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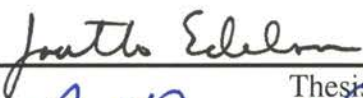
AND CUCUMBER BEETLES IN

WATERMELON

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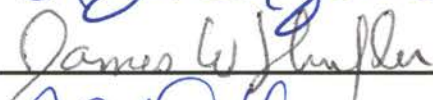the Degree of
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MANAGEMENT STRATEGIES FOR SQUASH BUG

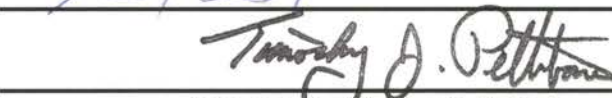# AND CUCUMBER BEETLES IN

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PREFACE

Research was conducted from 2000-2003 to compare strategies for managing squash bugs and cucumber beetles in watermelon using a squash trap crop and Standard Recommended Practice (SRP). Squash bug population distribution patterns in watermelon were determined and a sampling protocol for squash bugs was developed. The dissertation is presented in five sections. Chapter I provides a general introduction to the squash bug and cucumber beetles and their importance in cucurbit production in Oklahoma. Chapter II provides a review of literature about squash bug and cucumber beetles. Pest management practices in watermelon are compared in Chapter III. Chapter IV details research conducted to determine abundance and temporal distribution of squash bugs in watermelon grown under different management systems. Chapter V details research conducted to define spatial distribution patterns of squash bugs in watermelon and the development of a sequential sampling protocol.

It is necessary to acknowledge several individuals for their contributions to this study. I would like to express my sincere gratitude to Dr. Jonathan V. Edelson, advisor, colleague and friend, for his guidance, assistance, understanding, and patience throughout my study and research. I also extend special thanks and gratitude to Dr. James W. Shrefler for his guidance and help throughout the hard field work. His special help, guidance and encouragement made completion of this degree possible. I am sincerely grateful to people on my graduate committee; Dr. Kristopher Giles, Dr. B. Warren Roberts and Dr. James A. Duthie for their guidance and assistance. Dr. Mark Payton provided time and expertise on statistical analyses and my gratitude is expressed for his efforts. I am especially grateful to Dr. Russell E. Wright for his help, encouragement and

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CHAPTER I

INTRODUCTION

INTRODUCTION

Cucurbit production is of important economic value in the south central United States including Texas and Oklahoma. Watermelon production constitutes an important proportion of cucurbit production in the region. In the vegetable industry, growers need to produce a quality crop to meet consumer demand in a highly competitive market. Pest management with maximum efficiency and minimum cost is a key factor in the profitability of vegetable production.

Squash bug and cucumber beetles are significant cucurbit pests that impede production in southern parts of the United States. Traditional pest management strategies such as cultural and mechanical control are labor intensive and partially effective for small, home garden plots. Therefore, those strategies are impractical to implement for commercial scale production. Generally commercial growers rely upon synthetic chemical insecticides for insect pest control. Insecticides offer versatility and generally provide significant control in short periods of time. Chemical control can be ineffective due to pest tolerance to the active compounds and difficulties in making suitable application of the chemicals to the target pests. Development of insect pest resistance leads to the use of higher dosages of existing insecticidal compounds and a need for compounds of different modes of action in freshly consumed agricultural commodities. Most pesticides in the organophosphate and carbamate groups and as well those classified as potential carcinogens that are currently being used for management of squash bugs are under review of the Environmental Protection Agency (EPA) as required by the Food Quality Protection Act of 1996 of the U.S.A. Losses or significant reduction in the availability of these pesticides may result in reduced crop yield and quality as well as

decreased profitability to growers. Therefore, alternative pest management strategies need to be developed for the sustainability of cucurbit production in the region.

The main reason for conducting this research was to develop alternative, environmentally sound, efficient and economical means of squash bug and cucumber beetle management. Cucurbit growers mainly depend on insecticides to manage squash bugs and cucumber beetles. Insecticide applications have been based on perceived need and not been based on scientifically determined economic injury level or action threshold

Although cucumber beetles are polyphagous, they mainly feed on cucurbits. Squash bugs are more selective and feed only on cucurbit plants. The research reported herein was conducted to compare cucurbit pest management strategies and to develop a sampling protocol for squash bugs in watermelon. Previous studies conducted under controlled environmental conditions have indicated squash bug feeding can cause watermelon seedling mortality and yield reduction. There is a need for defining economic injury level and action thresholds for squash bug populations in watermelon for feasible management of the pest. The concept of action threshold, based on reliable estimates of pest infestation, require the development of an appropriate sampling protocol. Therefore, determination of the minimum required number of samples for different stages of squash bugs will be important to the outcome of this study. Precise assessment of squash bug infestation in watermelon requires a defined sampling program. Quantitative analysis of spatial distribution of squash bugs in watermelon will be an important part of this study.

CHAPTER II

LITERATURE REVIEW

LITERATURE REVIEW

Cucurbits are of significant economic value in the south central United States including Oklahoma. Watermelon, *Citrullus lanatus* (Thunberg) Matsumura and Nakai (Cucurbitaceae), is an economically important horticultural crop grown commonly in the southern regions of North America. Approximately 16,000 hectares (40,000 acres) are grown in the south central states of Texas and Oklahoma (USDA 1999). The crop is valued at approximately $1,000 per acre for a total estimated annual value of $40,000,000 in the south central states, where production throughout is based on similar cultural practices and has similar pest problems (Riley et al. 1998, Bolin and Bradenberger 2001).

Watermelon and squash belong to the family Cucurbitaceae. Cucurbits originally can be traced back to both the Old and New World. Watermelon originated in Africa and was brought to the New World by early settlers (Rodale 1977). Watermelon is best grown on sandy soil with good drainage to reduce the occurrence of diseases. Watermelon requires 80 to 100 days from planting to mature fruits (Bolin and Bradenberger 2001). Producers prefer to plant early so as to harvest early because of high prices between late June and early July. Early planted watermelon often grows slowly, because soil temperatures are low at the time of planting (from March to early April). For optimal seed germination soil temperature must be 15 °C or higher, therefore the use of transplants and plastic mulch has become more popular in order to produce early watermelon (Bolin and Bradenberger 2001). Reflective mulches may increase the soil temperature for early planting dates, keep the soil moist and control weed populations. Mulch is recommended for growers that want to produce watermelon before July 4th to meet the market demand. Insect pests of cucurbits including squash bugs and cucumber

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beetles may be affected by using plastic mulch. Higher numbers of squash bugs and cucumber beetles were found on host plants grown on black plastic mulch (Cartwright et al. 1990).

Management of insect pests is very important, as insects can destroy entire plant stands, reduce and delay plant development, and reduce fruit production (Foster and Brust 1995). Insects are known as vectors of many pathogens including bacterial, fungal, and viral through their feeding activities. Plants weakened by insect feeding are more susceptible to pathogen infections (Beard 1940, Butter and Rataul 1977, Legrand and Power 1994, Bextine et al 2001, Ciche and Ensign 2003).

Squash bugs and cucumber beetles, *Acalymma vittatum* (F.) and *Diabrotica undecempunctata howardii* (Barber), are important pests of cucurbits throughout much of the United States (Beard 1940, Foster and Brust 1995, Pair 1997). Adult cucumber beetles and squash bugs may destroy an entire stand of seedlings. Cucumber beetle larvae cause severe damage on cucumber seedling roots. Squash bug adults and nymphs feed on xylem and interrupt the sap transportation and cause the plant to wilt (Neal 1993). Squash bugs are a main pest of pumpkin and squash (Bonjour et al. 1990), however, when populations increase they often attack watermelon (Pair 1997, Riley et al. 1998, Edelson et al. 1999).

The common squash bug (*Anasa tristis* DeGeer) is one of the most important widespread native pests of cucurbit crops and may cause considerable damage especially to plants in the genus Cucurbita, such as squash (Quintance 1899, Isley 1927, Beard 1940, Metcalf and Flint 1962, Fargo et al. 1988, Nechols 1987, Bonjour at al.1990). Squash bug management is often difficult due to the resistance of the pest to some of the

insecticides in the market (Criswell 1987). Pyrethroids are effective against different stages of squash bugs. However, those insecticides may increase mite and aphid population in cucurbits (Edelson et al. 1999).

Adult squash bugs overwinter close to fields and emerge from overwintering sites in late spring, generally synchronized with the emergence of cucurbit plants (Fargo et al. 1988, Beard 1940, Pair 1997). Fargo and Palumbo reported that first generation nymph populations on squash increase slowly prior to flowering and increase to large numbers during fruit harvest periods.

Squash bug eggs are laid in masses, usually on the underside of leaves of the host (Palumbo et al. 1991a). The egg size is about 1.48 mm in length and 1.02 mm in width. Eggs are white to yellow in color when first deposited but gradually darken and become dark bronze by the time of hatching (Beard 1940, Metcalf and Flint 1962). Female squash bugs lay eggs throughout the growing season (Beard 1935, 1940, Palumbo et al.1991a). Females lay 15-20 eggs in masses, and generally on the abaxial surface of the leaves (Beard 1940), especially on leaves near the ground (Bonjour et al. 1990, Palumbo at al. 1991a). It takes 30 to 45 days to complete the life cycle and two to three overlapping generations can mature per year in the southern regions of the United States (Fargo et al. 1988). Newly hatched nymphs feed together as a colony on leaves and petioles, but the degree of aggregation decreases as nymphs grow and disperse (Beard, 1935, Palumbo et al. 1991b). Aggregation is a natural response and is not affected by management practices (Palumbo et al. 1991b).

Squash bug nymphs pass through five nymphal stages. It is possible to find all development stages on host plants in August and September due to the long period of

oviposition (Beard 1940). Squash bug nymphs are brightly colored upon hatching with a green abdomen and red antennae, thorax and legs. The red color becomes black within a few hours after hatching. This coloration repeats after each molting. (Beard 1940) The forth and fifth instar are easily distinguishable from the earlier instars by their size and the relative development of wing pads (Beard 1935, 1940, Metcalf and Flint 1962).

Both mature and immature squash bugs feed on cucurbit plants by sucking plant nutrients and water (Beard 1935, 1940, Metcalf and Flint 1962). During the production season populations may grow very rapidly and often whole plants can be covered with squash bug adults and nymphs (Fargo et al. 1988). The populations reach the highest numbers during fruiting stages (Fargo et al. 1988, Palumbo et al. 1991a). Planting dates affect squash bug population growth. However, regardless of planting dates squash bug populations reach the highest levels at the time of fruit set (Palumbo et al. 1991a). Squash bugs can greatly reduce or delay fruit production (Beard 1935). Some symptoms of abundant squash bug populations on host plants are wilting, stunting, yellowing, and necrosis, often resulting in plant death (Beard 1935). Adults prefer to feed on stems, petioles and leaves (Beard 1940), especially those on the ground (Palumbo et al. 1991a) and wilting is a common symptom of infestation (Beard 1940). Wilting is due to xylem interruption caused by squash bug feeding (Neal 1993). Young watermelon seedlings can be killed by squash bugs (Beard 1940, Edelson 2002, 2003). The majority of squash bugs do not leave host plants unless the plant dies and then they move to adjacent plants (Palumbo et al. 1991a).

Management of squash bugs has often been difficult (Metcalf and Flint 1962), because the insects were not susceptible to some of the insecticides in use (Criswell 1987,

Palumbo et al. 1993). Young nymphs are more susceptible to insecticides compared to older nymphs and adult squash bugs (Criswell 1987). Therefore, early detection of eggs and newly hatched nymphs is important for management and insecticide application has been recommended to coincide with early nymph development (Criswell 1987). However, recent studies have shown that insecticides including several pyrethroids, organophosphate and carbamate insecticides are effective in controlling squash bugs and other cucurbit pests (Edelson et al. 1999).

Cucumber beetles, *Acalymma vittatum* (F.) and *Diabrotica undecempunctata howardii* Barber, are indigenous to North America and are dispersed from Canada to Mexico (Metcalf and Flint 1962). They overwinter as unmated adults under plant debris, in the soil and in other plant residues. Cucumber beetles are polyphagous but mainly feed on squash and other cucurbits (Metcalf and Flint 1962, Zitter et al. 1996). Overwintered adults emerge and feed mainly on the stems and cotyledons of seedlings. Seedlings may be attacked and the beetles can chew the stem at or below the soil surface and destroy the growing point of the stem. Entire stands of cucurbit crop seedlings may be killed (Metcalf and Flint 1962). Adult beetles feed on other parts of plants and may delay or reduce fruit production. The beetles produce up to four generations per year in the southern United States (Metcalf and Flint 1962). In the early season, the beetles can cause significant seedling damage (Quintance 1899, Metcalf and Flint 1962, Foster and Brust 1995).

Cucurbitacin levels are low in cultivated varieties and greatly affect host seeking and feeding habits of cucumber beetles. Cucurbitacins are secondary plant defense chemicals that belong to triterpenoid compounds. Cucurbitacins are common in wild and

cultivated Cucurbits that are toxic to some organisms (Radin and Drummond 1994). However, cucurbitacins are feeding stimulants for cucumber beetles and there is an association between aggregations and level of cucurbitacins (Howe et al. 1972, Howe and Rhodes 1976, Lewis et al. 1990, Radin and Drummond 1994). The aggregation of cucumber beetles increases the intensity of the pests (Radin and Drummond, 1994, Howe et al. 1972). Therefore, management of the pests becomes critical in seedling stages of cucurbits (Ferguson et al. 1983).

Traditional cultural and mechanical management techniques are labor intensive and partially effective for small home garden plots. Some cultural techniques such as netting plants until the fourth leaf stage were recommended before development of inexpensive and effective chemical pesticides (Weed and Conradi 1902, Hokkanen 1991). Other cultural management techniques such as cultivating seedbeds and removing plant debris after harvesting to reduce the overwintering and sheltering places of squash bugs were recommended (Weed and Conradi 1902). Early planted squash either on field borders or squash planted between rows of other cucurbit were used as a trap crop. Squash bugs moved onto the trap crop from overwintering sites and were regularly hand picked from the trap crop (Weed and Conradi 1902).

Current management techniques are mainly based on the use of insecticides (Palumbo et al. 1993). Insecticide applications are generally preferred by growers due to the quick results (Palumbo et al. 1993). Insecticides are a very important part of cucurbit production especially for large scale commercial productions. (Quintela and McCoy 1997). However, insecticide applications are limited during cucurbit pollination by the

need to protect honeybees and bumblebees, which are critical for fruit production (Palumbo 1991a).

