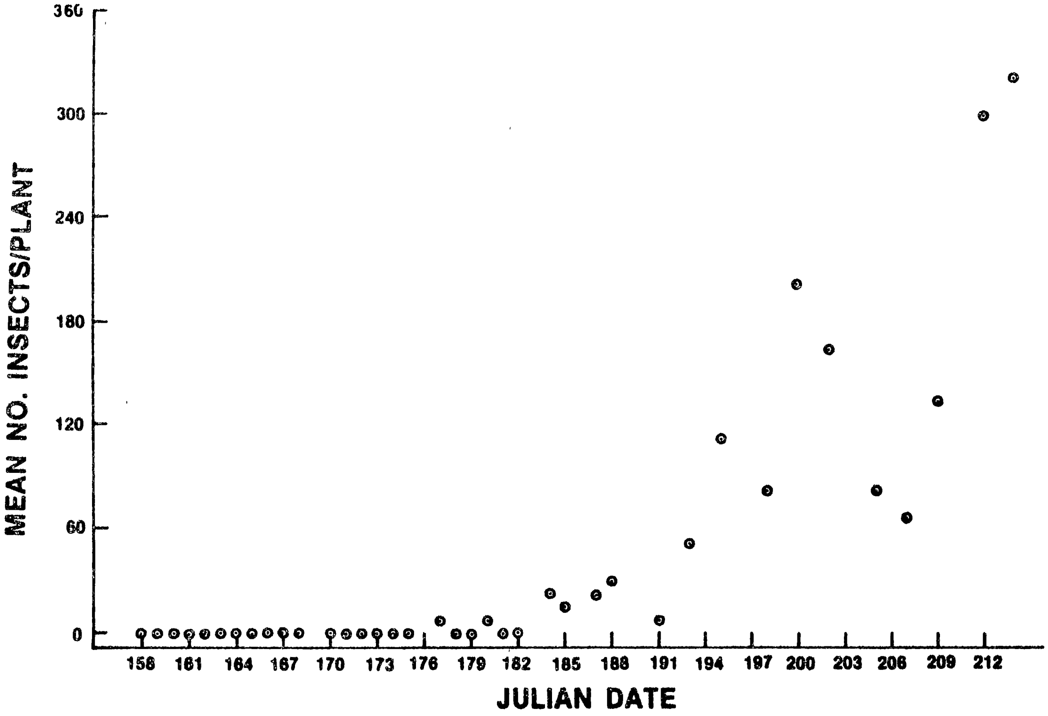

Figure 6. The Mean Number of Squash Bugs (Adults and Nymphs)/Squash Plant Sampled by Julian Date

bugs/plant began about JD 184. The very high mean numbers late in the season, 325 bugs/plant on JD 214, represented an accumulation of several generations. The decrease in mean numbers between JD 202 and 209 represented a time lag between developing squash bug generations. During this interval, the early generation nymph numbers decreased. Adult numbers were increasing but at a rate less than that of the nymphal decrease. Thus, nymphal mortality throughout the five instars was probably responsible for reducing adult numbers. Mean egg numbers/plant were increasing at this point due to the increased number of adults ovipositing eggs.

Adult male and female squash bugs were first sampled in the field on JD 158 and 159, respectively. Early season increases were slow but the mean number of adult male and female squash bugs increased at an exponential rate beginning on JD 200 (Figure 7). The numbers before this period represent the accumulation of overwintered and first generation adults. The observed exponential increase was due to the accumulation of first and second generation adults. The mean number of adults increased throughout the season, and had not reached a maximum at the conclusion of this study. Increasing adult numbers late in the season may be the result of an accumulation of first, second, and possibly third generation adults. The mean number of male adult squash bugs was generally one or two above that of the females. Such a sex ratio may help to ensure fertilization of the female adults. An actual season long sex ratio of

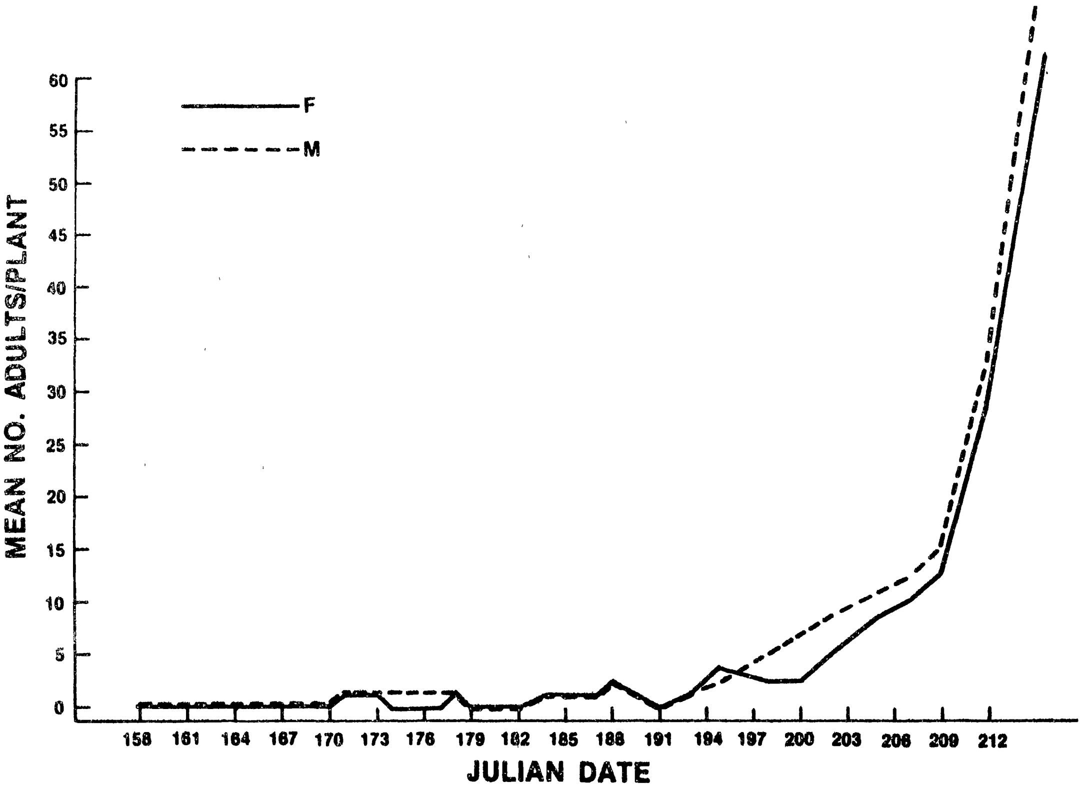

Figure 7. The Mean Number of Squash Bug Adults/ Squash Plant Sampled by Julian Date

1.15:1 male to female adults was observed (s=0.63).

The mean number of eggs/plant increased very much like the mean number of adult females/plant. Eggs oviposited by overwintered females were first observed in the field on JD 159. Egg numbers increased slowly early in the season (Figure 8), paralleling the adult female trend. The mean number of eggs/plant increased drastically beginning about JD 203. The mean number of eggs increased similarly to that of the mean number of females, but 2-3 Julian dates later. Female ovarian development appears to be completed during these intervening days (Beard 1940). The exponential increase in the mean number of eggs/plant occurred due to the simultaneous occurrence of late first and second generation females. Similar to the mean adult numbers, the mean number of eggs/plant reached a maximum on the final day of sampling. An average of 1400 eggs/plant was counted. Larger mean egg numbers beyond JD 214 are probable in the field.

The seasonal trend of the mean number of eggs/female adult squash bug/plant differed from those squash bug parameters already discussed. Early in the season the mean number of eggs/female/plant was around nine. An increase, reaching a peak of 55 eggs/female/plant, occurred between JD 161 and 164 (Figure 9). Figure 9 is a sliding average plot taken over five Julian days. This oviposition was due to the overwintered population. A decline in the mean number of eggs/female/plant followed until JD 170. An additional increase in the mean number of eggs/female/plant was observed

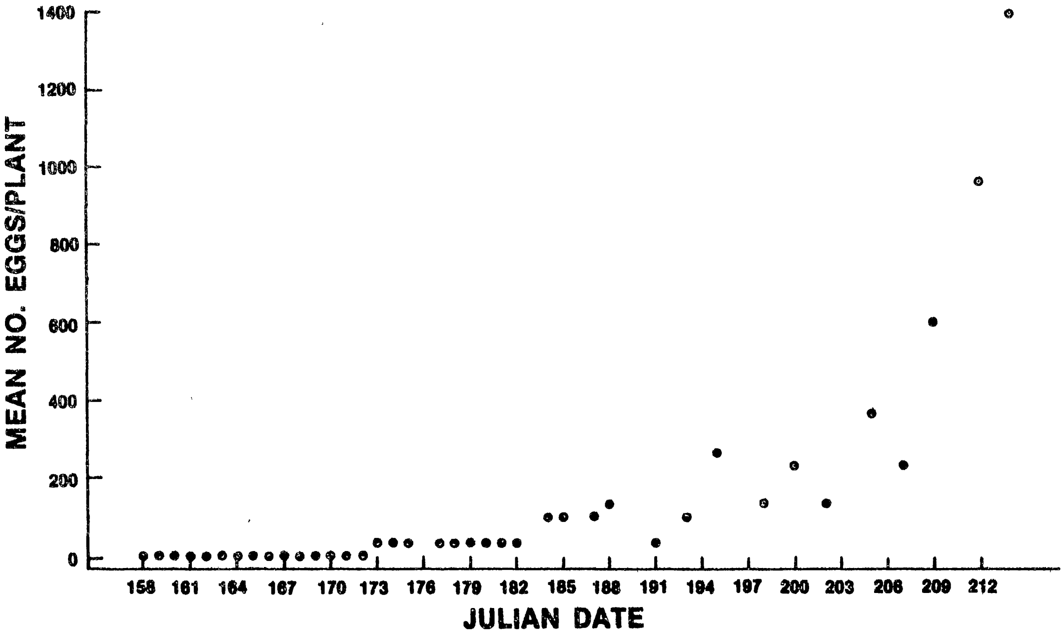

Figure 8. The Mean Number of Squash Bug Eggs/ Squash Plant Sampled by Julian Date

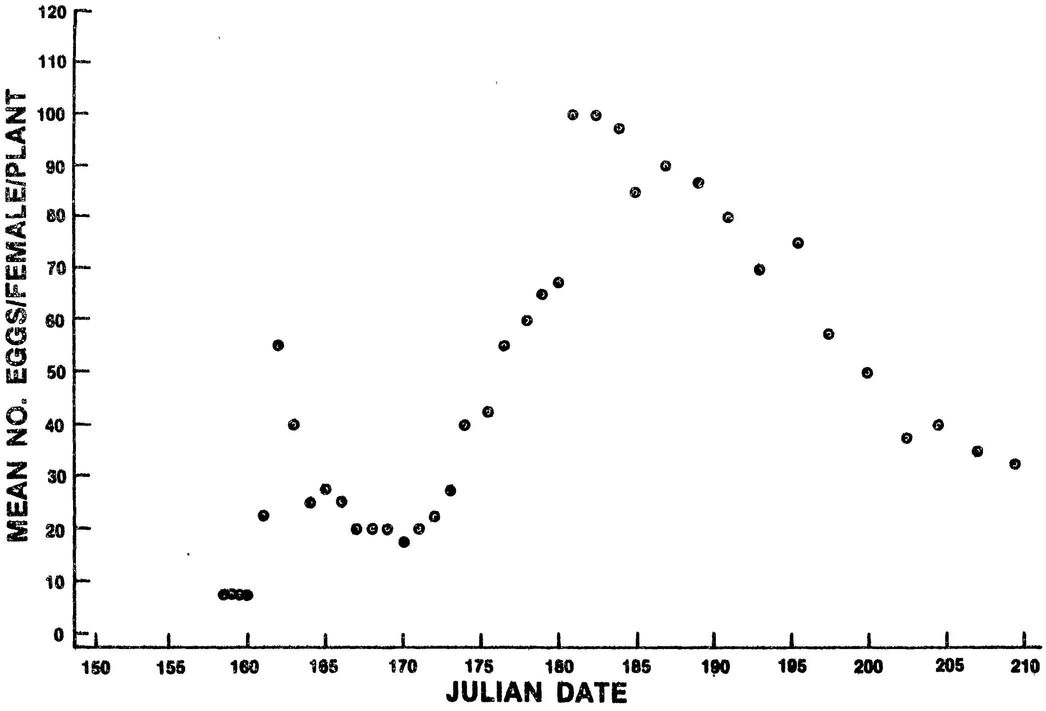

Figure 9. The Mean Number of Squash Bug Eggs/Female/Squash Plant Sampled by Julian Date

from JD 171 to 183. This increase was probably attributable to first generation females. A maximum of 100 eggs/female/plant was recorded on JD 183. The mean number of eggs/female/plant decreased over the remainder of the season, ending up near 30 eggs/female/plant. Overwintered females appeared to oviposit many eggs early in the season. The first peak, which occurred between JD 161 and 164, corresponded to this event. First generation females along with overwintered females also continued to oviposit many eggs. The second peak, JD 183, corresponds to this ovipositional trend. The early to mid-season decrease in the number of eggs/female/plant occurred prior to the development of the first generation females and was due to a decline in oviposition by the overwintered females. Later in the season the number of eggs/female/plant decreased. Since the mean number of females and eggs increased through the end of the sampling period, females late in the season oviposited fewer eggs than those females which occurred earlier. Although the number of females/plant increased late in the season, oviposition may have declined due to poor host plant quality. The lack of oviposition by females preparing to overwinter may have also reduced the number of eggs oviposited/female.

The increased numbers of squash bug adults and subsequent eggs throughout the growing season, led to an increase in the mean number of nymphs/plant (Figure 10). First instar nymphs were initially sampled on JD 170, while second, third, fourth, and fifth instar nymphs were first

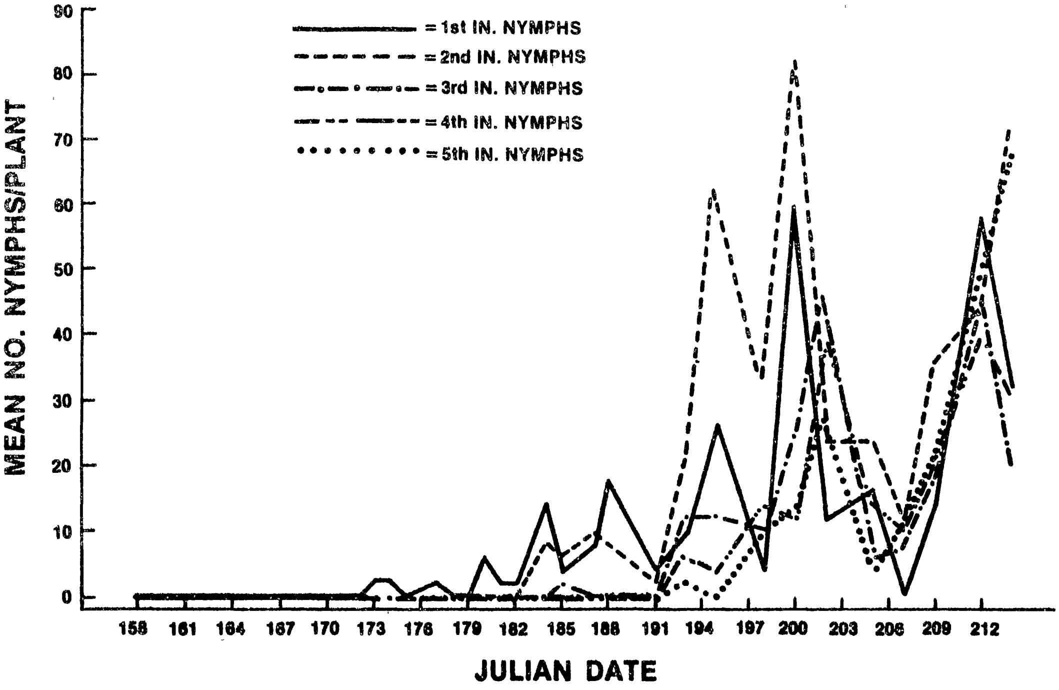

Figure 10. The Mean Number of Squash Bug Nymphs (All Instars)/Squash Plant Sampled by Julian Date

sampled on JD 171, 173, 179, and 180 respectively. Increases in the mean numbers of various nymphal instars occurrred repeatedly and at different times during the growing season. Initially, the number of first instar nymphs increased. As the early first instar nymphs molted into second instar nymphs, the number of first instar nymphs decreased and the second instar numbers increased. In addition, continued egg hatch again increased the number of first instar nymphs, while the number of third instars increased due to molting of the second instar nymphs. The development trend between successive nymphal instars occurred among all instars and throughout the season. Variation in development times within instars also expanded the bases of the peaks in Figure 10. The saw-blade shaped curve is attributed to nymphal development trends. The total number of instars present decreased between JD 205 and 207. The majority of first generation nymphs completed development at this time and molted into adults. Adult numbers increased dramatically at this point of the season (Figure 7). Excessive irrigation on JD 205 may have contributed to a decreased nymphal population. Beyond JD 207, the second generation nymphs developed and peaks were reached from JD 210-214. The second generation nymphs which developed early in the season may have led to a partial third generation of nymphs and adults.

Squash bug effects on the host squash plant

Some of the squash bug/squash plant interactions have been examined. Squash bug feeding on the plant leaves, which might result in foliar damage, could reduce overall plant photosynthesis. Squash plant physiological processes and growth could be reduced in a situation of reduced photosynthesis. The development of flower buds, flowers, immature fruit and mature fruit may be slowed or reduced over a growing season due to a squash bug induced reduction in photosynthesis.