Pesticides used for currently recommended control strategies include organophosphate and carbamate insecticides. These are currently under review by the U.S.A. Environmental Protection Agency as mandated by the Food Quality Protection Act of 1996. If registration of these pesticides is reduced, commercial cucurbit production in the region may be seriously affected. It is critical to producers and consumers alike that alternative pest management strategies be established for the control of this major cucurbit pest.

Prior to the development of effective synthetic chemical insecticides, there were not many options available for adequate control of many insect pests. The use of trap crop techniques is one of the oldest management practices and was used for hundreds of years (Hokkanen 1991). The use of trap crops has been overlooked mainly due to the advent of chemical insecticides (Hokkanen 1991). Quaintance (1899) reported the recommendation of squash as a trap crop for management of squash bugs in the late 1800s. It has become an important pest management practice since the development of pest resistance and increased concern about pesticide residues (Hokkanen 1991).

Trap crop plant pest management is based on the idea of providing a more susceptible or preferred host for the pest and thus causing the pest to aggregate on the trap plant instead of the main crops. Producers may implement control practices while the pest is on the trap plant (Hokkanen 1991). Trap cropping works on the basis that most insects have a preference for species, cultivar, or growth stage. Therefore it is important that the trap plant be more attractive than the main crop (Hokkanen 1991). Radin and

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Drummond (1994) reported that insects with strong host preference and prolonged feeding or breeding habits are most likely to respond to trap plants. Crops can be manipulated so that a more desirable host is available at certain times of the year or in an area where the insect will most likely be intercepted (Hokkanen 1991). The purpose of a trap plant is to attract the insect pest away from the main crop, which also enables them to be isolated and easily destroyed with insecticides if this option is chosen (Hokkanen 1991).

The use of trap crops may decrease the amount of total pesticides used by limiting application to only the trap plants. If carefully developed, the trap crop could become an alternative crop and add extra value to grower income. The success of trap crop plant systems depends on the pest species and its preferred host (Hokkanen 1991). Recent studies in small experimental plots indicate that using squash as a trap crop around watermelon could effectively control cucumber beetles and squash bugs (Radin and Drummond 1994, Pair 1997).

Chemical control in cucurbit pest management has typically not been based on quantitative assessment of pest density but rather the casually determined pest presence-absence on the host plants (Palumbo 1991a). More significantly, there is a lack of knowledge concerning cucurbit yield loses in relation to squash bug density levels in watermelon. Scientifically determined economic injury levels and action thresholds are important criteria for implementing pest management techniques.

Determination of spatial and temporal distributions of a pest is important in accurate pest population density estimation. Sampling efficiency can be improved by focusing sampling efforts on certain plant parts when insect distribution within host

plants is determined (Edelson 1986). A study related to spatial distribution of squash bugs in squash was conducted by Palumbo et al. (1991b). However, the spatial distribution of squash bugs on other host plants such as watermelon is unknown. Studies have shown that host plants influence spatial distribution and colonization of insect pests (Pires et al. 2000, Jones and Peruyero 2002). Therefore, it is expected that the spatial distribution and colonization of squash bugs will be different in watermelon as compared to summer squash.

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CHAPTER III.

MANAGEMENT STRATEGIES FOR SQUASH BUG AND CUCUMBER

BEETLES IN WATERMELON

ABSTRACT

Efficacy of cucurbit pest management practices, a squash trap crop and standard recommended practice, were compared. Fewer adult squash bugs were found in watermelon in the trap crop fields. However, the trap crop was not effective in reducing adult cucumber beetle populations in watermelon adjacent to the trap crop. At-planting standard recommended practices reduced squash bug and cucumber beetle populations during the early watermelon growth stages. Later in the season, effects of the treatments on squash bugs and cucumber beetles varied across years as compared to untreated watermelons. Although fewer squash bugs and cucumber beetles were found in SRP treated watermelon, the treated watermelons consistently produced lower marketable watermelon fruits than untreated watermelons. Different stages and combinations of the pest populations were regressed against watermelon yield. Regression analysis did not detect negative linear trends in yield responses to the pest populations in late planted watermelons. In early planted watermelons, there was a negative correlation between the pest population densities and yield responses. However, none of the correlations were statistically significant.

INTRODUCTION

The squash bug (*Anasa tristis*) is an important and widespread native pest of cucurbit crops in North America and may cause considerable damage to plants in the genus *Cucurbita* such as squash and watermelon (Quintance 1899, Isley 1927, Beard 1935, 1940, Metcalf and Flint 1962, Fargo et al. 1988, Nechols 1985, 1987, Bonjour et al.1990, Edelson et al. 2002).

Feeding damage caused by squash bugs may kill small plants and runners of larger plants. Squash bugs show the greatest feeding preference for pumpkin, *Cucurbita pepo* var *pepo* L., followed by squash, *Cucurbita pepo* var *melopepo* L., and watermelon, *Citrullus lanatus* (Thunb.), (Metcalf and Flint 1962, Bonjour et al. 1990). Edelson et al. (2002, 2003) reported significant squash bug damage to watermelon seedlings and mature plants and negative effects on yield.

The most significant damage caused by squash bugs is that caused by overwintered adults when they move onto newly emerged cucurbit seedlings in the spring. At the seedling stage one squash bug can kill numerous plants in a very short time (Weed and Conradi 1902, Edelson, et al., 2002).

Host plant morphology has a significant affect on squash bug preference (Bonjour et al. 1990, Woodson and Fargo 1992, Palumbo et al. 1991a, b). Squash bugs prefer large leaves for shade and shelter as are typical for mature squash plants (Palumbo et al. 1991a, Bonjour et al. 1990,). Significantly greater adult squash bug population densities were recorded on early planted squash plants containing more leaves than on younger plants with fewer leaves (Palumbo et al.1991a). Plants with large leaves may be preferred by squash bugs due to the protection afforded from predators during mating (Palumbo et al.

1991a). Large leaves may also provide increased oviposition sites, resulting in less competition for sites for egg laying (Bonjour et al. 1990). Large leaves near the ground provide better protection and feeding sites for newly hatched nymphs (Bonjour et al. 1991).

Early in the growing season, cucumber beetles may become important pests of cucurbits. Cucumber beetles can cause significant seedling damage (Quintance 1899, Metcalf and Flint 1962). These beetles are indigenous to North America and are distributed from Canada to Mexico (Metcalf and Flint 1962). They overwinter as unmated adults under plant debris, in the soil and in other plant residues. Cucumber beetles are poliphagous but adults readily feed on squash and other cucurbits (Metcalf and Flint 1962, Elsey 1988, Zitter et al. 1996). Overwintered adults emerge and feed on the stems and cotyledons of seedlings. Seedlings may be attacked and the beetles can chew the stem at or below the soil surface and destroy the growing point of the stem. Entire stands of cucurbit crop seedlings may be killed (Metcalf and Flint 1962, Elsey 1988). Adult beetles feed on other parts of plants and may delay or reduce fruit production. The beetles produce up to four generations per year in the southern region of the United States (Metcalf and Flint 1962).

Squash bug and cucumber beetles are key pests of cucurbit crops at the seedling stage (Foster and Brust 1995, Edelson et al. 2002). Significantly greater adult squash bug populations were found on early planted (6 May) cucurbits at Stillwater, OK (Palumbo 1991). Overwintered squash bugs were first detected on April 17, in Atoka Co., and squash bug emergence was completed by June 8 (Pair 1997). Cucurbit crops planted after the migration of overwintered adults in early spring may escape damage because the

adults settle, feed and remain in fields that had emergent crops present during the spring migration (Lu et al. 2003).

Traditionally, growers in the southern region of the U.S.A. try to market melons before July 4 because of the high value of the crop during the fourth of July holiday season. This requires planting of watermelon by April, which coincides with the time of emerging overwintered adult squash bugs in southern Oklahoma (Bolin and Brandenberger 2001). Small plants are more susceptible to squash bug feeding damage which causes plants to wither and die (Beard 1940, Edelson et al., 2002). Therefore, management of cucurbit pests is necessary in early planted watermelon. Generally, carbofuran (Furadan® 4F) is prophylactically applied to the soil with early to mid season pest control in watermelon (Bolin and Brandenberger 2001).

Historically, several cultural management practices have been described for controlling squash bug populations. Early-planted squash either on field borders or between rows of other cucurbits may be used as trap crops. Squash bugs that move onto the trap crop from overwintering sites can be hand picked from the trap crop (Weed and Conradi 1902) thus leaving the other crop with no or low infestations.

Prior to the development of effective synthetic chemical insecticides, there were few options available for adequate control of many insect pests. Often the available techniques were time consuming and labor intensive, involving extensive mechanical or cultural practices (Hokkanen 1991). Trap crop techniques were used until the development of cheap and effective synthetic chemical pesticides (Hokkanen 1991). The use of trap crops diminished due to the development of effective synthetic insecticides (Hokkanen 1991). Quaintance (1899) reported the use of squash as a trap crop for

management of squash bugs in other cucurbits and squash planted after the trap crop squash. There has been a renewed interest in the use of trap cropping techniques with the development of pest resistance to insecticides and increased concern about pesticide residues in the food supply (Hokkanen 1991).

Trap crop plant pest management is based on the idea of providing a more susceptible or preferred host for the pest and thus causing the pest to aggregate on the trap crop plant instead of the main crop. Producers may apply control practices to the trap crop while the pest is on the trap plant (Hokkanen 1991). Trap cropping works on the basis that most insects have a preference for a species, cultivar, or growth stage. Therefore, it is important that the trap plant be more attractive than the main crop (Hokkanen 1991). Radin and Drummond (1994) reported that insects with strong host preference and prolonged feeding or breeding habits are most likely to be successfully controlled with this technique. The purpose of the trap plant is to attract the insect pest away from the main crop, which also enables them to be isolated and easily destroyed with insecticides if this option is chosen (Hokkanen 1991).

Results from recent studies conducted using small experimental plots indicate that using squash as a trap crop around watermelon could control cucumber beetles and squash bugs (Radin and Drummond 1994, Pair 1997). However, in order to determine if a trap crop system can be recommended to producers it is advisable to evaluate the use of the technique on a commercial production scale. In addition, currently recommended management practices make use of insecticides that are under review by the United States Environmental Protection Agency as required by the Food Quality Protection Act of 1996. This review could lead to cancellation of these critical insecticides and leave

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growers with no adequately tested insect management options. Insecticides under review include carbamate and organophosphate products that are currently approved and recommended for use in cucurbits. In a trap crop (squash) study conducted by Pair (1997) pesticides under review of EPA were used with the trap crop and the study was conducted in small research plots. Therefore, the objective of this study was to compare the effectiveness of the trap crop management system (without pesticides that under EPA review) with standard recommended practices (SRP) for controlling squash bugs and cucumber beetles and test the applicability of the trap crop system under commercial production.

MATERIALS AND METHODS

Cucurbit pest management strategies were compared in 2000, 2001 and 2002. The experiment was conducted using a randomized complete block design with 3 replications in 2000, 4 replications in 2001 and 3 replications in 2002 for each treatment. Treatments consisted of pest management regimes for controlling the key pests of early-planted watermelon, the squash bug and cucumber beetles.

Treatments were as follows:

1- Standard recommended practice (SRP) - Furadan® 4F, carbofuran (2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) FMC, Philadelphia, PA, applied at a rate of 0.249 kg (AI)/ 1000 linear meters in a 18 cm band over the seed furrow, with monitoring of plants to detect pests followed with foliar applications of Thiodan® EC, endosulfon (hexachloro hexahydromethano-2,4,3-benzodloxathlepin-3-oxide)LLC, Eagan, MN, or Capture®2EC, bifenthrin ((2 methyl[1,1-biphenyl]-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl) 2,2-dimethyl propanecarboxylate) FMC, Philadelphia, PA, if pest

populations exceed thresholds of 1 adult squash bug or 1 cucumber beetle adult per plant at seedling stage (Edelson et al. 2002, Brust and Foster 1999).

2- Trap crop system – summer squash transplanted around the perimeter of the watermelon field prior to emergence or transplanting of watermelon, with monitoring of pests in the trap crop and watermelon, followed by foliar applications of Thiodan or Capture when pests occur in the trap crop or exceed thresholds of 1 adult squash bug or 1 cucumber beetle adult per plant (Edelson et al 2002, Brust and Foster 1999).

3- Untreated – watermelon planted without a perimeter trap crop and not treated with insecticides.

To control weeds and diseases, herbicide and fungicide were applied to watermelon fields as it was needed. Fields were hoed and cultivated to control weeds. Soil from all the fields was tested and fertilizer was applied at-planting based on Oklahoma Cooperative Extension Service recommendations (Motes and Roberts 1994).

Trial I. The study was conducted in 2000 at three locations, the Wes Watkins Agricultural Research and Extension Center (WWAREC) at Lane, Oklahoma, the Oklahoma State University Vegetable Research Station at Bixby, Oklahoma, and at the Caddo Research Station at Fort Cobb, Oklahoma. Each location constituted a replicate block of the randomized complete block design experiment. Two fields approximately 0.4 ha in size were selected at each location and randomly assigned one of two treatments; trap crop or SRP (untreated fields were not included during 2000). Two rows of trap crop (yellow summer squash, Peto 391) were transplanted at the perimeter of one field at each location approximately 2 weeks prior to planting of watermelon. Watermelon, 'Jubilee', was seeded in the third week of May. Plants were spaced 0.9 m

apart within the row and rows were 3.65 m apart. Watermelon and squash at Bixby and Ft. Cobb were irrigated by sprinkler irrigation while drip irrigation was used at Lane.

In the trap crop treatment field, 16-22 squash plants (dependent on length of squash rows) were checked for squash bugs and cucumber beetles. For watermelon in the trap crop fields, 20-26 watermelon plants (dependent on field size) from the first and last watermelon rows on both sides of the field, at the perimeter of the field adjacent to the trap crop and from rows in the middle of watermelon field were selected for visual examinations. In the SRP watermelon field, 16-28 watermelon plants from the first rows at the perimeter of field and watermelon rows in the middle of the field were selected. Plants were visually examined at 3-4 day intervals at the beginning of the seedling stage until the end of June. Sampling was continued once a week until the end of July and sampling was terminated when fruit matured.

All plant structures (leaf, stem and petioles) and the soil surface immediately underneath each plant within a 40 cm radius of the stem were visually examined for the presence of squash bug adults, nymphs, egg masses and adult cucumber beetles. Due to similarity of their feeding habit and damage to cucurbits, spotted and striped cucumber beetles species counts were pooled.

For both treatments, first rows on both sides of the fields and two middle rows of watermelon plants were selected for yield measurement. Watermelons were visually examined and fruits without deformities and of marketable size were harvested and weighed.

Trial II. Experiments in 2001 were conducted at four locations. There were two replicates at Lane, (WWAREC), and one each at El Reno, Oklahoma, (USDA ARS

Grazinglands Research Facility) and Caney, Oklahoma (commercial production fields). At each location, three fields or plots within a field measuring approximately 46x80 meters in size were selected for each replicated treatment. The fields were plowed and disk harrowed and seedbeds prepared.