Early season squash bug damage was concentrated on the leaves. Damaged leaves, being wilted or dried, may have caused a decrease in photosynthesis, which over the season could have reduced fruit yield. Insect density (number of squash bugs/m^2 of plant leaf area) was an indicator of potential leaf damage in the field. The mean insect density increased steadily throughout the season (Figure 11). Figure 11 is a sliding average plot taken over five Julian days. A peak mean of 5.5 insects/m^2 of plant area was reached on JD 207. The mean number of squash bugs/m^2 of plant area decreased slightly toward the end of the study. Early in the season, up to approximately JD 185, the squash plant leaf area increased faster than the squash bug numbers. The mean insect density therefore increased at a slow rate up to this date. The mean insect density increased beyond this point in the season, and squash plant leaves became heavily damaged. Squash plant reproductive structures, especially marketable fruit, could have been indirectly damaged by a reduction in leaf area and quality. The mean squash plant leaf area and

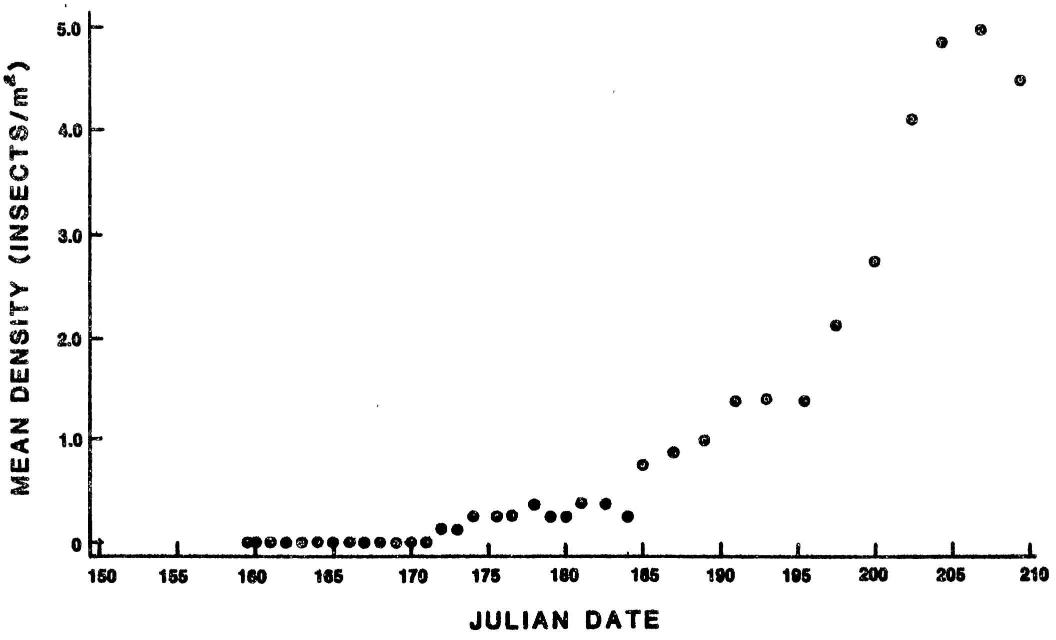

Figure 11. The Mean Insect Density Sampled by Julian Date

the mean squash bug density were correlated, r=0.85. The mean squash plant leaf area and the mean nymph density/plant were more highly correlated, r=0.87. Nymphs, especially congregated first and second instars, were observed to greatly damage the plant foliage. These correlations probably relate more directly to environmental conditions influencing the growth of both populations. Damage to the plants increased as the insect numbers increased later in the season. Squash plants planted early may be imparted some ecological resistance by evading the large squash bug populations.

The squash plant reproductive parameters were affected by the squash bug population. Similar to the mean plant leaf area, the mean number of male and female flower buds and flowers decreased late in the season corresponding to the large increase in squash bug numbers. Early in the season, both the number of flower buds and squash bugs were increasing. A maximum mean of 210 male flower buds/plant was recorded when a mean of 162 squash bugs/plant, nymphs and adults, was present in the field (Figure 12). The mean number of squash bugs/plant increased while the mean number of male flower buds/plant decreased. The mean number of female flower buds reached a maximum of 148 when a mean of 140 squash bugs was present on the plant (Figure 13). The number of female buds decreased as the number of squash bugs increased. The mean number of squash bugs/plant and the mean numbers of male and female flower buds were correlated,

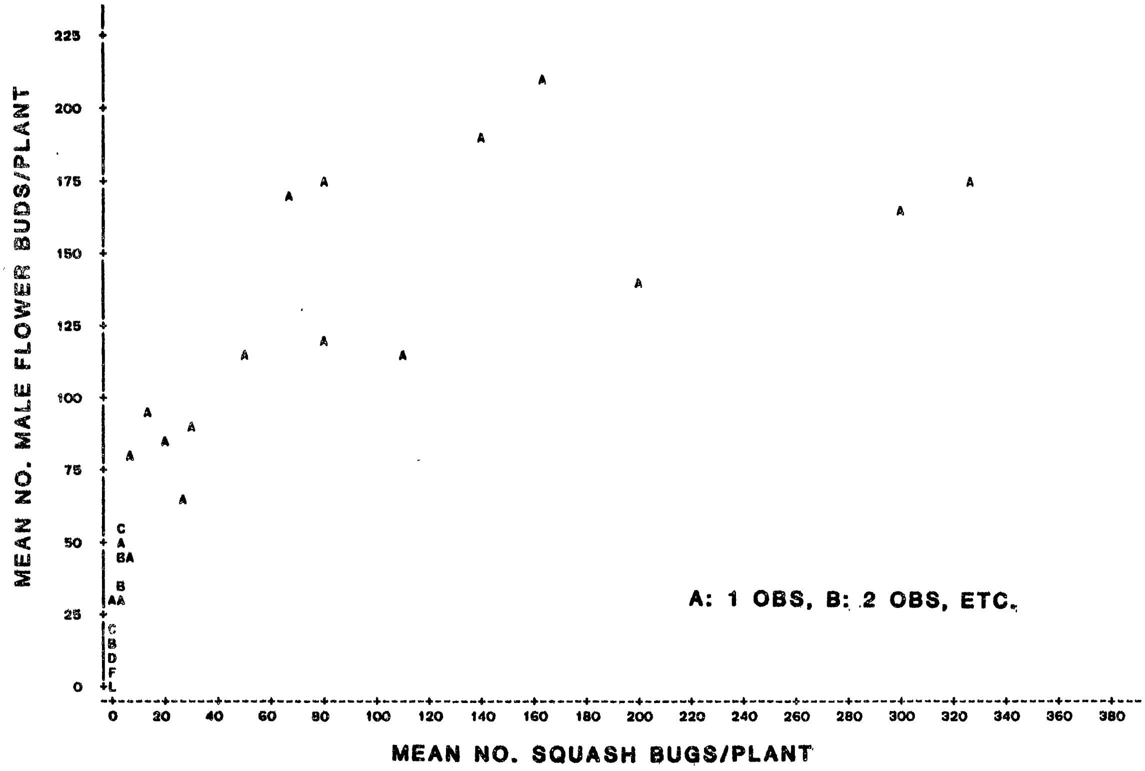

Figure 12. Relationship of the Mean Numbers of Male Flower Buds and Squash Bugs/ Squash Plant

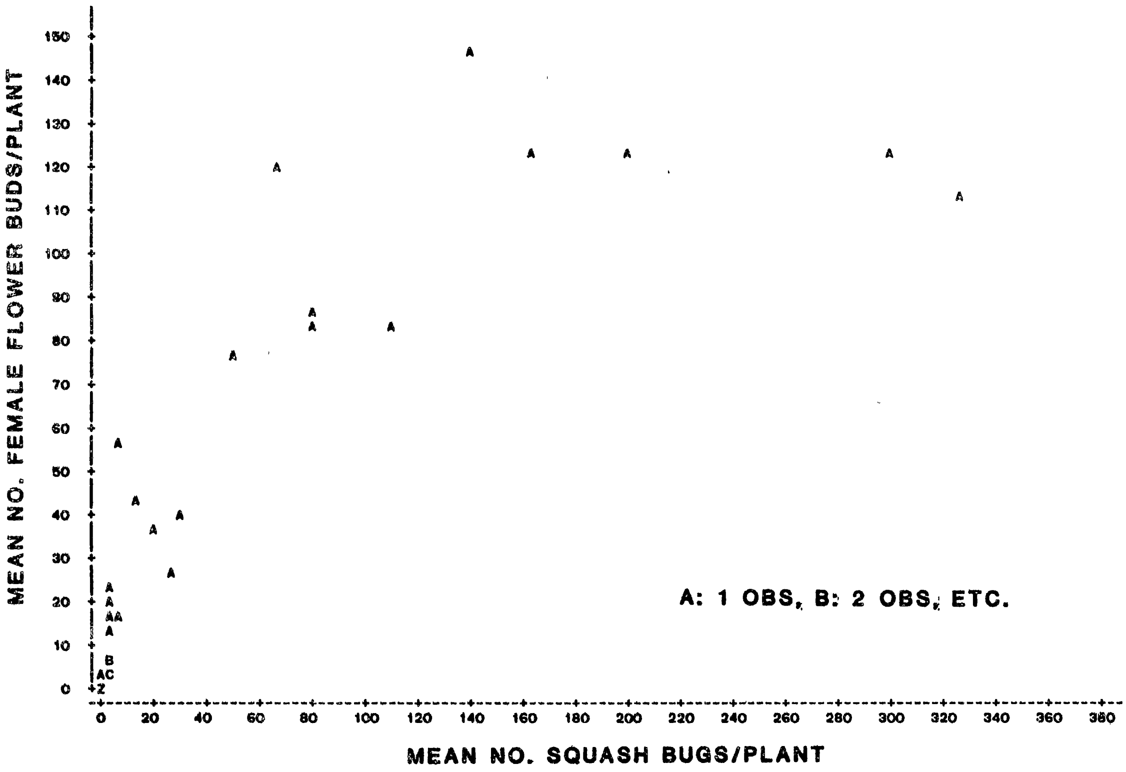

Figure 13. Relationship of the Mean Numbers of Female Flower Buds and Squash Bugs/ Squash Plant

r=0.75 and 0.78 respectively. Feeding pressure of the squash bug population on the squash plants may have reduced the number and development rate of male and female flower buds.