A minimum distance of 30 meters was maintained between fields or plots at each location to avoid the overlapping effects of treatments. Each field was divided into 16 (11x20 meters) sub-sampling plots.

Watermelons were planted the first week of May at Caney, the third week of May at Lane, and the second week of June at El Reno. This trial included three treatments; SRP, trap crop, and an untreated field. One row of squash was transplanted on two sides of one field at each location. A distance of 7.5 meters was left between the trap crop (squash) rows and watermelon rows. Carbofuran was applied as a 18 cm wide band over the seed furrow at 0.249 kg (AI) / 1000 linear meters at the time of planting to one of the fields at each location. The third field at each location did not receive any pest management treatment and only watermelon was planted. The fields without trap crops or carbofuran application served as an untreated comparison to determine how insect populations respond without the treatments. The trap crop was treated with foliar applications of insecticides during the growing season to control pests as needed to maintain pest populations below the economic thresholds level of one adult squash bug per plant. At Lane and El Reno drip irrigation systems were used for watermelon and the trap crop. The fields at Caney were not irrigated.

Each field was divided into 16 sub-sampling plots overlaid on the portion planted to watermelon. Rows of squash trap crop were divided into eight sub-sampling units.

Each sub-sampling unit was assigned a number and three plants per sub-sampling unit were randomly selected to be visually examined for squash bugs and cucumber beetles. A total of 48 samples from the watermelon planted portions of fields and 24 samples from the squash trap crop portions of fields were visually examined on each sampling date. The plot numbers were recorded on field maps to mark location and movement of squash bugs within the field.

Plants were visually examined at 4-7 day intervals from the seedling stage until the end of June. Plants were monitored once a week from the end of June until the end of July or when watermelon fruit matured or plants died. All plant structures (leaf, stem and petioles) and the soil surface immediately underneath each plant within a 40 cm radius of the plant stem crown were examined for the presence of squash bug adults, nymphs, egg masses and adult cucumber beetle adults. Squash bug adults, nymphs, eggs and cucumber beetle adults were recorded separately according to the sections of plants where found.

To measure yield, six-meter long sections of watermelon rows were randomly selected. All watermelon fruit within this row section were harvested and weighed. Watermelon fruit weighing less than 6.5 kg were classified as non-marketable. Watermelon fruit that weighed more than 6.5 kg and without deformities was classified as marketable. A total of 16 samples were taken per field.

Trial III. In 2002, experiments were conducted at three locations Lane, OK, Bennington, OK, and Leon OK. Three fields at each location, approximately 46x80 meters in size were selected as in the 2001 trial. Squash, 'Peto 391' and watermelon, 'Legacy', seedlings were transplanted the first week of May. The experimental design and sampling procedures were identical to those used in the experiment in 2001.

Irrigation was not used at any location in 2002.

In 2002, three harvests were conducted at the Lane location. For each harvest, different areas of the fields were selected and all fruits were harvested and classified as either marketable or non-marketable as described for the 2001 trial.

Insect abundance data were analyzed using PROC MIXED, a repeated measurements procedure (SAS Institute 1997). Watermelon yield data were analyzed using PROC GLM and means were separated using the Fishers's least significant difference method (SAS Inst. 1997). To determine the effect of insecticides applied to the trap crop foliage on the pest abundance in watermelon, pest abundance before and after insecticide application in watermelon were compared using paired t-test procedure (SAS Inst. 1997). Due to the pest importance during the early growth stages of watermelon, sampling intervals were grouped into two (early and late) sampling periods. Regression analysis to determine the relationship between insect abundance and yield was conducted using PROC REG procedure (SAS Inst. 1997). The early sampling period covered from seedling stage to fruit set and the late sampling period covered from fruit set to fruit maturity. Different combinations of mean and cumulative number of the pest abundance per plant were calculated for early sampling period and were regressed against total (marketable and non-marketable) watermelon yield per plant.

RESULTS

Squash bug and cucumber beetle populations in watermelon were below the economic threshold of /per plant for three years with, the exception of one watermelon field in 2002. Therefore, watermelon plants were not treated with any foliar applied insecticide. Watermelons in one of the trap crop fields at Lane were treated with insecticide due to abundant cucumber beetles. However, the squash trap crop was treated with foliar insecticides several times each year.

Squash bugs

Trial I. Squash bug adults were first observed June16 on squash and June 29 on watermelon in the trap crop treatments at all locations. At Lane, squash bug adults were first noted July 6 on watermelon in the SRP treatments. At Bixby, squash bug adults were first noted on June 24 on squash. Squash bugs were not found on watermelon in the trap crop treatment or the SRP treatment throughout the season. At Ft. Cobb, squash bug adults were first detected on June 23 on squash and watermelons.

Abundance of adult squash bugs peaked at 0.5 per plant on August 7 in watermelon in the trap crop treatments. Abundance of adult squash bugs peaked at 0.4 per plant in the SRP treatments by August 1 (Table 1). Squash bug adult populations decreased in abundance in watermelon in the subsequent samplings. Squash bug abundance was similar across the treatments throughout the season (Fig.1).

Squash bug eggs were first noted on June 6 in SRP treated watermelon and watermelon in the trap crop fields. No significant difference in abundance of squash bug eggs was detected in watermelon across treatments. However egg numbers were significantly different among treatments on July 22 (Table 2). Squash bug egg numbers

on watermelon in the trap crop field were significantly greater than in SRP treated watermelons.

Squash bug nymphs were not found in watermelon in the trap crop fields until July 14. Nymph abundance was similar in SRP treated watermelon and watermelon in the trap crop fields for most sampling intervals. However, SRP treated watermelon had significantly more nymphs compared to watermelon in the trap crop fields on the last sampling date (Table 3).

Trial II. Adult squash bugs were first recorded at Lane on June 3 on squash and on July 2 on watermelon in the SRP treatment and untreated fields. Squash bugs were recorded on July 7 in watermelon in the trap crop treatments, approximately one week later than in the other treatments. At Caney, squash bug adults were recorded on June 2 on squash and watermelon in the trap crop treatments and on watermelon in the SRP and untreated fields. At El Reno, squash bug adults were recorded on June 20 on squash in the trap crop treatments and on watermelon in the SRP field. Squash bugs were not found on watermelon plants in the trap crop treatment.

There were no significant differences in abundance of adult squash bugs on watermelon among treatments from 3 June to 6 July. However, squash bug adults were significantly more abundant on watermelon in the SRP treatments compared to watermelon in the trap crop treatments on 13 and 22 July and 1 August (F=14.89; df =2, 12.4; P=0.0005 and F=18.81; df=2,17.7; P=0.0001 respectively). Squash bug populations increased throughout the sampling period (Table 1). Squash bug adults were more abundant in the untreated fields than in the trap crop treated fields on 22 July and 1 August (F=3.29; df= 2, 10.4; P= 0.0782) (Table 1).

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When cumulative adult squash bug means were compared, there were significant differences of adult squash bugs among treatments (F=43.35; df=2, 5429; P=0.0001). Squash bug populations were more abundant in SRP treated watermelon followed by untreated watermelons and watermelons in the trap crop fields (0.47, 0.30 and 0.08 squash bug/plant respectively). Squash bugs in untreated watermelons were significantly more abundant than in watermelon in the trap crop fields.

Foliar applied insecticide applications to the trap crop did not significantly (t= -2.9; P=0.0624) reduce the pest abundance in watermelon in the trap crop field. Squash bug populations in watermelon in the trap crop fields before and after insecticide applications were similar throughout the season, indicating squash bugs remained on watermelon plants after moving onto watermelon plants (main crop).

Squash bug eggs were first noted on 8 June in SRP treated watermelons and trap crop treated watermelons and on 14 June in untreated watermelon. Squash bug eggs in SRP treated and untreated watermelon were significantly more abundant than in watermelon in the trap crop fields on July 22 and August 1 (F=5.78; df= 2, 83.5; P=0.004, F=37.87; df= 2, 147; P=0.0001 respectively). During the last sampling interval, the squash bug eggs were more abundant in untreated watermelon as compared to watermelon either treated with SRP or the trap crop (Table 2).

Squash bug nymphs were first found in untreated watermelons and watermelons with the trap crop on June 20 while in SRP treated watermelons they were found approximately one week later (Table 3). Squash bug nymph abundance was significantly different across treatments on August 1 (F=79.39; df= 2, 1303; P=0.0001). Although squash bug adults were more abundant in SRP treated watermelon fields, squash bug

nymphs were more abundant in untreated watermelon compared to watermelon treated with SRP or the trap crop (Table 3).

Squash bug nymphs were significantly (F=8.1; df=2, 4251; P=0.0003) more abundant in untreated watermelon as compared to watermelon in the trap crop fields. Nymphs in SRP treated and untreated watermelons were not significantly different. Nymphs in SRP treated watermelon were also significantly more abundant than in watermelon in the trap crop fields.

Trial III. At Lane, squash bug adults were observed on May 15 in the squash trap crop, on June 1 in watermelon in the trap crop fields and in watermelon treated with SRP and in untreated watermelons on May 25. At Bennington, squash bug adults were first recorded in the trap crop and watermelons either treated or untreated with carbofuran on May 11 and on May 16 in watermelons from the trap crop fields, approximately 5 days later than other treatments. At Leon, squash bug adults were first detected on May 14 in the trap crop and in watermelon that either had the trap crop or that were untreated. Abundance of squash bugs was not significantly different across the treatments during all sampling intervals with exception of on May 29 (F=2.89; df= 2, 47.4; P= 0.0657). During the sampling interval, squash bugs in SRP treated watermelons were significantly greater than in untreated watermelons and watermelons in the trap crop fields (Table 1).

When cumulative abundance of adult squash bugs was compared, differences were not significant (F=0.00; df= 2, 3,883; P= 0.9986) across the treatments. There was an average of approximately 0.6 squash bugs per plant on watermelon in the trap crop fields, SRP treated and untreated watermelons.

Similar to the previous experiment, foliage insecticides applied to the trap crop did not significantly (t=0.11; P= 0.92) reduce squash bug populations in watermelon in the trap crops fields. Squash bug populations tended to remain on watermelon once locating watermelon as a host plant.

Squash bug eggs were more abundant in SRP treated watermelon fields compared to watermelon that had the trap crop and untreated watermelons. Squash bug eggs were significantly greater (F=4.42; df= 2, 40.5; P= 0.0184) in SRP treated watermelons than untreated watermelons but not significantly higher than in watermelon in the trap crop fields during the sampling interval on June 14 (Table 2). Abundance of squash bug eggs in watermelons with the trap crop was not significantly different than in untreated watermelons. Squash bug egg abundance was significantly different among treatments on July 20 and June 28 (F=6.09; df= 2, 40.5; P= 0.0049 and F=22.32; df= 2, 40.5; P= 0.0001) (Table 2). During both sampling intervals eggs in carbofuran treated watermelons were more abundant than in untreated watermelons and watermelons with the trap crop (Table 2).

Squash bug nymphs were first noted on June 3 in the untreated watermelons and approximately one week later in watermelon that had the trap crop. In SRP treated watermelons nymphs were detected approximately 3 weeks later as compared to untreated watermelons (Table 3). Abundance of nymph populations in watermelon varied significantly across treatments in the last sampling interval. Watermelons with the trap crop had significantly (F=4.19; df=2, 10.4; P= 0.0462) greater nymph populations than carbofuran treated and untreated watermelons (Table 3).

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There were 0.71, 0.50 and 0.38 nymphs per plant on watermelon in the trap crop, untreated and SRP treated watermelons, respectively when cumulative numbers were compared across the treatments. Nymph populations were not significantly (F=2.4; df=2, 3883; P= 0.0905) different across the treatments.

Overall, fewer adult squash bugs were found on watermelon in the trap crop fields during early growth stages of watermelon. Effect of the trap crop on adult squash bugs varied across years during late watermelon growth stages. Squash bug egg and nymph abundance was not significantly different in watermelon in the trap crop fields as compared to untreated watermelons. SRP application reduced squash bug adults and eggs for first several weeks after at-plant pesticide application. During late watermelon growth stages, squash bug adult, egg and nymph abundance was not significantly different as compared to untreated watermelons and watermelons in the trap crop fields.

Cucumber beetles

Trial I. Cucumber beetle adults were first observed on June 16 in both trap crop and watermelon with the trap crop at Lane. Approximately two weeks later, on June 29, cucumber adults were observed in SRP treated watermelons. At Bixby, cucumber beetles were first observed on June 27 in the trap crop and on watermelon planted with the trap crop and on July 7 in carbofuran treated watermelons. At Ft. Cobb, cucumber beetle adults were first observed on June 14 in the trap crop and on watermelons that had the trap crop and on June 24 in watermelon treated with carbofuran.

Adult cucumber beetles were more abundant in watermelon in the trap crop field as compared to carbofuran treated watermelons. Abundance of adult cucumber beetles in watermelon with the trap crop and SRP treated watermelon fields was significantly

(F=9.29; df= 1,30.4; P=0.0047) different on July 22 sampling (Table 4). During the other sampling intervals similar adult cucumber beetle populations were noted (F=0.09; df= 1, 1175; P=0.9125).

Trial II. At Lane, adult cucumber beetles were observed on June 22 in the trap crop and in the untreated watermelons. In watermelons that had the trap crop or those treated with carbofuran, cucumber beetles were first detected on July 2. Occurrence of cucumber beetles in SRP treated watermelon and watermelon in the trap crop fields was delayed approximately 10 days as compared to untreated watermelons. At Caney, cucumber beetle adults were observed in the trap crop on July 8 and no cucumber beetle adults were found in watermelon throughout the sampling times. At Ft Cobb, Cucumber beetles were observed on July 21 in carbofuran treated watermelons while in watermelons that had the trap crop cucumber beetles were found on July 27. Cucumber beetles were not detected in untreated watermelons. At El Reno, cucumber beetle adults were observed on June 27 in the trap crop and on July 6 in all watermelon fields.

In 2001, adult beetle populations were not abundant in any watermelon fields throughout the season. During the last three sampling intervals, cucumber beetles increased in abundance in watermelons in the trap crop fields as compared to the other treatments, however, the differences were not significant across treatments (Table 4). No significant (F=0.87; df= 2, 4251; P= 04186) differences in abundance of cucumber beetles across the treatments was detected when cumulative cucumber beetle means were compared.