The male and female flower numbers were affected by the squash bug population in much the same manner as the flower bud numbers. The mean number of flowers and squash bugs increased early in the season. A maximum mean of 61 male flowers/plant was reached when a mean number of 140 squash bugs was present. The mean number of male flowers/plant decreased as the squash bug mean number increased to over 300/plant. The mean number of female flowers/plant increased as the mean number of squash bugs/plant increased. A maximum mean of 10.5 female flowers/plant was present in the field when a mean of 325 squash bugs/plant was also present. The mean number of squash bugs/plant was highly correlated with the mean number of male and female flowers/plant, r=0.86 and 0.85 respectively. Squash bug feeding on the squash plants may have reduced the number and growth of the male and female flowers.

In addition, the mean number of immature fruit/plant decreased throughout the season as the mean number of squash bugs increased (Figure 14). A maximum mean number of 2.62 immature fruit/plant corresponded with a mean number of 30 squash bugs/plant. The mean number of immature fruit decreased the remainder of the season, while the mean number of squash bugs increased. The mean numbers of squash bugs and immature fruit/plant were not highly correlated, r=0.28.

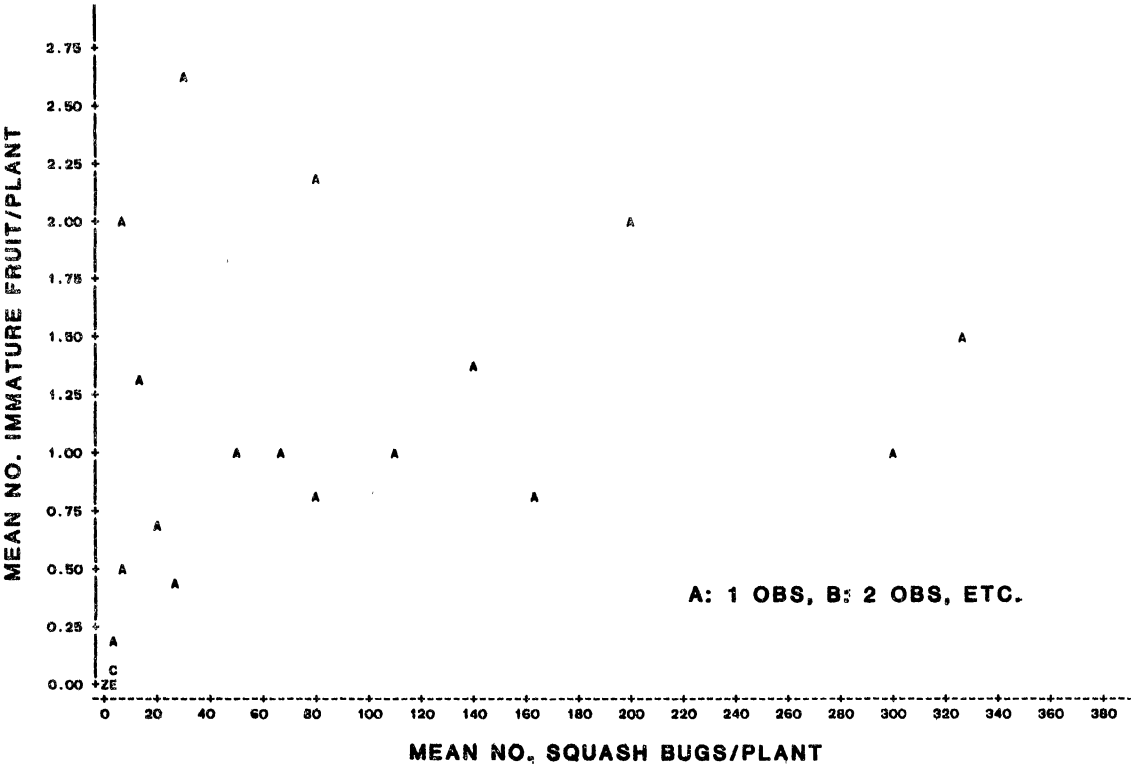

Figure 14. Relationship of the Mean Numbers of Immature Fruit and Squash Bugs/ Squash Plant

The mean number of mature fruit/plant was of special interest because of the economic value of the fruit. The mean numbers of mature fruit and squash bugs increased early in the season. The maximum mean of 0.67 fruit/plant was reached when an average of 82 squash bugs was sampled/plant. The mean number of fruit declined as the mean number of squash bugs increased to over 100/plant (Figure 15). A decrease in the mean number of fruit/plant late in the season paralleled the dramatic increase of squash bugs. The mean number of fruit/plant may have decreased due to direct squash bug feeding on the fruit. Mean daily fruit weight yield also decreased late in the season (Figure 16). A mid-season peak of 108 grams of fruit/plant was reached on JD 193. A decline in mean fruit weight/plant occurred between JD 194 and 201. The mean numbers of squash bug nymphs and adults increased during this same period (Figure 7 and 10), and may have damaged fruit production. A later season peak of 139 grams of fruit/plant was reached on JD 207. The mean number of nymphs/plant decreased at this point in time. Feeding stress by the nymphs may have decreased at this point, allowing an increase in mean fruit weight. The late season decrease in mean fruit weight yield corresponded to the large increase in mean squash bug numbers. Cumulative mean fruit weight yield/plant increased throughout the season (Figure 17). Plateaus occurring around Julian dates 197 and 202, and late in the season, corresponded to the decreases in daily mean fruit weight yield/plant discussed above. Squash bug feeding

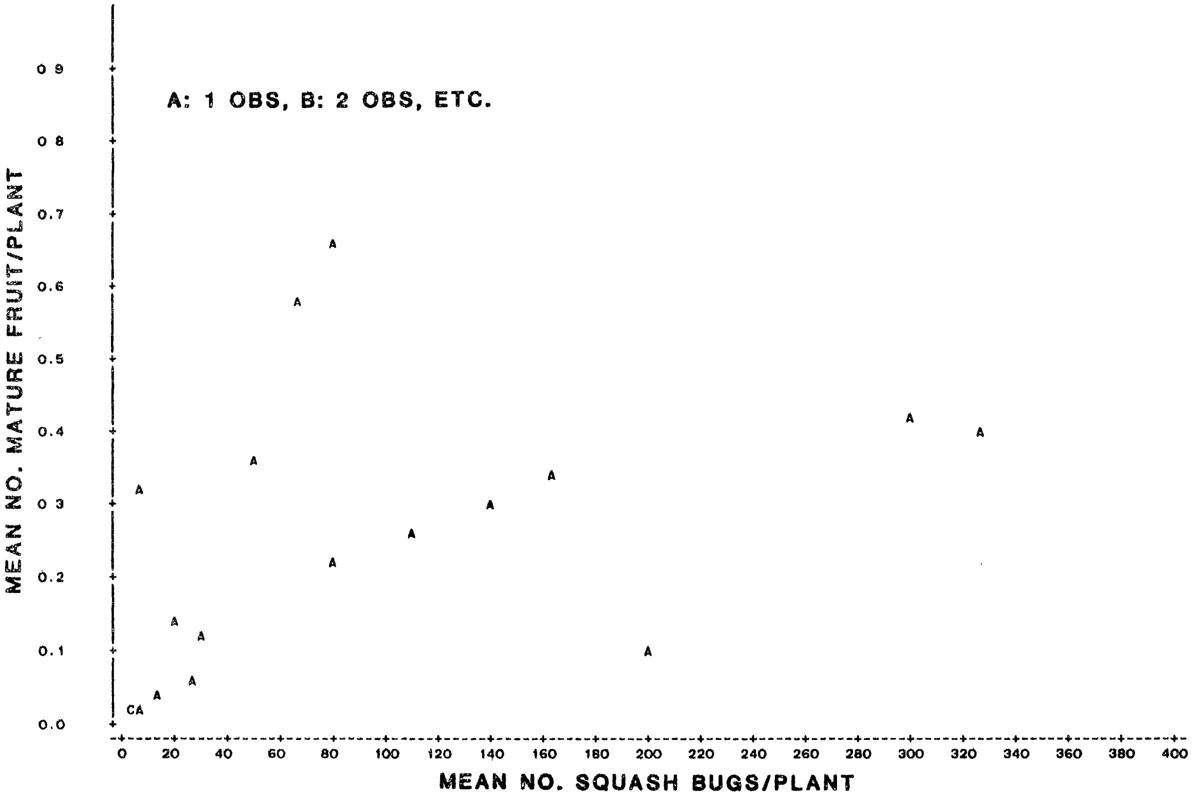

Figure 15. Relationship of the Mean Number of Mature Fruit and Squash Bugs/Squash Plant