Trial III. Although watermelons and the squash trap crop were transplanted approximately within a one-week period across all the study locations, cucumber beetle

adults were recorded at different times across locations. At some locations cucumber beetles occurred shortly after transplanting watermelons and the trap crops while at other locations cucumber beetles colonized the watermelon 2-3 weeks later. At Lane, cucumber beetles were observed on May 15 in squash and watermelons in the trap crop field. Cucumber beetles were detected in SRP treated and untreated watermelons fields on May 22. At Bennington, cucumber beetles were first noted in the trap crop on May 11 and on May 15 in watermelons in the trap crop treatment. In SRP treated and untreated watermelon fields, cucumber beetles were recorded on June 7, approximately 3 weeks later as compared to watermelons in the trap crop treatment. At Leon, cucumber beetle adults were first detected on May 29 in squash and in watermelons in the trap crop fields while in untreated watermelons cucumber beetles were found on June 6 and in watermelons treated with carbofuran on May 17. Cucumber beetles colonized untreated watermelons approximately one week later and SRP treated watermelons two weeks later as compared to watermelons in the trap crop fields.

During most of sampling intervals, cucumber beetle populations were more abundant in watermelons that had the trap crop than in watermelon that either received the conventional treatment or that remained untreated (Table 4). In 2002, cucumber beetle abundance was significantly different among treatments on June 8, June 20 and June 28 sampling intervals (F= 3.28; df= 2, 30.4; P= 0.0513; F= 4.78; df= 2, 30.4; P= 0.0156 and F= 2.88; df= 2, 30.4; P= 0.0715 respectively). On June 8, cucumber beetles in watermelons in the trap crop field were significantly more abundant than in carbofuran treated and untreated watermelons (Table 4). In general cucumber beetles were more

abundant on watermelons in the trap crop fields than in SRP treated and untreated watermelons throughout the season (Fig. 2).

Cucumber beetles were significantly (F=8.11; df= 2, 3883; P= 0.0003) more abundant in watermelon in the trap crop fields as compared to SRP treated watermelon and untreated watermelons when cumulative beetle means were compared. SRP treated and untreated watermelon had a similar abundance of cucumber beetle populations.

In general greater abundance of cucumber beetles was found on watermelon in the trap crop fields for all watermelon growth stages. Therefore, the trap was not only ineffective in controlling adult cucumber beetles in watermelon as compared to SRP treated fields but it also showed potential for increasing the insect populations over those of untreated watermelons. Fewer adult cucumber beetles were found in SRP treated watermelon as compared to watermelon in the trap crop field and untreated watermelon.

Watermelon yield

In 2000, fruit yield was 9.1 kg/plant for watermelon in the trap crop treatments and 8.0 kg/plant for SRP treatments. Watermelon plants in the trap crop treatments produced significantly greater yields compared to watermelon plants in the SRP treatments (Table 5).

In 2001, watermelons grown in the trap crop field produced 3.8 kg fruit/plant marketable yield and 6.1 kg fruit/plant non-marketable. SRP treated watermelons produced 4.0 kg fruit/plant marketable and 6.0 kg fruit/plant non-marketable watermelon yield while untreated watermelon produced 5.4 kg fruit/plant marketable and 6.3 kg fruit/plant non-marketable yield. Although SRP treated watermelons produced the greatest total watermelon yield compared to watermelons from the trap crop treatments

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and untreated watermelons, the SRP treatment resulted in a lower marketable yield compared to untreated watermelon plants (Table 5). Marketable watermelon yield in untreated fields was significantly (F=2.88; df=2, 139; P=0.0596) greater than watermelon yield in the trap crop fields but was not significantly greater than SRP treated watermelon. SRP treated watermelon produced similar yield with watermelons in the trap crop fields (Table 5).

In 2002, untreated watermelons produced 6.8 kg fruit/plant, SRP treated watermelons produced 5.4 kg fruit/plant and watermelons in the trap crop fields produced 4.8 kg fruit/plant marketable watermelon yields (Table 5). Marketable watermelon yield in untreated fields was significantly (α=0.1) greater than watermelon in the trap crop fields but not significantly greater than SRP treated watermelons (F=2.57; df=2, 139; P=0.0805).

To determine the effect of insect abundance and pest management strategies on watermelon yield; watermelons were harvested 3 times at Lane in 2002. Samples were taken from different areas of rows within the same plot on each date. During the consecutive sampling dates, previously harvested plants were not included. When data from multiple harvests at Lane were combined with data from the other locations, average marketable yield of fruit from untreated watermelon plants was the greatest, followed by SRP treated watermelon plants and watermelon plants from the trap crop treatments at 10.2 kg/plant, 8.0 kg/plant and 7.9 kg/plant respectively (Table 6). Watermelons in the untreated plots produced significantly greater marketable yield compared to SRP and the trap crop treatments (F=4.47; df= 2, 233; P= 0.0125). Fruit yield from SRP treated watermelons was not significantly different from that of

watermelon yield from the trap crop fields. Non-marketable watermelon fruit yields were not significantly (F=1.97; df=2, 233; P=0.1412) different across treatments.

At Lane, total (combined marketable and non-marketable) watermelon fruit yield from the first harvest was 7.5 kg/plant for watermelons from the trap crop treatments, 14.6 kg/plant from the SRP treated watermelons and 14.0 kg/plant from untreated watermelons. Although SRP treated watermelon plants produced greater total yield compared to other treatments, this treatment produced lower marketable yield compared to untreated watermelon plants, 5.7 kg/plant, 8.2 kg/plant respectively (Table 7).

In the second harvest at Lane, watermelon from the trap crop field produced 16.5 kg fruit/plant, SRP treatment watermelon produced 20.5 kg fruit/plant and untreated watermelon produced 19.5 kg fruit/plant. Yields from the second harvest were similar to the first harvest across all treatments. Watermelon receiving the SRP treatment produced greater total yield compared to other treatments, but produced lower marketable yield compared to untreated watermelon plants (Table 8).

In the third harvest at Lane, untreated watermelon produced the greatest total marketable yield compared to other treatments. In the third harvest, total watermelon yield declined in SRP treatments while watermelons from the other treatments produced greater yields than the second harvest (Table 9).

For fruit yield averaged across from all three harvests at Lane, untreated watermelons produced the greatest total watermelon yield, followed by SRP treatment watermelons and watermelons from the trap crop treatments. Watermelons receiving the SRP treatment and watermelons from the trap crop fields produced similar marketable

yield, but watermelon from the SRP treatment produced the greatest non-marketable yield compared to other treatments (Table 10).

To assess the effect of the pest populations on watermelon yield reduction, pest abundance was regressed against fruit weight. The regression was not significant and slope of the regression was positive, indicating the pest population did not cause yield reduction when watermelons were planted late in end of May (Table 11). In 2002, all response variables indicated negative correlations between watermelon yield and different pest combinations indicating the pest populations may cause yield reduction when watermelon planted/transplanted in end of April in the southern parts of Oklahoma. Although the correlation coefficients (R^2) were high, no significant correlation was detected (Table 11). When cumulative numbers of the pest combinations were regressed against watermelon yield, results were approximately similar to the correlations of the pest means and watermelon yields (Table 12).

Although fewer adult squash bugs were found on watermelon in the trap crop fields, watermelon consistently produced lower marketable and non-marketable fruit weight as compared to SRP treated and untreated watermelon. SRP treated watermelon produced lower marketable but greater non-marketable watermelon yield when compared to untreated watermelon. Watermelon yield differences across the treatments were not associated with the pest abundance in watermelon.

DISCUSSION

The original goal of this project was to evaluate key pest management strategies for early-planted watermelon in southern Oklahoma. However, due to field conditions and scheduling challenges we were not able to plant seed prior to May 1 in 2000 and

2001. Transplants were used in 2002 to achieve earlier planting. Producers in north Texas and southern Oklahoma generally must direct seed or transplant watermelon prior to May to achieve harvest prior to 4 July which is a critical market date due to the greater prices for fruit just prior to and during the 4 July holiday season. Previous studies have indicated that squash bugs and cucumber beetle populations most commonly migrate to watermelon fields in this region in April and early May. Therefore, results from this research are more similar to and indicative of mid-season watermelon production which is also common in the region and for which fruit harvests occur during July and August.

Detection of overwintered adult squash bugs differed across the three years of this study in which planting dates also differed. Watermelon was transplanted to fields earlier in 2002 than in 2000 or 2001 and we recorded immediate movement of pests into the fields in 2002 (Fig. 1). Squash bug adults were more abundant in the fields during 2002 in which we were able to make the earlier plantings in comparison to 2000 and 2001. In 2002, watermelons were transplanted approximately 2 weeks earlier than the seeding of watermelon in 2001 and 3 weeks earlier than seeding in 2000. Squash bug populations in watermelon were greater in 2002 compared to 2000 and 2001, suggesting an effect of planting date on occurrence of squash bug populations in watermelon (Fig. 1). These results for watermelon are similar to the study conducted in summer squash by Palumbo et al (1991a). They found greater squash bug populations in early-planted summer squash compared to late-planted summer squash. Previous studies have indicated that squash bug adults emerge from overwintering sites by mid-April (Pair 1997) and search for suitable hosts. It can be inferred that planting date may have a substantial effect on colonization of watermelon by squash bugs.

Adult squash bugs can cause significant damage to watermelon seedlings (Edelson at el. 2002) indicating that management of overwintered squash bug populations is important during early watermelon growth stages. Squash bugs were almost always detected earlier in the squash trap crops than in watermelons. In watermelons from the squash trap crop fields, fewer squash bugs were found on watermelon plants compared to untreated watermelons. This indicates that the trap crop can delay squash bug occurrence in watermelon, which may be important for reducing seedling mortality.

Although squash bug populations were less abundant in the trap crop after insecticide applications, we did not detect reductions in squash bug populations in watermelon (Fig. 1). Squash bug abundance before and after insecticide application on watermelon plants were compared. The squash bug abundance reduction in watermelon in the squash trap crop fields due to insecticides applied to the squash was significant in 2001 and 2002.

Cucumber beetle occurrence in watermelons was not consistent across years and locations. Although in 2001 watermelon was planted earlier than in 2000, cucumber beetle populations were not greater than in 2001. However, cucumber beetle populations were more abundant in 2002 when watermelon was established earlier than in 2000 and 2001 (Fig. 2). Although in 2002, at all locations, watermelons and the squash trap crop were transplanted within a one-week period, there were approximately 2-3 weeks time differences between occurrences of cucumber beetles across locations. Although foliar insecticide application to the squash trap crop reduced cucumber beetles in the trap crop, no reduction of cucumber beetles in watermelon due to insecticide applications was apparent (Fig. 2).

Cucumber beetles overwinter as adults along field borders and become active in the early spring (Brust and Foster 1999). Adult beetles begin feeding on small seedlings shortly after germination and emergence or following transplanting of seedlings. Adult beetle feeding can cause complete defoliation of small plants and result in transmission of *Erwinia tracheiphila* (E. F. Smith) Holland (Brust and Foster 1999) to cucurbits. Watermelon varieties are not as susceptible to bacterial wilt as many other cucurbits. Feeding damage of cucumber beetles on small watermelon seedlings is more important and complete defoliation of watermelons can cause significant yield reduction. Therefore, management of cucumber beetles can be critical in watermelon during the early growth stages (Brust and Foster 1999). Applicaton of Furadan® 4F at planting can reduce cucumber beetle adult abundance during the first 2-3 weeks of the crop growth and this may be adequate for successful management of cucumber beetles in watermelons.

The squash trap crop treated with insecticides resulted in reduced squash bug abundance in watermelon. However, watermelon in the trap crop fields produced 5 to 30% lower marketable fruit yields in 2001 and 2002 as compared to SRP treated and untreated watermelon plants. Reduction of squash bugs in watermelons due to the trap crop did not lead to an increase in watermelon yield as compared to untreated watermelons. Watermelon yield reduction was not correlated with the number of different stages of squash bugs and adult cucumber beetles in watermelon (Table 11-12). Therefore, the exact cause of yield reduction in watermelon is unknown.

Although the SRP treatment was effective in reducing squash bugs and cucumber beetles, the treated watermelon plants consistently produced a reduced yield of marketable fruit compared to untreated watermelons. The result of this study is in

contradiction to the findings of Foster and Brust (1995) who reported significant yield increases with the at-planting application of carbofuran (Furadan® 15G) in watermelons. In that study only marketable watermelon yield was measured. The marketability of watermelon fruits was based on subjective classification of fruit quality. In our study all watermelon fruit were harvested and fruit weight was used as criteria for marketability classification. In addition, watermelon yield was measured from larger fields and more samples were taken over several years at different geographic locations.

Although the cause of watermelon yield reduction is uncertain, it is possible that non-target effects of treatments including disruption of pollinators by at-planting application of carbofuran may cause yield reduction in watermelon (Kremen et al 2002). At-planting soil application of carbofuran to watermelon was consistently associated with reduced marketable fruit yield. Watermelon flowers require insect pollination for successful fruit production, and fruit size, shape quality and number of fruit has been correlated to increased abundance of pollinating insects. Studies have shown that bee species were very effective at pollination in organically grown watermelon (Kremen et al 2002). However, conventional watermelon growers experienced greatly reduced abundance and intensity of bee populations resulting in insufficient pollination in watermelon as compared to organically grown watermelons (Kremen et al 2002).

CONCLUSIONS

Squash bug and cucumber beetle populations were not abundant in any of the trial fields in any year with exception of one field in 2002 and therefore results of this research are only indicative of conditions under which pest abundance is below the current recommended action threshold. Previous studies have shown that squash bugs prefer

squash plants over watermelon plants for nutritional factors (Bonjour and Fargo 1989) and for squash plant architecture (Bonjour et al. 1990) that makes the plant a better hiding place from natural enemies during its prolonged mating time.

Cucumber beetle populations were more abundant in watermelon with squash plants around the perimeter of the fields in comparison to watermelon fields that were managed using the SRP and were untreated. Therefore, the trap crop management approach as used in our study is not a viable alternative to the use of pesticides for the management of cucumber beetles in watermelons.

The use of a trap crop with a systemic insecticide was found to be highly effective in controlling squash bugs and cucumber beetles in watermelon (Pair 1997). In our study the use of scouting-based decision application of foliar insecticide applications to the trap crop were not effective in controlling cucumber beetles in watermelon. Therefore, a systemic insecticide treatment to the trap crop may be necessary to increase the efficacy of the trap crop for controlling squash bugs and especially cucumber beetles in watermelons. The presence of a systemic insecticide on the trap crop may prevent the movement of attracted insect pests into watermelons.

The application of carbofuran resulted in reduced abundance of squash bugs and cucumber beetles in watermelons for 3-4 weeks. The first 3-4 weeks of watermelon growth is the most susceptible stage to squash bugs and cucumber beetles (Edelson 2002, Foster and Brust 1995). Therefore, the control of squash bugs and cucumber beetles for the 3-4 weeks provided by carbofuran could be an adequate time period for the management of these insect pests in watermelon.

Although carbofuran controlled squash bugs and cucumber beetles in watermelon, the reduction in abundance did not result in an increase in watermelon fruit yield as compared to untreated watermelons. The application of carbofuran may therefore have potential for reducing grower profit by reducing marketable yield and increasing production input due to the cost of the insecticide application.

In a previous trap crop study conducted by Pair (1997), carbofuran was applied to the trap crop that is currently under review of EPA. In this study we wanted to eliminate the use of carbofuran with trap crop due to the possibility of being removed from the market. Therefore, foliar applied insecticides were used on the trap crop for controlling the pest populations. Based on the trap crop system used in this study, we were able to manage adult squash bug populations in watermelon as good as or better than SRP. However, the use of trap crop with foliage insecticide application was not effective in reducing cucumber beetles in watermelon. A combination of the trap crop and a systemic insecticide may be more effective and promising to replace SRP for controlling cucurbit pests in watermelon.

The results of our study indicated that use of at-plant carbofuran application for cucurbit pest management in watermelon planted as a mid-season production crop may have adverse effects on watermelon fruit yield production. However, because the watermelon crops were not planted until May we were not able to evaluate the comparative effectiveness of the different pest management strategies for controlling squash bugs and cucumber beetles in March to early April planted watermelon production systems in north Texas and southern Oklahoma.

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Table 1. Adult squash bugs on watermelon grown under different management systems.

	Treatment	Mean density of squash bugs (number /plant)[1]								
		Date of sampling[2]								
		06/14	**06/20**	**06/28**	**07/06**	**07/13**	**07/22**	**08/01**	**08/07**	**08/12**
2000	Trap crop	0.07	0.02	0.03	0.07	0.33	0.38	0.23	0.52	0.25
	SRP	0.02	0.02	0.04	0.20	0.17	0.23	0.41	0.26	0.06
		06/03	**06/08**	**06/14**	**06/20**	**06/28**	**07/06**	**07/13**	**07/22**	**08/01**
2001	Trap crop	0.0	0.04	0.02	0.0	0.0	0.01	0.08b	0.10c	0.68c
	SRP	0.0219	0.03	0.0	0.0	0.02	0.19	0.66a	1.40a	2.25a
	Untreated	0.0130	0.02	0.12	0.0	0.04	0.22	0.46ab	0.73b	1.19b
		05/12	**05/17**	**05/22**	**05/29**	**06/03**	**06/08**	**06/14**	**06/20**	**06/28**
2002	Trap crop	0.01	0.02	0.04	0.11b	0.59	1.08	1.19	1.45	0.92
	SRP	0.01	0.08	0.0	0.12b	0.74	0.78	1.40	1.58	0.69
	Untreated	0.05	0.06	0.11	0.54a	0.74	0.80	1.14	1.24	0.70

[1]Numbers within a column followed by same letter are not significantly different (p<0.05) (LSMeans procedure).

[2]Sampling interval is median day of all locations sampled.

Table 2. Squash bug eggs on watermelon grown under different management systems.

	Treatment	Mean density of squash bug eggs (number /plant)[1]								
		Date of sampling[2]								
		06/14	**06/20**	**06/28**	**07/06**	**07/13**	**07/22**	**08/01**	**08/07**	**08/12**
2000	Trap crop	0.10	0.10	0.09	0.54	0.69	4.28a	2.89	1.20	0.0
	SRP	0.07	0.07	0.21	0.36	0.36	0.66b	0.97	1.91	0.0
		06/03	**06/08**	**06/14**	**06/20**	**06/28**	**07/06**	**07/13**	**07/22**	**08/01**
2001	Trap crop	0.0	0.10	0.0	0.0	0.0	0.09	0.0	0.24b	1.86c
	SRP	0.0	1.05	0.07	0.10	0.10	0.0	0.30	2.54a	6.16b
	Untreated	0.0	0.0	1.20	0.32	0.02	0.20	0.70	2.40ab	9.85a
		05/12	**05/17**	**05/22**	**05/29**	**06/03**	**06/08**	**06/14**	**06/20**	**06/28**
2002	Trap crop	0.0	0.0	0.07	0.0	0.42	0.63	2.10ab	2.38ab	1.41ab
	SRP	0.0	0.0	0.0	0.0	0.14	0.54	3.06a	4.17a	5.87a
	Untreated	0.0	0.0	0.31	0.07	0.21	0.07	0.66b	1.37b	1.01b

[1]Numbers within a column followed by same letter are not significantly different (p<0.05) (LSMeans procedure).

[2]Sampling interval is median day of all locations sampled.

Table 3. Squash bug nymphs on watermelon grown under different management systems.

	Treatment	Mean density of squash bug nymphs (number /plant)[1]								
		Date of sampling[2]								
		06/14	06/20	06/28	07/06	07/13	07/22	08/01	08/07	08/12
2000	Trap crop	0	0	0	0	0.14	0.08	0.07	0.03	0.37b
2000	SRP	0	0	0	0	0	0.16	0.07	0.54	1.40a
		06/03	06/08	06/14	06/20	06/28	07/06	07/13	07/22	08/01
2001	Trap crop	0.0	0.0	0.0	0.1302	0.0	0.0	0.06	0.09	1.19c
2001	SRP	0.0	0.0	0.0	0.0	0.1719	0.21	0.05	0.32	6.01b
2001	Untreated	0.0	0.0	0.0	0.0845	0.0	0.0	0.32	0.90	7.18a
		05/12	05/17	05/22	05/29	06/03	06/08	06/14	06/20	06/28
2002	Trap crop	0.0	0.0	0.0	0.0	0.0	0.10	0.06	1.05	5.13a
2002	SRP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.33	3.10b
2002	Untreated	0.0	0.0	0.0	0.0	0.01	0.17	0.19	0.85	3.18b

[1]Numbers within a column followed by same letter are not significantly different ($p < 0.05$) (LSMeans procedure).

[2]Sampling interval is median day of all locations sampled.

Table 4. Adult cucumber beetles on watermelon grown under different management systems.

Treatment		Mean density of cucumber beetles (number/plant)								
		Date of sampling[2]								
		06/14	06/20	06/28	07/06	07/13	07/22	08/01	08/07	08/12
2000	Trap crop	0.0	0.0	0.10	0.05	0.11	0.09b	0.19	0.0	0.21a
	SRP	0.0	0.0	0.02	0.05	0.08	0.34a	0.14	0.0	0.0
		06/03	06/08	06/14	06/20	06/28	07/06	07/13	07/22	08/01
2001	Trap crop	0.03	0.03	0.03	0.0	0.02	0.21	0.08	0.11	0.24
	SRP	0.03	0.03	0.03	0.0	0.02	0.27	0.08	0.10	0.20
	Untreated	0.03	0.03	0.03	0.0	0.01	0.22	0.06	0.04	0.13
		05/12	05/17	05/22	05/29	06/03	06/08	06/14	06/20	06/28
2002	Trap crop	0.07	0.02	0.0	0.04	0.39	0.54a	0.58a	0.79	0.73a
	SRP	0.0	0.09	0.02	0.02	0.17	0.22b	0.39b	0.51	0.57ab
	Untreated	0.0	0.05	0.02	0.0	0.32	0.28b	0.42ab	0.90	0.42b

[1]Numbers within a column followed by same letter are not significantly different (p<0.05) (LSMeans procedure). Sampling interval is median day of all locations sampled.

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Table 5. Marketable, non-marketable and total watermelon yield in 2000, 2001

and 2002.

Year	Treatment	Watermelon yield (±SEM)		
		Marketable (kg/plant)	Non-marketable (kg/plant)	Total yield (kg/plant)
2000	Trap crop	9.12 ±0.19	-------------	----------------
	SRP	8.04 ±0.21	-------------	----------------
2001	Trap crop	3.81±0.81	6.13±0.51	9.94±1.20
	SRP	4.03±0.49	5.95±0.40	9.99±0.74
	Untreated	5.24±0.66	6.28±0.48	11.71±0.94
2002	Trap crop	4.76 ±0.58	4.80±0.25	9.56 ±0.52
	SRP	5.39 ±0.60	6.16 ±0.73	11.57 ±0.93
	Untreated	6.78 ±0.76	4.92 ±0.34	11.70 ±0.77

Table 6. Marketable, non-marketable and total watermelon yield averaged across

all locations in 2002. (Following and including multiple harvests at Lane).

Treatment	Mean watermelon yield (±SEM)		
	Marketable (kg/plant)	Non-marketable (kg/plant)	Total yield (kg/plant)
Trap crop	7.85 ±0.70	5.74 ±0.30	13.59 ±0.82
SRP	8.02 ±0.64	6.79 ±0.52	14.81 ±0.86
Untreated	10.17 ±0.88	5.98 ±0.41	16.15 ±0.99

Table 7. Marketable, non-marketable and total watermelon yield for first

harvest at Lane in 2002.

Treatment	Mean watermelon yield (±SEM)		
	Marketable (kg/plant)	Non-marketable (kg/plant)	Total yield (kg/plant)
Trap crop	2.36 ±0.59	5.13 ±0.46	7.49 ±0.69
SRP	5.66 ±0.71	8.98 ±1.85	14.64 ±1.93
Untreated	8.23±1.28	5.78±0.47	14.01 ±1.57

Table 8. Marketable, non-marketable and total watermelon yield for second

harvest at Lane in 2002.

Treatment	Watermelon yield (±SEM)		
	Marketable (kg/plant)	Non-marketable (kg/plant)	Total yield (kg/plant)
Trap crop	10.31 ±1.53	6.23±0.69	16.54 ±1.62
SRP	11.98 ±1.19	8.47±0.90	20.46 ±1.51
Untreated	12.70 ±1.53	6.82 ±0.72	19.52 ±1.45

Table 9. Marketable, non-marketable and total watermelon yield for third harvest at Lane in 2002.

Treatment	Watermelon yield (±SEM)		
	Marketable (kg/plant)	Non-marketable (kg/plant)	Total yield (kg/plant)
Trap crop	14.66 ±1.40	8.06±0.82	22.73±1.76
SRP	11.96 ±1.60	6.93±0.94	18.88 ±1.91
Untreated	17.81 ±2.43	8.30±1.47	26.11 ±2.58

Table 10. Marketable, non-marketable and total watermelon yield at Lane

(average of multiple harvests at Lane) in 2002.

Treatment	Watermelon yield (±SEM)		
	Marketable (kg/plant)	Non-marketable (kg/plant)	Total yield (kg/plant)
Trap crop	9.19±1.01	6.48±0.42	15.58±1.22
SRP	9.87 ±0.82	8.13±0.75	17.99 ±1.08
Untreated	12.91 ±1.19	6.97±0.57	19.88 ±1.31

Table 11. Regression analysis indicates the interaction between squash bug adults, adults+nymphs, adult cucumber beetles and adult squash bugs+beetles and yield losses in watermelon grown under different management systems. Means of the pest combinations during the early watermelon growth stages were regressed against mean yield per plant for each treatment.

| Response variable | Year | | | |
| | 2001 | | 2002 | |
	P	R^2	P	R^2
Squash bug adult/yield	0.21	0.89	0.50	0.49
Adults and nymphs /yield	0.10	0.97	0.51	0.48
C. beetle adults/yield	0.00	0.00	0.30	0.80
Adult beetle and bug/yield	0.23	0.88	0.67	0.23

Table 12. Regression analysis indicates the interaction between squash bug adults, adults+nymphs, adult cucumber beetles and adult squash bugs+beetles mean per plant and yield losses in watermelon grown under different management systems. Cumulative number of the pest combinations were regressed against mean yield per plant for each treatment.

Response variable	Year			
	2001		2002	
	P-value	R^2	P-value	R^2
Adult squash bug /yield	0.18	0.92	0.48	0.52
Adults and nymphs /yield	0.17	0.92	0.48	0.51
C. beetle adults/yield	0.00	0.00	0.31	0.78
Adult beetle and bug/yield	0.18	0.92	0.66	0.24

Figure 1. Adult squash bugs on watermelon grown under different treatment conditions in 2000, 2001 and 2002.
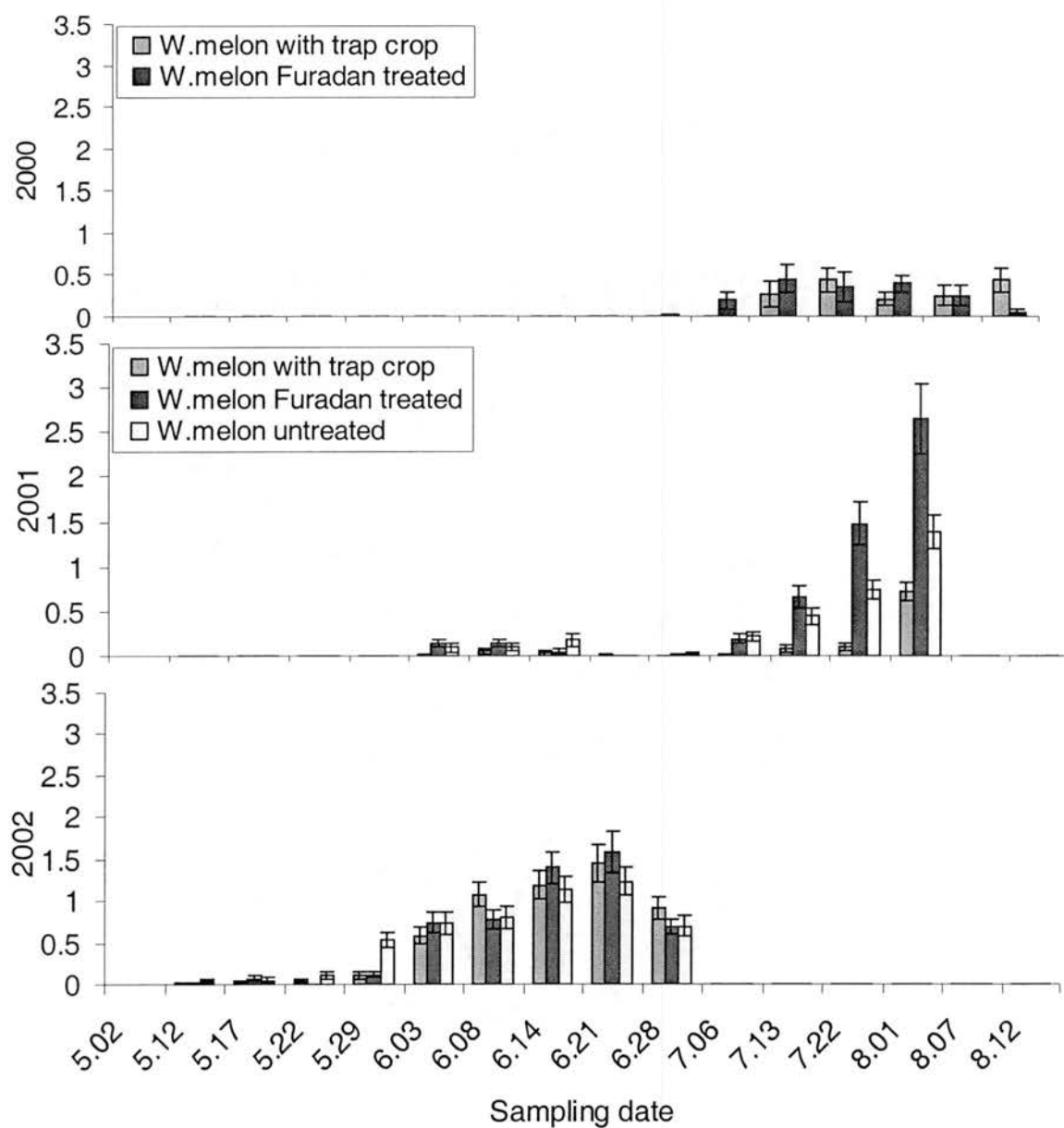
Watermelons were seeded in the 4th week of May in 2000, 3rd of May in 2001 and transplanted in the 4th week April 2002.