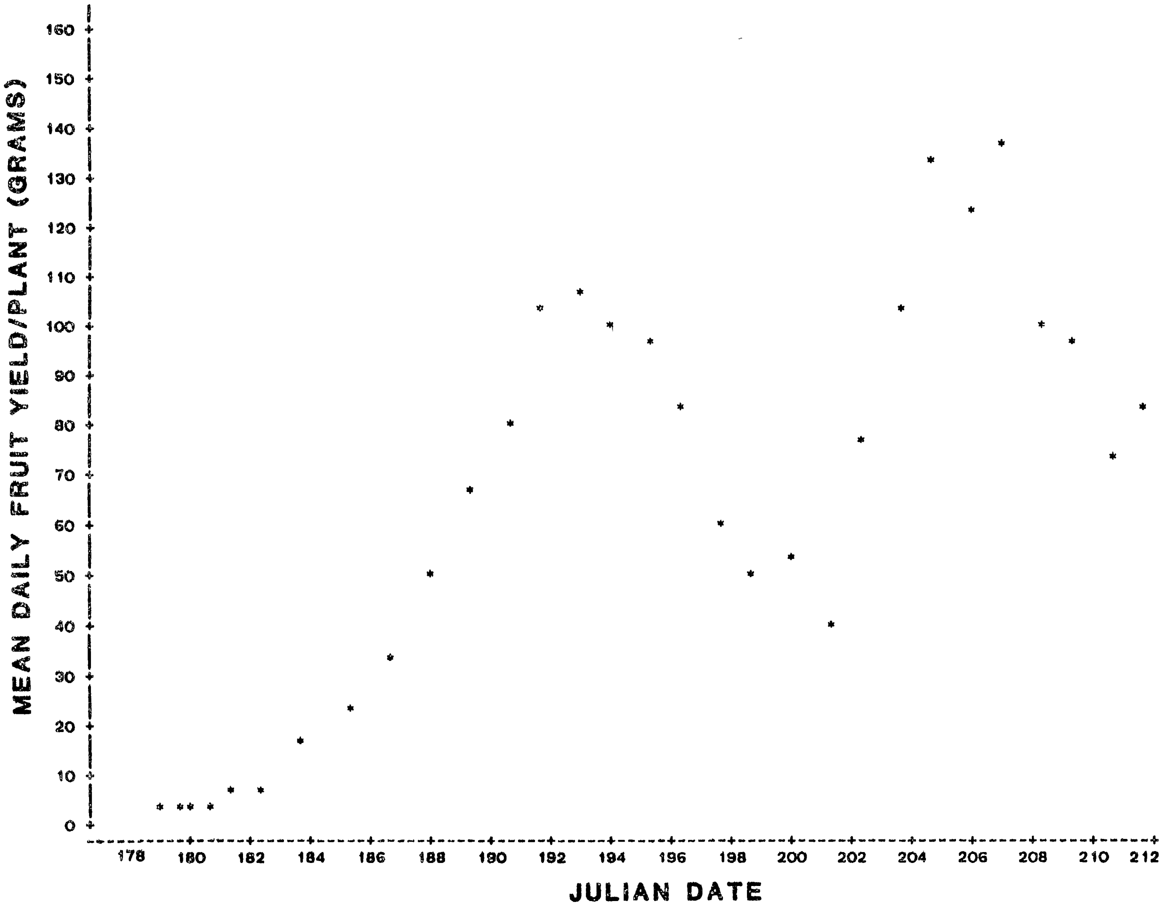

Figure 16. Mean Daily Fruit Yield/Squash Plant

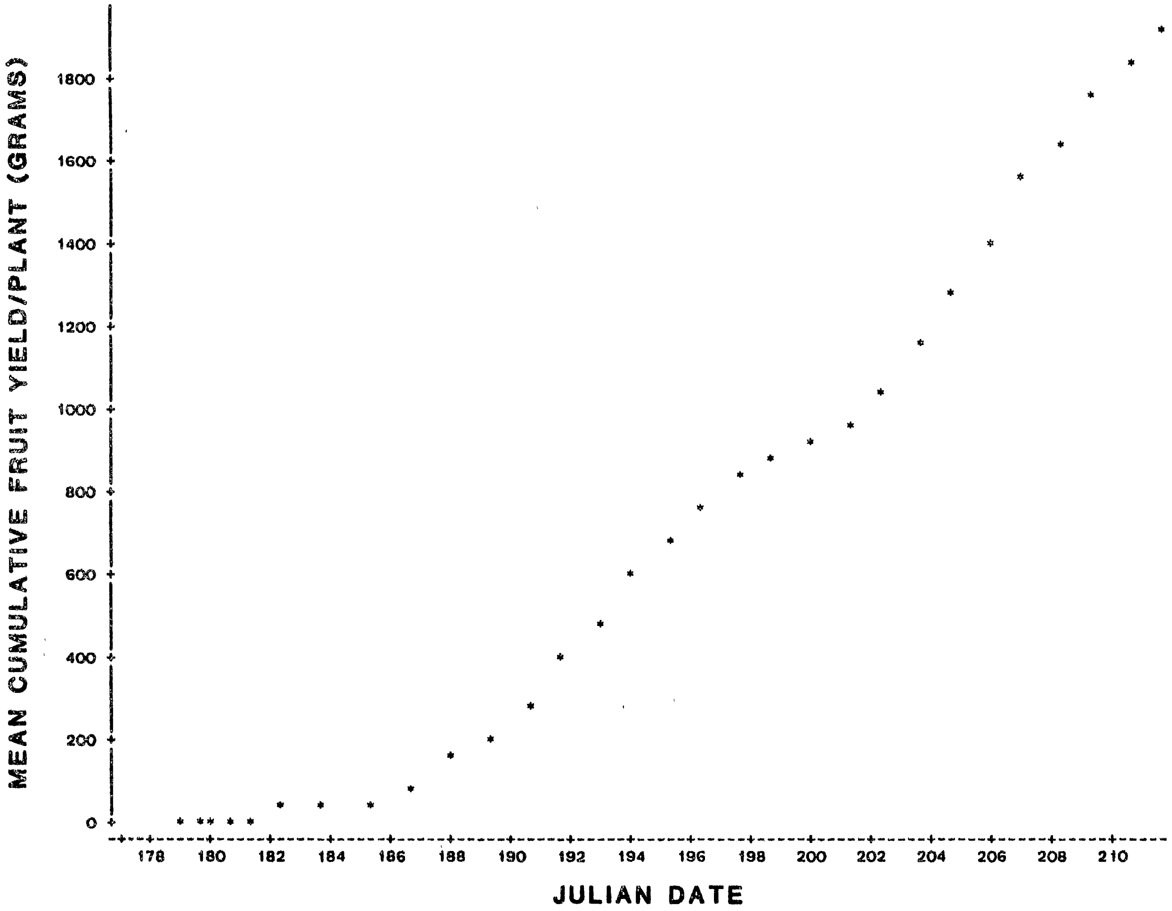

Figure 17. Mean Cumulative Fruit Yield/Squash Plant

damage to the leaves, resulting in a reduction of photosynthesis, may have also indirectly reduced fruit numbers and yield weights.

Environmental impact on the squash bug/squash plant system

Correlations between specific environmental factors and squash bug or squash plant growth and development were difficult to make. Appendix B contains an example of a computer file used to store and analyze weather data. Squash bug numbers and squash plant growth, particularly plant leaf area and flower bud and flower numbers, increased as the season progressed. Temperature and photoperiod increases were probably responsible for this increased growth. A seasonal average daily temperature (minimum plus maximum temperature divided by two) of approximately 26.5°C was calculated beyond JD 158 (Figure 18). The early season temperature average was lower, about 20°C, and several minimum daily temperatures were quite cool. Temperature data (Figure 18) is presented as a five day sliding average. Squash bug oviposition and nymphal development accelerate at higher temperatures (Beard 1940). Increasing photoperiod and/or temperature may be responsible for stimulating squash bug adults to leave overwintering sites, while decreasing photoperiod and/or temperature may stimulate second and/or third generation adults to seek overwintering sites. Daily photoperiod reached a maximum of 16.25 hours between Julian dates 170 and 177 (June 18-25). Early season increases and