Figure 2. Adult cucumber beetles on watermelon grown under different treatment conditions in 2000, 2001 and 2002.
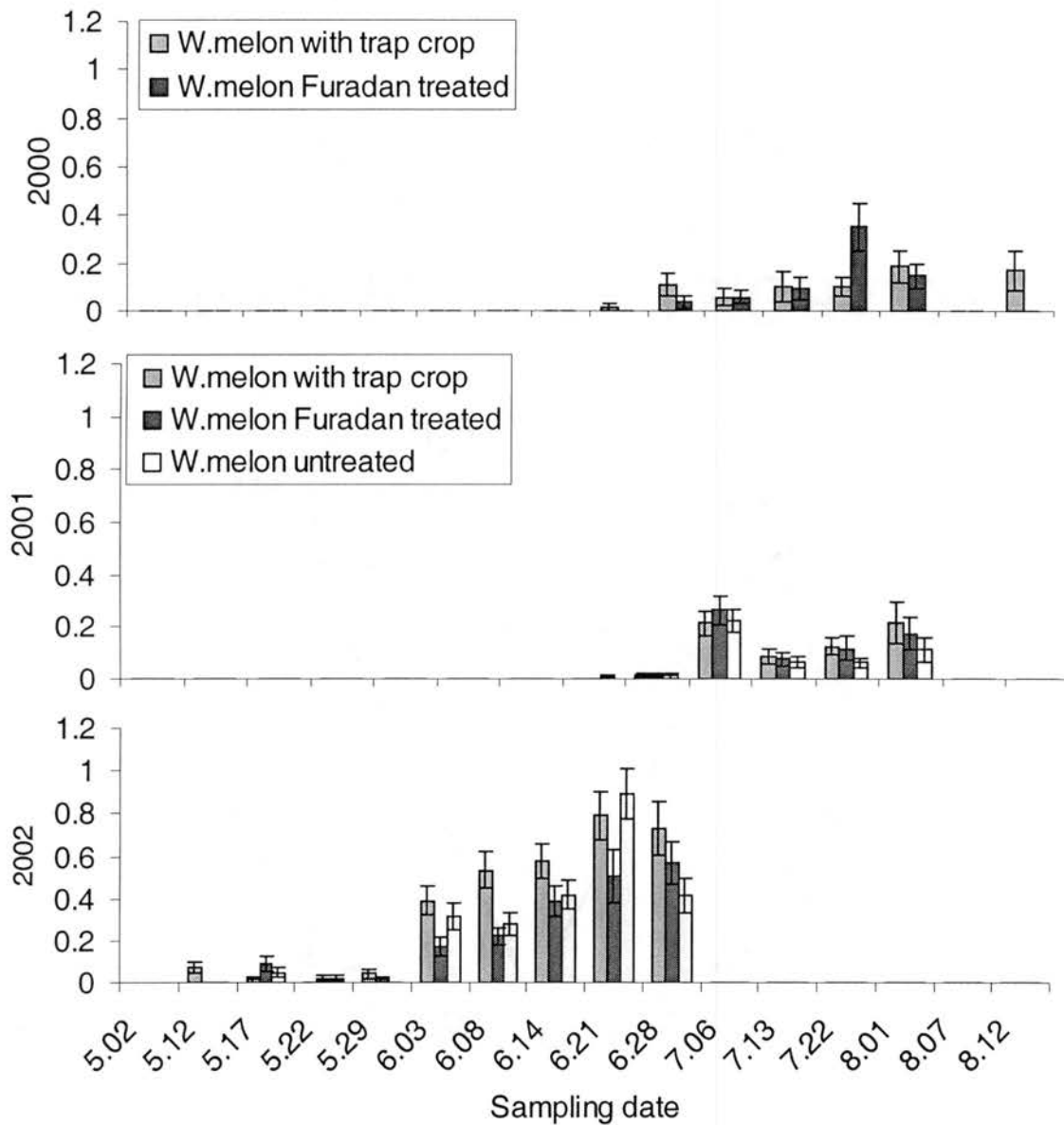
Watermelons were seeded in the 4th week of May in 2000, 3rd of May in 2001 and transplanted in the 4th week April 2002.

CHAPTER IV.

TEMPORAL ABUNDANCE AND SPATIAL DISTRIBUTION OF SQUASH BUG

IN WATERMELON UNDER DIFFERENT MANAGEMENT SYSTEMS

ABSTRACT

The temporal abundance and spatial distribution of squash bugs (*Anasa tristis* DeGeer) in watermelon (*Citrullus lanatus* (Thunb.)) grown under different management systems were investigated. More adult squash bugs colonized the plant crown during early watermelon growth stages. However, later in the season adult squash bugs were found on all the plant parts. Most squash bug eggs were found on old and young leaves of the plants and few were found on the plant crown. Squash bug nymphs were primarily found on old leaves in the early growth stages, and on the plant crown and old leaves in the late growth stages. Squash bugs were found randomly distributed across field sections for early planted watermelons. However, more abundant squash bugs were found in the corners of late planted watermelons. Pest management systems did not affect squash bug distribution within the plant parts and field sections. The plant crown should be examined more intensively for sampling overwintered squash bugs in the early growth stages of watermelon. All plant parts and field sections should be included in field surveys due to the random distribution of squash bug across field sections.

INTRODUCTION

The squash bug is native to North America and is dispersed throughout the Americas (Beard 1940, Metcalf and Flint 1962). Squash bugs mainly feed on pumpkin and squash followed in preference by watermelon and other cucurbits (Bonjour et al 1990). Unmated squash bug adults move to protected areas such as field borders, fences and plant debris to overwinter late in the fall (Beard 1940, Fargo et al. 1988). Squash bug adults emerge in early spring (Fargo et al. 1988, Palumbo et al. 1991a, Pair 1997) in Oklahoma. Squash bug nymph populations gradually increase prior to fruit setting and reach large numbers during fruit harvesting period (Palumbo et al. 1991a).

Squash bugs are important pests in the southern region of the United States (Bonjour and Fargo 1989, Bonjour et al. 1990, Palumbo et al. 1993). The seasonal development of the squash bug varies largely based on different geographic locations. Host plant types have significant effects on development, life span and reproduction of squash bugs (Bonjour et al. 1990, Fargo et al. 1988).

The life history of the squash bug varies depending on geographical locations. The pest can complete 1-3 generations per year (Nechols 1987, Fargo et al. 1988). Feeding damage to young seedlings caused by adults and nymphs reduces plant vigor and growth (Beard 1940, Edelson et al. 2002) and can cause plant wilting (Neal 1993). Numerous squash bug infestations can significantly reduce yield of cucurbits (Palumbo et al. 1993, Edelson et al. 2003).

To be competitive in the fresh cucurbit market, growers need to produce high-quality fruits. Therefore, management of squash bug populations is important for profitability of cucurbit production (Palumbo et al. 1991a). Adult squash bugs are not

susceptible to some available insecticides (Criswell 1987). Pyrethroid insecticides are effective in controlling adult squash bugs in cucurbits. However, multiple applications of pyrethorid insecticides can increase aphid and mite populations by reducing beneficial insect populations (Edelson et al. 1999).

Squash bugs have been known to be important pests of pumpkin and squash for a century (Quintance 1899, Weed and Conradi 1902, Beard 1940, Fargo et al 1988, Bonjour et al. 1990). However, recent studies have indicated that squash bug feeding especially during the early growth stages of watermelon growth can cause serious damage leading to seedling mortality and yield reduction as well (Pair 1997, Edelson et al. 2002, 2003). Studies have indicated that varying the planting date is an important management technique to avoid squash bug damage in cucurbits (Beard 1940, Fargo et al. 1988, Palumbo et al. 1991a). Squash bugs emerge from overwintering sites in the spring and move onto available cucurbit plants (Beard 1940, Palumbo et al. 1991a). Early in the spring, due to limited host plants, greater aggregation of squash bugs occurs on early planted cucurbits. Squash bug feeding can cause significant watermelon seedling mortality (Edelson et al. 2002). Therefore, early growth stages of cucurbits are more vulnerable to squash bug feeding. A delayed planting date may be a valuable technique to deter squash bug damage in watermelon. However, growers plant watermelon early in the spring to produce watermelon fruits by July 4th because of the increased value of the crop during the Fourth of July holiday season. This requires planting of watermelon by April, which coincides with the time of emerging overwintered adult squash bugs in southern Oklahoma (Bolin and Brandenberger 2001). Therefore, use of a delayed planting date may not be a practical management strategy for squash bug management in watermelon.

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Prior to development of a pest management technique, understanding of pest population behavior such as seasonal development, spatial distribution and reproduction is essential. Studies have been conducted to determine colonization and seasonal development of squash bug in summer squash (Palumbo et al. 1991b) and cantaloupe (Edelson 1986). However, seasonal development and spatial distribution of squash bug in watermelon has not been determined. Therefore, the objectives of this study were (1) to determine the temporal abundance and spatial distribution and (2) to determine the effects of management systems on spatial distribution of squash bugs within and between watermelon plants.

MATERIALS AND METHODS

Experiments were conducted over the course of two years, 2001 and 2002, at different locations in Oklahoma. The experiment was a randomized complete block design with 4 replications in 2001 and 3 replications in 2002 for each treatment.

Treatments were as follows:

1- Standard recommended practice (SRP) - Furadan® 4F, carbofuran (2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) FMC, Philadelphia, PA, applied at a rate of 0.249 kg (AI)/ 1000 linear meters in a 18 cm band over the seed furrow, with monitoring of plants to detect pests followed with foliar applications of Thiodan® EC, endosulfon (hexachloro hexahydromethano-2,4,3-benzodloxathlepin-3-oxide)LLC, Eagan, MN, or Capture®2EC, bifenthrin ((2methyl[1,1-biphenyl]-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl) 2,2-dimethyl propanecarboxylate) FMC, Philadelphia, PA, if pest populations exceed thresholds of 1 adult squash bug adult per plant at seedling stage (Edelson et al. 2002).

2- Trap crop system – summer squash transplanted around the perimeter of the watermelon field prior to emergence or transplanting of watermelon, with monitoring of pests in the trap crop and watermelon, followed by foliar applications of Thiodan or Capture when pests occur in the trap crop or exceed thresholds of 1 adult squash bug per plant (Edelson et al. 2002).

3- Untreated – watermelon planted without a perimeter trap crop and not treated with insecticides.

To control weeds and diseases, herbicide and fungicide were applied to watermelon fields as it was needed. Fields were hoed and cultivated to control weeds. Soil from all the fields was tested and fertilizer was applied at-planting based on Oklahoma Cooperative Extension Service recommendations (Motes and Roberts 1994).

Studies have shown that pest populations especially in vining crops may be overdispersed within plant parts (LeRoux and Reimer 1959, Edelson 1986). Various biological and environmental factors affect interplant distribution of an organism (Southwood 1978). To determine intra and interplant distribution of different stages of squash bugs in watermelon, watermelon plants were divided into 3 sections, crown, old leaves and young leaves. Watermelon fields were also divided into 3 sections, corner, edge and middle. Squash bugs cause significant damage on cucurbits at the early growth stages (Palumbo et al. 1991a, Woodson and Fargo 1992, Edelson et al. 2002). Therefore, the sampling intervals were grouped into two time periods to compare early and late season pest distribution. The first five sampling intervals were pooled as early sampling period and coincided with the seedling to fruit set plant stages and the last four sampling

intervals were pooled as late sampling period that coincided with fruit set to fruit maturation.

Trial I. Experiments in 2001 were conducted at three locations with a total of four replicates. There were two replicates at Lane, (WWAREC) OK, and one at El Reno, OK, USDA ARS Grazinglands Research Facility) and one with a commercial producer at Caney, OK. For each replicate, three fields, approximately 46x80 meters in size were selected for each replicate. The fields were plowed and disk harrowed and seedbeds were prepared.

Watermelon was planted in the first week of May at Caney, in the third week of May at Lane, and in the second week of June at El Reno. A distance of 7.5 meters was left between the trap crop (squash) rows and watermelon rows. The field without trap crops or insecticide applications served as an untreated comparison to determine how insect populations behave with and without management systems. The trap crop was treated with foliar insecticides during the growing season to control pests as needed to maintain pest populations below the economic threshold level of 1 adult squash bug per plant during seedling stage. Drip irrigation was used at Lane and El Reno for watermelon and the trap crop. At Caney, watermelons were not irrigated.

Each field was divided into 16 sub-sampling plots overlaid on the portion planted to watermelon. Rows of trap crop were divided into 8 sub-sampling units. Each sub-sampling unit was assigned a number and 3 plants per sub-sampling unit were randomly selected to be visually examined for squash bugs and cucumber beetles. A total of 48 samples from the watermelon planted portions of fields were visually examined on each

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sampling date. The plot numbers were recorded on field maps to mark location and movement of squash bugs within the fields.

Different stages of squash bugs were examined at 4-7 day intervals from the seedling stage until the end of June. Plants were monitored once a week until the end of July or when watermelon fruit matured. After plants developed to the vining stage, as shown by the development of plant runners, they were divided into three sub-section areas (1) crown (2) old leaves (3) young leaves as described in the previous section. A 40 cm radius circle around the watermelon plant roots was considered the plant crown throughout the season. A length of 20 cm from the last point of plant vines were grouped as young leaves and the plant section between the crown and young leaves were recorded as old leaves. All plant structures (leaf, stem and petioles) and the soil surface immediately underneath each plant within a 40 cm radius of the plant stem crown were examined for the presence of squash bug adults, nymphs and eggs. Squash bug adults, nymphs and eggs were recorded separately according to the sections of plants where found.