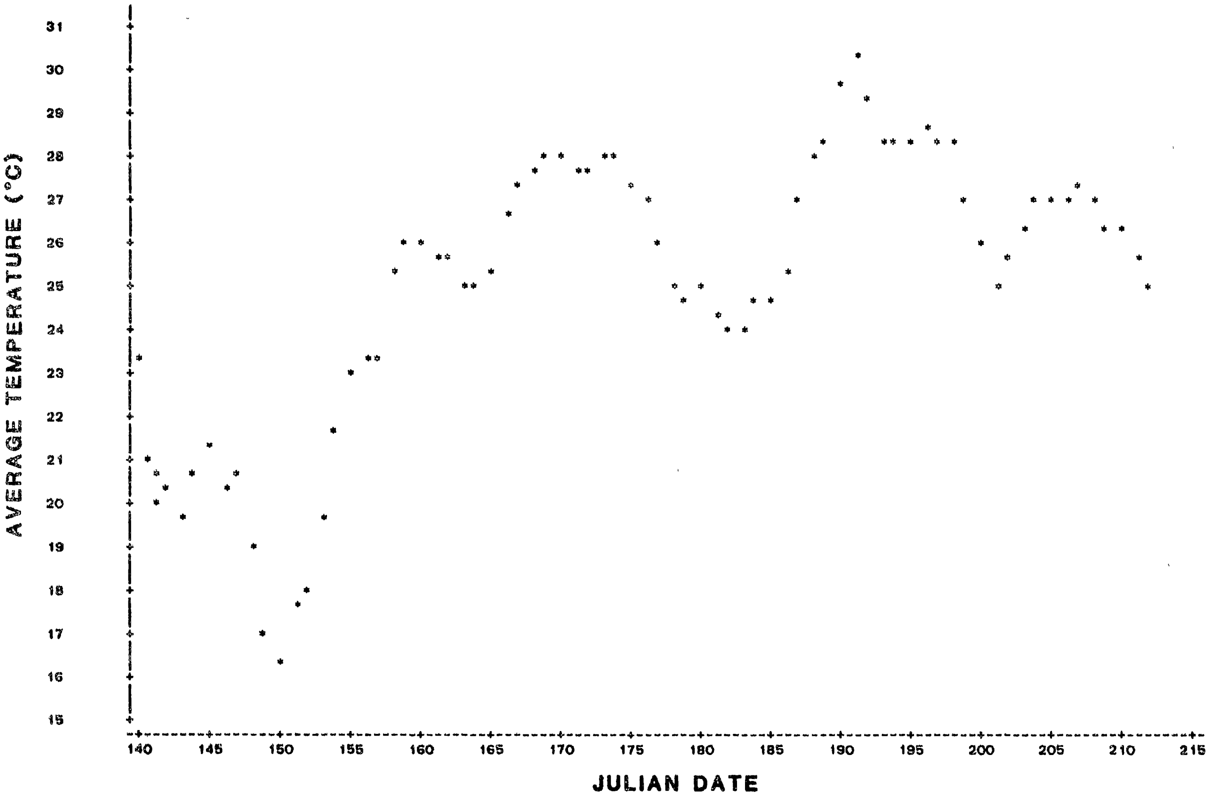

Figure 18. Average Daily Temperature-Perkins 1984

late season decreases in photoperiod were quite apparent (Figure 19). Adult squash bugs were not observed in the field until the photoperiod had reached 16.15 hours. Temperature and photoperiod varied little over the course of the season. However, a period of high temperatures may have helped cause an increase in the mean number of nymphs/plant between JD 192 and 198 (Figure 10).

Rainfall and irrigation levels may have had a more direct effect on squash bug numbers. A 10.16 cm (four inch) rain and irrigation total on JD 178 may have increased nymphal mortality and reduced the mean number of nymphs for a day or two (Figure 10). First instar nymphs can be easily dislodged from a plant by rainfall or irrigation. Heavy irrigation totals on JD 191 and 205 may have also decreased the mean number of nymphs/plant for a short time period. However, late season increases in the mean number of nymphs and adults/plant seemed to nullify the effects of precipitation and temperature extremes earlier in the season. The effect of the environment on the squash bug and squash plant populations may only be detrimental when extremes in temperature and precipitation occur.

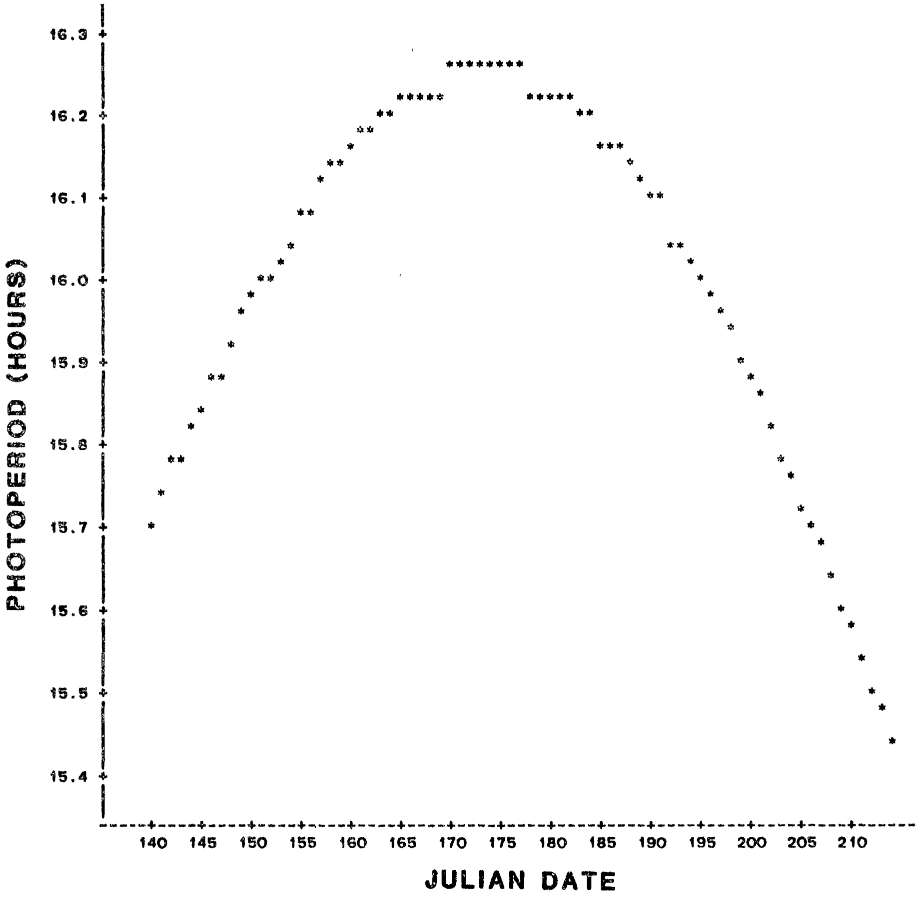

Figure 19. Daily Photoperiod-Perkins 1984

CHAPTER V

SUMMARY AND CONCLUSIONS

Squash plant, Cucurbita pepo variety Hyrific, seasonal development and squash bug, Anasa tristis, population dynamics were monitored during the spring and summer of 1984. Research was conducted at the O.S.U. Horticulture/Agronomy Research Station near Perkins, Oklahoma. Squash plant development was monitored by estimating daily plant leaf area, counting reproductive structures, and maintaining yield records. The squash bug population dynamics were monitored by counting the number of egg masses, total eggs, total nymphs in each of five instars, and male and female adults. Mean numbers/plant were calculated for all the various growth parameters of both the squash plant and bug. Seasonal squash bug population trends and changes in relation to the host plant development were monitored. Environmental factors were recorded and related to the developmental components.

Growth and development of the squash plant increased throughout the season. Mean plant leaf area and the number of leaves increased slowly early in the season, faster through mid-late season, and slowed again late in the season. A sigmoid-shaped growth curve resulted. The development of flower buds, flowers, and immature and mature fruit also followed a sigmoid-shaped growth curve throughout the season. Mean leaf area changes over the season affected the eventual development of buds, flowers, and fruit.

Squash bug population parameters also increased throughout the season. Overwintered adult females oviposited large numbers of eggs early in the season. The first generation nymphs and adults increased the overall number of squash bugs in the field. The development of second generation nymphs and adults caused a drastic increase in the total number of squash bugs present. The total number of squash bugs, adults, and eggs in the field increased at an exponential rate beginning about JD 192. These parameters may not have reached a peak when this study was concluded. Females late in the season appeared to oviposit fewer eggs/plant than overwintered or first generation females. Poor host quality late in the season, or a reduction of reproducing adult female numbers due to the beginning of overwintering, may have caused this reduction in the mean number of eggs/female/plant.