Trial II. In 2002, experiments were conducted at three locations; Lane (WWAREC) and on commercial production farms at Bennington, (Southeast Oklahoma, and Leon (South central Oklahoma). Three fields at each location, approximately 46x80 meters in size were selected as in the 2001 trial. A trap crop (squash Peto 391) and watermelon (Legacy) were transplanted in the first week of May. Experimental design and sampling procedure was identical to the experiment in 2001. Irrigation was not needed at any location in 2002.

Statistical analysis. The experimental design was randomized complete block with four

replications in 2001 and three replications in 2002. Different stages of squash bugs were grouped by plots according to their locations in the fields such as middle, edge and corner. Due to the importance of squash bugs in the seedling stage, sampling intervals were grouped as early and late sampling period. Early sampling period covered from seedling stage to fruit set and late sampling period covered from fruit set to fruit maturity. Because sampling intervals were considered as repeated observations of sampling units (plants) data were analyzed by repeated measures analysis of variance by using a 'Repeated' statement in PROC MIXED procedure (SAS Institute Inc.1997).

RESULTS

Trial I. *Distribution of squash bugs within watermelon plants-* in the early sampling period, adult squash bug abundance in watermelons in the trap crop fields was not significantly (F= 0.93; df= 2, 7191; P= 0.3959) different across plant parts. In standard recommended practice (SRP) treated and untreated watermelons, squash bug adults were significantly (F= 14.51; df= 2, 7191; P= 0.0001 and F= 10.03; df= 2, 7191; P= 0.0001, respectively) different across plant parts. Adult squash bugs in SRP treated watermelon plants were significantly more abundant on plant crown than on old leaves. In untreated watermelons, squash bugs were not significantly different across plant sections (Table 1).

Adult squash bugs across treatments on plant crown were significantly (F= 3.81; df= 2, 13.1; P= 0.0494) different. SRP treated and untreated watermelons had similar number of squash bugs on the plant crown, however, squash bugs on crown of watermelon in the trap crop fields were significantly lower as compared to SRP treated and untreated watermelons (Table 1).

Comparing within plant distribution in late growing season, adult squash bugs in watermelon in the trap crop fields were significantly (F= 2.35; df= 2, 5544; P= 0.0957) different across plant parts. Old plant leaves had significantly more adult squash bugs as compared to young leaves, but similar to plant crown in watermelons in the trap crop fields (Table 1). In SRP treated watermelon fields, old watermelon leaves had greater adult squash bugs as compared to plant crown and young leaves (Table 1). In untreated watermelon fields, squash bug distribution across plant parts was similar to SRP treated watermelon plants (Table 1).

Across the treatments, old leaves of SRP treated watermelon had significantly (F= 4.15; df= 2, 6.95; P= 0.0650) greater adult squash bugs as compared to old leaves of untreated watermelons and watermelons in the trap crop fields. Adult squash bugs in the untreated watermelons and watermelons in the trap crop fields were similar. Squash bugs on the plant crown and on young leaves were similar across treatments.

In the early sampling period, squash bug egg numbers were not significantly (F=0.04; df= 2, 7192; P=0.9655) different across plant parts in SRP treated watermelons and watermelons in the trap crop fields. However, squash bug eggs on old leaves of untreated watermelons were significantly (F=2.44; df= 2, 7192; P=0.0875) greater than plant crown and young leaves. Squash bug eggs on young leaves were similar to on the plant crown (Table 1).

Across treatments, squash bug eggs on old leaves of SRP treated and untreated watermelon plants were significantly (F=3.06; df= 2, 33.8; P=0.0599) greater than old leaves of watermelon in the trap crop fields. No squash bug eggs were found on the plant crown and young leaves of SRP treated watermelons and watermelons in the trap crop

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fields.

During the late sampling period, squash bug eggs were found only on old leaves of watermelon in the trap crop fields. Squash bug eggs on old leaves of SPR treated and untreated watermelons were significantly (F=13.25; df= 2, 5544; P=<0.0001 and F=23.28; df= 2, 5544; P=<0.0001 respectively) greater in numbers than on young leaves. The crown of watermelons in both treatments had no squash bug eggs.

Across treatments, squash bug eggs on old leaves of SRP treated and untreated watermelons were similar but greater than on old leaves of watermelons in the trap crop fields (Table 1). Squash bug eggs on young leaves of SRP treated and untreated watermelons were similar.

During the early sampling, squash bug nymph populations were low in watermelons across all the treatments as compared to late sampling period. Although, squash bug nymphs were found on old leaves of watermelon plants no significant differences were detected across treatments.

During the late sampling, squash bug nymphs in watermelon in the trap crop fields were not significantly (F=0.65; df= 2, 5545; P=0.5227) different across plant parts. Squash bug nymphs in SRP treated and untreated watermelons were significantly (F=7.96; df= 2, 5545; P=0.0004 and F=2.55; df= 2, 5545; P=0.0782 respectively) different across plant sections. Old leaves of SRP treated watermelons had more squash bug nymphs than the plant crown and no nymphs were found on young leaves. The numbers of nymphs on old leaves of untreated watermelon plants were greater than on the plant crown and young leaves.

Across treatments nymph numbers on old leaves were significantly (F=4.35; df= 2, 26.9; P=0.0231) different. Old leaves of SRP treated and untreated watermelons had more nymphs as compared to watermelons in the trap crop fields (Table 1). Old leaves and plant crown of SRP treated and untreated watermelons had similar squash bug nymphs. Squash bug nymphs were not found on young leaves of SRP treated watermelons and untreated watermelons in the trap crop fields.

Trial II. In 2002, Adult squash bugs on old leaves and plant crown of watermelon in the trap crop fields were significantly (F= 24.66; df= 2, 6465; P= 0.0001) greater than on young leaves. The plant crown and old leaves of watermelons in the trap crop fields had similar squash bug adults. Adult squash bug distribution across plant parts of SRP treated watermelon was similar to watermelon parts in the trap crop fields. Untreated watermelon parts had significantly (F= 17.65; df= 2, 6465; P= 0.0001) different number of squash bugs. The plant crown had greater squash bugs as compared to old leaves and young leaves. There were more squash bugs on old leaves than on young leaves (Table 2).

Across treatments, the plant crown had significantly (F= 5.78; df= 2, 2.81; P= 0.0260) different squash bugs. Squash bugs on the crown of untreated watermelon plants were greater than on crown of SRP treated watermelons and watermelons in the trap crop fields. Old and young leaves of all the treatments had similar numbers of squash bugs (Table 2).

During the late sampling, adult squash bugs on old leaves of watermelons in the trap crop fields, SRP treated and untreated watermelons were significantly (F= 114.86; df= 2, 5169; P= 0.0001, F= 125.58; df= 2, 5169; P= 0.0001 and F= 86.11; df= 2, 5169;

P= 0.0001 respectively) greater than on the plant crown and young leaves. Plant crown and young leaves of all the treatments had similar numbers of squash bugs. Across the treatments, squash bugs on crown, young and old leaves were similar for all the treatments.

In the early sampling, squash bug eggs were low across plant parts within and across treatments. Some eggs were found on the crown of watermelon plants in the trap crop fields and in untreated watermelons while old leaves of SRP treated and untreated watermelons had some eggs. No eggs were recorded on young leaves of all the treatments.

During the late sampling period, squash bug eggs on plant parts of watermelons in the trap crop fields and SRP treated watermelon were significantly (F= 22.28; df= 2, 5169; P= <0.0001, F= 111.33 df= 2, 5169; P= <0.0001) different across plant parts. However, eggs on parts of untreated watermelons were not significantly (F= 2.53; df= 2, 5169; P= 0.0769) different. No squash bugs were found on the crown of watermelons in the trap crop fields and untreated watermelons. Old leaves of SRP treated watermelons and watermelons in the trap crop fields had greater egg numbers as compared to the young watermelon leaves. Across treatments, eggs on old leaves of watermelon plants were significantly (F=22.39; df= 2, 7.04; P=0.0009) different. Old leaves of SRP treated watermelons had greater egg numbers and followed by old leaves of untreated watermelons and watermelons in the trap crop fields (Table 2).

During the early sampling of 2002 when watermelons were planted earlier than 2001, squash bug nymphs were not found in watermelons in all the treatments. In the late sampling, most of the squash bug nymphs were found on the plant crown and old leaves.

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No squash bugs were found on young leaves of watermelons for any of the treatments. Squash bug nymphs on old leaves were significantly (F= 19.99; df= 2, 5169; P= <0.0001, F= 12.89; df= 2, 5169; P= <0.0001 and F= 9.53 df= 2, 5169; P= <0.0001 respectively) greater than on plant crowns for all treatments (Table 2). Squash nymphs across treatments were not significantly different for all plant parts.

Distribution of squash bugs within watermelon fields (Trial I.)-in the early samplings, adult squash bugs were significantly (F= 2.7; df= 2, 546; P= 0.0681) different at the corner of watermelon fields across the treatments while edge and middle of the fields were not significantly (F= 1.26; df= 2, 545; P= 0.2858 and F= 1.98; df= 2,544; P= 0.1398 respectively) different.

Adult squash bug populations in the corner of watermelon fields in the trap crop fields were significantly less as compared to squash bug populations in the corner of SRP treated and untreated watermelon fields (Table 3). Squash bugs in the corner of carbofuran treated and untreated watermelon fields had similar squash bug populations. Adult squash bugs in the corner, edge and middle of watermelon fields in the trap crop, SRP treated and untreated watermelon fields were not significantly (F= 0.48; df= 2, 785; P= 0.6207, F= 0.61; df= 2, 784; P= 0.5431 and F= 0.18; df= 2, 786; P= 0.8375 respectively) different. Spatial distribution of adult squash bugs within the fields across field sections was similar.

In the late sampling, adult squash bugs in the corner, edge and middle of watermelon fields across treatments were significantly (F= 14.23; df= 2, 431; P= 0.0001, F= 12.32; df= 2, 431; P= 0.0001 and F= 6.36; df= 2, 430; P= 0.0019 respectively) different (Table 3). Corner, edge and middle of SRP treated watermelon fields had

greater squash bugs as compared to corner, edge and middle of untreated watermelons and watermelons in the trap crops. Corner and edge of untreated watermelons had more squash bugs than corner and edge of watermelons in the trap crop fields while middle of both treatments had similar numbers of squash bugs (Table 3).

During the early sampling, squash bug eggs were found only in the edge of watermelons in the trap crop fields. In SRP treated watermelon fields, squash bug eggs were significantly (F= 5.19; df= 2, 789; P= 0.0058) different across field sections. Eggs in the corner of the watermelon fields were greater as compared to in edge and middle sections. Edge and middle sections of the field had similar egg numbers. Squash bug eggs in untreated watermelons and watermelons in the trap crop fields were not significantly (F= 0.67; df= 2, 789; P= 0.5101) different across field sections.

Across the treatments, Squash bug eggs in the corner of SRP treated watermelon fields were significantly (F= 4.47; df= 2, 572; P= 0.0119) greater than the corner of untreated watermelons (Table 3). Squash bug eggs in the edge and middle of the watermelon fields were not significantly (F= 1.72; df= 2, 572; P= 0.1806 and F= 0.25; df= 2, 572; P= 0.7800 respectively) different across treatments.

During the late sampling, squash bug eggs were not significantly different across field sections within the fields for all the treatments. However, across the treatments squash bug eggs in the corner and edge of watermelon fields were significantly (F= 2.78; df= 2, 572; P= 0.0633 and F= 6.33; df= 2, 325; P= 0.0020 respectively) different. The corners of untreated watermelon fields had similar numbers of squash bug eggs to the corner of SRP treated watermelon fields but greater than in the corners of watermelons in the trap crop fields. Squash bug eggs in the corner of carbofuran treated watermelons and

watermelons in the trap crop fields were not different. Squash bug eggs in the edge of untreated and SRP treated watermelons were similar while the edge of both treatments had more squash bug eggs as compared to the edge of watermelons in the trap crop fields (Table 3).

In the early sampling period, squash bug nymphs in the corners of watermelon fields were significantly ($F= 2.65$; $df= 2, 575$; $P= 0.0718$) different across the treatments. Squash bug nymphs in the edge and middle of fields were not significantly ($F= 0.17$; $df= 2, 574$; $P= 0.8440$ and $F= 0.00$; $df= 2, 474$; $P= 1.0000$ respectively) different across the treatments. Within the same treatment, field sections of SRP treated watermelons had significantly ($F= 2.44$; $df= 2, 45.6$; $P= 0.0983$) different squash bug nymphs. The corners of SRP treated watermelon fields had more squash bug nymphs as compared to corner of untreated watermelon fields. In SRP treated watermelon fields, corners had more nymphs than the edges.

In the late sampling period squash bug nymphs in the edge of the fields were significantly ($F= 4.75$; $df= 2, 335$; $P= 0.0092$) different across treatments while other sections of the fields had similar number of squash bug nymphs. There were more squash bug nymphs in the edge of SRP treated and untreated watermelon fields than in the edge of watermelons in the trap crop fields. Squash bug nymphs in the edge of carbofuran treated and untreated watermelons fields were similar.

Distribution of squash bugs within watermelon fields (Trial II) - in the early sampling period, within the same treatment all field sections had similar numbers of adult squash bugs for all treatments (Table 4). Across the treatments, corners of watermelon fields had similar ($F= 0.85$; $df= 2, 415$; $P= 0.4283$) squash bug populations. Squash bugs

in the edge and middle of the treatments were significantly (F= 2.30; df= 2, 415; P= 0.1019 and F= 6.02; df= 2, 415; P= 0.0026 respectively) different. Squash bugs in the edge of untreated watermelon fields were greater in number than in the edge of SRP treated watermelons, but similar to the edge of watermelons in the trap crop fields. Squash bugs in the edge of SRP treated watermelons were similar to the edge of watermelons in the trap crop fields (Table 4). Squash bugs in the middle of untreated watermelon fields were greater than in the middle of SRP treated watermelons and watermelons in the trap crop fields. There was not a significant difference between squash bug numbers in the middle of SRP treated watermelons and watermelons in the trap crop fields (Table 4).

In the late sampling period, across field sections squash bugs were similar for all the treatments. Across the treatments, the edges of fields were significantly (F= 3.54; df= 2, 377; P= 0.0300) different while corner and middle of the fields had similar number of squash bugs. Adult squash bugs in edge of watermelons in the trap crop fields and SRP treated watermelon fields were significantly greater than in edge of untreated watermelon fields. Edge of carbofuran treated watermelon fields had similar squash bug populations in the edge of watermelons in the trap crop fields (Table 4).