The yearly life history of the squash bug can best be summarized by the use of a flowchart (Figure 20). Unmated, overwintered adults are triggered by an environmental stimulus, such as photoperiod and/or temperature, to leave overwintering sites. Early in the season the stimulus may not be reached and overwintering continues (loop 1, Figure 20). If the stimulus is reached, adults mate and eggs are laid. These eggs develop into first generation nymphs and

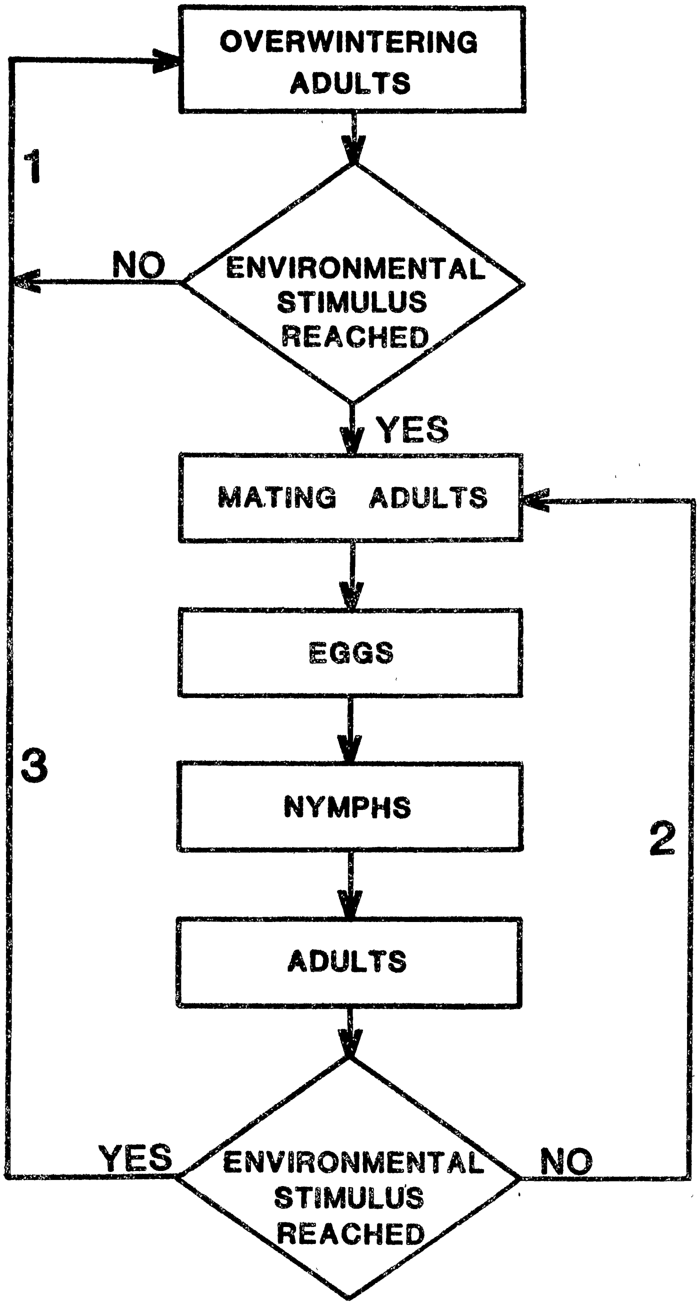

Figure 20. Flowchart Diagramming the Yearly Life History of the Squash Bug

adults. First generation adults mature early in the season and will not be stimulated to overwinter (loop 2, Figure 20). In more northern areas, first generation adults will be stimulated to overwinter (loop 3, Figure 20). A second generation develops in a similar manner. Second generation adults which develop early in the season, before an overwintering stimulus is reached, will mate and oviposit eggs which may lead to a third generation. Some second generation adults will develop late in the season, after an environmental stimulus is reached, and will overwinter. There are generally two complete generations of the squash bug/season in Oklahoma. Favorable environmental conditions will often stimulate the development of a partial or complete third generation. Two and three generations of the squash bug/season account for the devastating numbers of bugs late in the season.

Large numbers of squash bugs late in the season affected the squash plants and eventual fruit harvest. Feeding damage by the squash bugs on the leaves reduced the rate of photosynthesis and overall plant growth. Direct feeding of large numbers of bugs on immature and mature fruit increased late in the season. Plant growth and development increased early in the season. Plant growth declined as squash bug numbers increased later in the season. Squash plants planted early in the season may be afforded some temporal resistance by completing the majority of development before squash bug numbers increase drastically.

An understanding of squash bug and squash plant populations and their interactions will make an integrated control management plan possible. Initial field research into the squash bug/squash plant system was important. Further studies are needed to quantify potential squash bug damage on squash and other cucurbit plants. A known number of squash bugs on a plant, and resulting damage done to the plant, will better define the economic threshold of the squash bug. Early season seedings of squash plants may give the plants an early start in development over the squash bugs. Although control of the squash bug has been and still is difficult, an understanding of squash bug population dynamics and its effect on the squash plant, may expose weak links in the life history of the squash bug. Effective squash bug/squash plant management must be aimed at these weak links in order to effectively control the squash bug.

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APPENDIX A

MEAN GROWTH PARAMETERS DATA FILE

JD	MIN1	MIN2	MIN3	MIN4	MIN5	MMA	MFA	MEGGS	MMASS	MLVS	MMFB	MFFB	MMF	MFF	MIFR	MMFR	MPLA
144	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
145	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.25
146	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.54
147	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.00	1.73
148	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.00	0.00	0.00	0.00	0.00	0.00	2.97
149	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0 00	0.00	0.00	0.00	0.00	2.53
150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05	0.00	0.00	0.00	0.00	0.00	0.00	3.91
151	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.71	0.00	0.00	0.00	0.00	0.00	0.00	7.88
152	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.83	0.00	0.00	0.00	0.00	0.00	0.00	11.74
153	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00	0.00	22.94
154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.60	0.00	0.00	0.00	0.00	0.00	0.00	22.25
155	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.29	0 00	0.00	0.00	0.00	0.00	0.00	32.90
156	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.82	4.05	0.00	0.00	0.00	0.00	0.00	44.45
157	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.24	4.32	0.00	0.00	0.00	0.00	0.00	58.70
158	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	4.48	4.32	0.00	0.00	0.00	0.00	0.00	70.76
159	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.28	0.04	5.00	4 96	0.00	0.00	0.00	0.00	0.00	92.46
160	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.40	6.56	0.00	0.00	0.00	0 00	0.00	104.05
161	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.32	8.20	0.00	0.00	0.00	0.00	0.00	202.67
162	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	6.72	6 88	0.00	0.00	0.00	0.00	0.00	315.16
163	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.08	7.28	8.88	0.08	0.00	0.00	0.00	0.00	456.25
164	0.00	0.00	0 00	0.00	0.00	0.17	0.08	3.96	0.25	8.17	10.75	0.29	0.00	0.00	0.00	0.00	781.96
165	0.00	0.00	0.00	0.00	0.00	0.36	0.20	7.00	0.40	8.44	11 40	0.00	0.00	0.00	0.00	0.00	660.04
166	0.00	0.00	0.00	0.00	0.00	0.48	0.24	1.84	0.20	9.60	13.68	0.12	0.00	0.00	0.00	0.00	1367.40
167	0.00	0.00	0.00	0.00	0 00	0 08	0.12	4.20	0.36	9.96	16 40	0.52	0 00	0.00	0.00	0.00	2138.38
168	0.00	0.00	0.00	0.00	0.00	0.40	0.24	4.72	0.36	11.20	18.52	0.68	0.00	0.00	0.00	0.00	2864.31
169	0.00	0.00	0.00	0.00	0.00	0.24	0 20	3.32	0.32	12.20	18.80	0.52	0.00	0.00	0.00	0.00	3166.03
170	0.20	0.00	0.00	0.00	0.00	0.16	0.08	4.60	0.44	12.64	21.20	0 48	0.00	0.00	0.00	0.00	3459.48
171	0.28	0.08	0.00	0.00	0.00	0.96	1.04	16.36	1.20	15.28	32 08	2.60	0.00	0.00	0.00	0.00	11122.51
172	0.00	0.00	0.00	0.00	0.00	0.88	0.76	9.04	0.76	16.32	31.64	1.88	0.00	0.00	0.00	0.00	9890 18
173	1.36	0.04	0.04	0.00	0.00	0.96	0.80	23.04	1.52	17.80	33.32	3.28	0.08	0.00	0.00	0.00	17227 19
174	1.36	0.52	0.00	0.00	0.00	0.84	0.56	20.36	1.24	17.36	34.04	3.04	0.16	0.00	0 00	0.00	13498.42
175	0.08	0.16	0.00	0.00	0.00	0.96	0.72	37.72	2.44	19.48	44.76	7.12	0.52	0.00	0 00	0.00	26203.84
177	2.72	0.04	0.00	0.00	0.00	1.00	0.56	45.88	2.68	20.72	46.32	8.28	1 40	0.32	0.16	0.00	32252.76
178	0.00	0.00	0.00	0.00	0.00	0.92	1.31	44.85	2.38	22.08	54.00	15.77	2.54	0.08	0.00	0.00	39752.87
179	0.20	0.36	0.76	0.04	0.00	0.44	0 36	40.72	2.84	22.32	50 80	12.80	1 68	0.24	0.04	0.00	33752.50
180	6.08	0.33	0.17	0.00	0.00	0 50	0.50	41.75	2.08	23.08	47.08	17.25	3.58	0.75	0.50	0.00	45353.41
181	1.38	0.38	0.00	0.00	0 00	0.62	0.54	40.62	2.08	24.77	54.62	21.46	4.08	0.08	0.08	0.00	58595.40
182	2.00	0.17	0.58	0.00	0.00	0.50	0.42	43 08	2.33	24.83	57.42	24.00	3.58	0.08	0.08	0.00	55374.18
184	14.54	7.31	0.62	0.69	0.00	1.38	0.92	108.08	6.08	28.92	66.00	27.54	7.15	1.38	0.46	0.15	89499.09
185	4.67	6.83	1.08	0.00	0.00	1.25	0 92	93.17	6.08	30.58	93.67	43.00	9.92	2.33	1.33	0.00	113494 63
187	8.40	10.30	0.00	0.10	0.00	1.50	1.30	109.80	6.10	29.90	84 30	37.40	9.70	2.10	0.70	0.20	88295.86
188	17.70	8.30	0.00	0.10	0.00	2.40	2.30	143.20	7.80	32.30	88.80	39.10	14.90	3.00	2.60	0.20	147614.71
191	4.80	1.80	0.80	0.20	0.00	0.20	0.00	34.20	3.00	33.20	80.40	57.20	16.80	3.80	2.00	0.00	75603.40
193	9.20	21.20	11.80	5.00	1 00	1.40	1.00	107.20	6.20	37.20	117.00	78.00	22.00	1.80	1.00	0.80	169385.92
195	26.60	61.60	12.60	3.00	0.20	2.60	3.40	255.40	14.40	35.40	116.80	82.60	33.40	2.20	1.00	0.20	141512.41
198	4.40	33.80	9.60	14.40	10.80	4.40	3.00	134.60	7.20	38.40	173.20	83.80	25.60	6.00	2.20	0.20	125193.97
200	59.80	82.20	26.00	12.60	13.40	2.80	3.00	245.80	12.40	45.40	141.80	124 60	38.80	8.00	2.00	0.20	295484.32
202	11.40	24.20	46.20	40.40	26.00	9.20	5.00	138.80	8.60	45.00	208.80	123.20	36.80	6.20	0.80	0.60	223802 39
205	16.60	23.40	6.00	13.60	3.00	9.00	8.80	378.00	20.20	45.00	120.80	88.20	35.60	6.00	0.80	0.80	176595.90
207	0.80	11.60	7.80	10.40	12.40	12.00	10.40	237.60	11.40	43.20	167.80	119.00	46.40	6.80	1.00	0.80	225516.91
209	13.60	35.80	18.80	20.20	21 80	15.40	12.80	596.20	30.40	50.00	189.60	146.20	62.00	4.80	1.40	0.40	247175.56
212	58.20	43.00	46.00	39.60	50.60	32.60	29.20	982.80	55.20	50.00	167.40	122.20	60.60	7.80	1.00	0.00	288697.29
214	31.50	72.75	20.50	30.75	67.00	54.25	49.25	1408.00	88.50	42.25	177.25	112.25	58.75	10.50	1.50	0.50	221715.42

APPENDIX B

WEATHER DATA FILE EXAMPLE

OBS	YR	JD	LITE	MIN	MAX	PREC	IRR	MINM	MAXM	PRECM	IRRM
1	84	136	15.57	57	88	0.00	0.00	13.8889	31.1111	0.000	0.00
2	84	137	15.60	58	86	0.00	0.00	14.4444	30.0000	0.000	0.00
3	84	138	15.63	54	82	0.00	0.65	12.2222	27.7778	0.000	16.51
4	84	139	15.67	56	84	0.00	0.00	13.3333	28.8889	0.000	0.00
5	84	140	15.70	61	87	0.11	0.00	16.1111	30.5556	2.794	0.00
6	84	141	15.73	58	72	2.25	0.00	14.4444	22.2222	57.150	0.00
7	84	142	15.77	57	73	0.00	0.00	13.8889	22.7778	0.000	0.00
8	84	143	15.78	61	83	0.00	0.00	16.1111	28.3333	0.000	0.00
9	84	144	15.82	56	76	0.00	0.00	13.3333	24.4444	0.000	0.00
10	84	145	15.83	56	80	0.00	0.00	13.3333	26.6667	0.000	0.00
11	84	146	15.87	67	83	0.00	0.00	19.4444	28.3333	0.000	0.00
12	84	147	15.88	55	89	0.00	0.00	12.7778	31.6667	0.000	0.00
13	84	148	15.92	54	70	0.23	0.00	12.2222	21.1111	5.842	0.00
14	84	149	15.95	51	88	0.07	0.00	10.5556	31.1111	1.778	0.00
15	84	150	15.97	40	63	0.00	0.00	4.4444	17.2222	0.000	0.00
16	84	151	16.00	46	73	0.00	0.00	7.7778	22.7778	0.000	0.00
17	84	152	16.00	53	76	0.00	0.00	11.6667	24.4444	0.000	0.00
18	84	153	16.03	60	86	0.00	3.00	15.5556	30.0000	0.000	76.20
19	84	154	16.05	61	88	0.00	0.00	16.1111	31.1111	0.000	0.00
20	84	155	16.08	58	75	0.00	0.00	14.4444	23.8889	0.000	0.00
21	84	156	16.08	62	89	0.00	0.00	16.6667	31.6667	0.000	0.00
22	84	157	16.12	66	88	0.00	0.00	18.8889	31.1111	0.000	0.00
23	84	158	16.13	63	89	0.00	0.00	17.2222	31.6667	0.000	0.00
24	84	159	16.13	64	89	0.00	0.00	17.7778	31.6667	0.000	0.00
25	84	160	16.15	74	93	0.00	0.00	23.3333	33.8889	0.000	0.00
26	84	161	16.18	71	91	0.00	0.00	21.6667	32.7778	0.000	0.00
27	84	162	16.18	65	90	0.85	0.00	18.3333	32.2222	21.590	0.00
28	84	163	16.20	64	82	0.12	0.00	17.7778	27.7778	3.048	0.00
29	84	164	16.20	66	87	0.00	0.00	18.8889	30.5556	0.000	0.00
30	84	165	16.22	66	90	0.00	0.00	18.8889	32.2222	0.000	0.00
31	84	166	16.22	66	93	0.00	0.00	18.8889	33.8889	0.000	0.00
32	84	167	16.23	70	94	0.00	1.50	21.1111	34.4444	0.000	38.10
33	84	168	16.23	74	94	0.00	0.00	23.3333	34.4444	0.000	0.00
34	84	169	16.23	68	97	0.00	0.00	20.0000	36.1111	0.000	0.00
35	84	170	16.25	69	96	0.00	0.00	20.5556	35.5556	0.000	0.00
36	84	171	16.25	72	90	0.32	0.00	22.2222	32.2222	8.128	0.00
37	84	172	16.25	68	94	0.13	0.00	20.0000	34.4444	3.302	0.00
38	84	173	16.25	70	93	0.10	0.00	21.1111	33.8889	2.540	0.00
39	84	174	16.25	70	98	0.06	0.00	21.1111	36.6667	1.524	0.00
40	84	175	16.25	71	100	0.00	0.00	21.6667	37.7778	0.000	0.00
41	84	176	16.25	65	95	0.00	0.00	18.3333	35.0000	0.000	0.00
42	84	177	16.25	59	89	0.00	0.00	15.0000	31.6667	0.000	0.00
43	84	178	16.23	63	94	1.95	2.05	17.2222	34.4444	49.530	52.07
44	84	179	16.23	64	88	0.00	0.00	17.7778	31.1111	0.000	0.00
45	84	180	16.22	59	93	0.30	0.00	15.0000	33.8889	7.620	0.00
46	84	181	16.22	62	94	0.25	0.00	16.6667	34.4444	6.350	0.00
47	84	182	16.22	60	92	0.00	0.00	15.5556	33.3333	0.000	0.00
48	84	183	16.20	58	88	0.00	0.00	14.4444	31.1111	0.000	0.00
49	84	184	16.20	60	84	0.00	0.00	15.5556	28.8889	0.000	0.00
50	84	185	16.17	66	90	0.00	0.00	18.8889	32.2222	0.000	0.00
51	84	186	16.15	71	96	0.00	0.00	21.6667	35.5556	0.000	0.00
52	84	187	16.15	61	89	0.00	0.00	16.1111	31.6667	0.000	0.00
53	84	188	16.13	68	94	0.00	0.00	20.0000	34.4444	0.000	0.00
54	84	189	16.12	71	103	0.00	0.00	21.6667	39.4444	0.000	0.00
55	84	190	16.10	72	101	0.00	0.00	22.2222	38.3333	0.000	0.00
56	84	191	16.10	73	101	0.00	4.25	22.7778	38.3333	0.000	107.95

VITA \

Paul Erich Rensner

Candidate for the Degree of

Master of Science

Thesis: AN INSECT SURVEY OF SELECT HORTICULTURE CROPS IN OKLAHOMA, EMPHASIZING POPULATION DYNAMICS IN THE SQUASH BUG/SQUASH PLANT SYSTEM

Major Field: Entomology

Biographical:

Personal Data: Born in Chicago, Illinois, March 24, 1958, the son of Erich E. and Jeanette C. Rensner. Married to Cynthia F. Iknayan on August 15, 1981.

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