In the early sampling period, squash bug eggs were very low as compared to late sampling period for all the treatments. Some squash bug eggs were found on the edge of the fields for all the treatments. No significant egg differences were detected across the field sections and across the treatments.

In the late sampling period, Squash bug eggs were similar across the field sections for all the treatments (Table 4). Across the treatments, squash bug eggs in the edge and

middle of watermelon fields were significantly (F= 7.13; df= 2, 380; P= 0.0009 and F= 7.51; df= 2, 380; P= 0.0006 respectively) different; while squash bug eggs in the corner of watermelon fields were not significantly (F= 1.45; df= 2, 380; P= 0.2368) different. Squash bug eggs in the edge and middle of SRP treated watermelon fields were greater as compared to squash bug eggs in the edge and middle of untreated watermelon fields and watermelon in the trap crop fields. Squash bug eggs in edge and middle of untreated watermelons and watermelon in the trap crop fields were similar.

In the early sampling period, no squash bug nymphs were found in fields of all the treatments but there were a few in the middle of untreated watermelon fields (Table 4). In the late sampling, nymphs were found in all sections of the fields for all the treatments. Nymphs were not significantly different across field sections within the treatments and across the treatments within the field sections. In general, sections of watermelons in the trap crop fields had relatively higher nymphs as compared to the other treatments. However, none of the differences were statistically significant.

DISCUSSION

Squash bug distribution within watermelon plant parts- In 2001 during the early sampling, adult squash bugs were found more concentrated around the watermelon plant stem and crown. Few squash bugs were found on old leaves while no squash bugs were recorded on young leaves. In the late samplings when watermelon plants were at late growth stages, squash bugs were found on all plant parts. However, squash bugs tend to be more aggregated on old leaves as compared to plant crown and young leaves. Old leaf sections covered relatively larger space as compared to the plant crown and young

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leaves. Therefore, greater numbers of squash bug in old leaves may be a result of proportional size of plant parts rather than squash bug preference.

In the early sampling period, most of the squash bug eggs were found on old leaves as compared to plant crown and young leaves. Although during early sampling most adult squash bugs were colonized on the plant crown, most of the eggs were laid on old leaves. The old leaves section was the major proportion of the plants. Those leaves generally were full grown larger leaves as compared to the plant crown and young leaves. Studies have shown that squash bugs prefer plants with larger leaves (Bonjour et al. 1990, Palumbo 1991a) for egg laying sites. Therefore, it could be due to better protection from larger watermelon leaves that provide a safe site for egg deposition and safety for young nymphs. During the late sampling, although most squash bug eggs were deposited on old watermelon leaves, some eggs were recorded on young leaves. During the late sampling, squash bug eggs were not deposited on the plant crown (Table 1).

In the early samplings, most of squash bug nymphs were found on the old leaves section which is an expected reason due to greater egg deposition on old leaves. Although old leaves of SRP treated watermelon had significantly greater egg numbers, lower squash bug nymphs were found. However the differences were not statistically significant across treatments (Table 1).

In 2002, during early samplings, more squash bug adults were found on the plant crown and old leaves for all treatments as compared to young leaves. In SRP treated watermelons and watermelons in the trap crop field, the plant crown and old leaves had similar squash bug numbers but significantly greater as compared to young leaves. In untreated watermelon fields the plant crown had more squash bugs as compared to old

and young leaves. Although all parts of untreated watermelon had more squash bugs as compared to other treatments, only squash bugs on the plant crown were statistically greater than the other treatments.

In the late sampling, adult squash bugs were found on all parts of watermelons. Squash bugs on old leaves had higher numbers than on the plant crown and young leaves. Squash bug distributions within plant parts were similar across treatments. The pest management systems had no effect on squash bug distribution within watermelon plants in the late season. The result was consistent with Palumbo et al. (1991b) findings in summer squash.

In the early sampling, few squash bug eggs were found on all parts of watermelon when watermelons were transplanted earlier than in 2001. Squash bug eggs were not found on young leaves for all treatments. During the late sampling, the majority of squash bug eggs were recorded on old leaves as compared to plant crown and young leaves. Old leaves of carbofuran treated watermelons had significantly greater squash bug eggs than old leaves of untreated watermelons and watermelons in the trap crop fields. Squash bug egg distributions within watermelon plants indicate a similar distribution pattern for both years. In both years fewer squash bugs were found on plant crown and young leaves. However, squash bug egg quantities were relatively greater in the early growth stage of year 2001 as compared to year 2002. In 2001, watermelon plants were planted later than in 2002. Therefore, the greater squash bug egg numbers in 2001 may be due to late planting date as compared to early transplanted watermelons in 2002. Environmental factors may affect laid egg numbers when plants are planted early in the season.

During the late sampling, squash bug nymphs were not found in watermelon for all the treatments. In the late sampling, squash bug nymphs on old leaves were greater than the plant crown for all treatments. No squash bug nymphs were found on young watermelon leaves across treatments.

During late sampling, most squash bug nymphs were found on the plant crown and old leaves while few nymphs were found on young leaves of untreated watermelons. The results in 2001 within plant distribution indicated that adult squash bugs can be found on all parts of watermelon plants, however more squash bugs can be found on old leaves. Squash bugs tended to lay fewer eggs on the watermelon plant crown and young leaves as compared to early growth stages and late growth stages as well. The data indicate that fewer squash bug nymphs were found in the early growth stages of watermelon plants. Although squash bugs move onto watermelon plants at early growth stages, nymph developments coincide with late watermelon growth stages. Fewer squash bug eggs and nymphs should be expected in the early sampling period expected when watermelons are planted/transplanted early in the season. A majority of nymph development in watermelon occurs in June-July in southern of Oklahoma.

Squash bug distribution within watermelon fields- To compare squash bug distribution within watermelon fields, in 2001 during the early sampling period, more adult squash bugs were found in the corners of the fields as compared to the edge and middle of the fields for all the treatments. The edge and middle of watermelon fields had similar squash bug populations. In the late sampling, all sections of SRP treated watermelon fields had more squash bugs as compared to other treatments. Squash bug distributions across field sections were not significantly different for all treatments in the

late sampling. The corners and edges of trap crop fields had fewer squash bugs as compared to corner and edge of untreated watermelons. Squash bugs were evenly distributed across field sections later in the season.

During the early sampling period, egg distributions across field sections were similar for all the treatments. Squash bug eggs increased in watermelon fields during late growth stages of watermelons for all the treatments, however the distribution did not change across the field sections as compared to the early sampling period.

Squash bug nymphs were not found in the middle of watermelons during early samplings across the treatments. Nymphs in the edge section of fields were similar across treatments. The corner of SRP treated watermelon fields had greater number of squash bugs than the edge of the fields. In the late sampling, nymph distributions in watermelon fields were similar across field sections for all the treatments.

In 2002, during the early sampling, adult squash bugs were not significantly different across field sections for all treatments. Squash bugs in the edge and middle of untreated watermelon fields were significantly greater than squash bugs in the edge and middle of SRP treated watermelons and watermelons in the trap crop fields. Although, squash bugs densities were different across the treatments, squash bug populations were evenly distributed across field sections. In the late samplings, there was a similar pattern of squash bug distribution across the field sections for all the treatments.

In the early sampling, most squash bug eggs were found in middle section of watermelon fields. There were relatively more eggs in the middle section of untreated watermelons and watermelons in the trap crop fields as compared to SRP treated

watermelons. However the differences were not statistically significant. In the late samplings, squash bug eggs were not different across the field sections for all treatments. The treatments had different densities of squash bugs when the same section of the fields was compared across the treatments. However, within the same treatment, squash bugs eggs were found evenly distributed across field sections.

During the early samplings, no squash bug nymphs were found in watermelon field sections within the treatments and across the treatments. In late sampling, squash bug nymphs were not different across field sections. Nymphs found to be evenly distributed across field sections for all the treatments. Although squash bug eggs in all sections of SRP treated watermelons were greater as compared the sections of untreated watermelons and watermelons in the trap crop fields, similar distribution patterns were not found for squash bug nymphs. Relative to egg populations, lower nymph populations were found in sections of SRP treated watermelons as compared to the other treatments.

CONCLUSIONS

Squash bug adults appeared to colonize around plant stem and plant crown during early watermelon growth stages. However, later in the season squash bug adults utilized all plant parts. The majority of squash bug adults were found on old watermelon leaves while fewer were recorded on young leaves. Although the majority of overwintered adult squash bugs colonized on the plant crown, fewer eggs were found on the plant crown and the majority of eggs were laid on old leaves. The result is consistent with previous studies (Bonjour et al. 1991, Palumbo 1991) that reported the preference of larger plant leaves for egg deposition. During early watermelon growth stages nymphs seemed to colonize old plant leaves in the close proximity of laid eggs. During late growth stages of

watermelon, squash bug nymphs seemed to arrange themselves around the plant crown and old leaves.

Early planted watermelon plants have a higher risk of squash bug attacks due to limited suitable host plants in fields by early spring. Adult squash bugs generally localize around watermelon stems and plant crowns in the early watermelon growth stages. Fewer eggs and almost no nymphs should be expected when watermelons planted/transplanted early in the season.

Squash bug eggs and nymphs were more often observed on old leaves of watermelon plants later in the season. Therefore, sampling efforts for eggs and nymphs should be focused on old leaves to increase accuracy of sampling. Late in the growth stages it appears that squash bugs do not prefer the plant crown for egg laying while nymphs do not prefer young watermelon leaves for feeding. However, eggs were found on young watermelon leaves, nymphs were found on old leaves and plant crown. Nymphs may move toward the middle parts of watermelon plants after hatching from eggs to seek safer places.

Squash bug adults appeared evenly distributed within watermelon fields especially for early planted watermelons. However, in the late planted watermelons, squash bug adults seemed to be aggregated in the corner of watermelon fields as compared to edge and middle of watermelon fields. Greater squash bug concentrations in the field corners could be due to first generation squash bug adults developing on other host plants than they move into watermelon fields. Although squash bug population densities were different across management systems, no significant differences were

detected across field sections. So the treatments affected squash bug population densities but not distributions across field sections.

In late planted watermelon fields, corners and edges of watermelon fields tended to have more squash bug eggs as compared to the middle of the fields. In early planted watermelon fields, squash bug eggs and nymphs were found to be very low in all sections of the fields in the early sampling period. Although, in the late growth stages of watermelon, squash bug eggs and nymph numbers were different across the field sections, the differences were not significant.

Overall, all life stages of squash bugs were found throughout watermelon fields. Although field corners tended to have more abundant squash bugs as compared to other field sections, no significant differences were found among field sections.

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Table 1. Spatial distributions of different life stages of squash bugs within watermelon plants across plant parts grown under different management systems in 2001. The sampling intervals throughout the growing season were classified as early and late sampling periods. Early sampling period included first 5 sampling intervals and late sampling period included the last 4 sampling intervals.

Life stage	Treatment	Sampling period					
		Early sampling			Late sampling		
		Plant section			Plant section		
		Crown	Old leaves	Young leaves	Crown	Old leaves	Young leaves
Adult	Trap crop	0.01 (b)	0.01	0.0	0.02ab	0.10a(b)	0.01b
	SRP	0.05a(a)	0.01b	0.0	0.24b	0.53a(a)	0.07b
	Untreated	0.05 (a)	0.03	0.0	0.13b	0.28a(b)	0.08b
Egg	Trap crop	0.0	0.02 (b)	0.0	0.0	0.33 (b)	0.0
	SRP	0.0	0.29 (a)	0.0	0.0	1.13a(a)	0.28b
	Untreated	0.05b	0.24a(a)	0.02b	0.0	1.58a(a)	0.44b
Nymph	Trap crop	0.0	0.03	0.0	0.02	0.16 (b)	0.0
	SRP	0.04	0.01	0.0	0.33b	0.65a(a)	0.0
	Untreated	0.0	0.02	0.0	0.30b	0.65a(a)	0.34b

LSMeans in column and row followed by different letter are significantly different (P=0.05).

Letter in the parenthesis compare column and letter without parenthesis compare row for each life stage and sampling period.

Table 2. Spatial distributions of different life stages of squash bugs within watermelon plants across plant parts grown under different management systems in 2002. The sampling intervals throughout the growing season were classified as early and late sampling periods. Early sampling period included first 5 sampling intervals and late sampling period included the last 4 sampling intervals.

Life stage	Treatment	Sampling period					
		Early sampling			Late sampling		
		Plant sections			Plant sections		
		Crown	Old leaves	Young leaves	Crown	Old leaves	Young leaves
Adult	Trap crop	0.07a(b)	0.08a	0.01b	0.18b	0.93a	0.05c
	SRP	0.07a(b)	0.09a	0.02b	0.14b	0.94a	0.03c
	Untreated	0.16a(a)	0.11b	0.04c	0.15b	0.79a	0.02c
Egg	Trap crop	0.10	0.0	0.0	0.0	1.52a(b)	0.10b
	SRP	0.0	0.03	0.0	0.01b	3.33a(a)	0.07b
	Untreated	0.08	0.04	0.0	0.0	0.57 (c)	0.21
Nymph	Trap crop	0.0	0.0	0.0	0.42b	1.18a	0.0
	SRP	0.0	0.0	0.0	0.02b	0.84a	0.0
	Untreated	0.0	0.0	0.0	0.29b	0.81a	0.0

LSMeans in column and row followed by different letter are significantly different (P=0.05).

Letter in the parenthesis compare column and letter without parenthesis compare row for each life stage and sampling period.

Table 3 Spatial distributions of different life stages of squash bugs within watermelon field across field sections grown under different management systems in 2001. The sampling intervals throughout the growing season were classified as early and late sampling periods. Early sampling period included first 5 sampling intervals and late sampling period included the last 4 sampling intervals.

Life stage	Treatment	Sampling period					
		Early sampling			Late sampling		
		Field sections			Field sections		
		Corner	Edge	Middle	Corner	Edge	Middle
Adult	Trap crop	0.01(b)	0.02	0.0	0.07(c)	0.09(c)	0.02(b)
	SRP	0.08(a)	0.05	0.04	1.21(a)	0.84(a)	0.77(a)
	Untreated	0.09(a)	0.07	0.07	0.74(b)	0.46(b)	0.27(b)
Egg	Trap crop	0.0	0.03	0.0	0.58(b)	0.19(b)	0.27
	SRP	1.01a(a)	0.02b	0.03b	1.33(ab)	1.54(a)	1.18
	Untreated	0.09 (b)	0.46	0.23	2.64(a)	2.38(a)	1.00
Nymph	Trap crop	0.0	0.06	0.0	0.66	0.23(b)	0.06
	SRP	0.14a(a)	0.03b	0.0	1.38	1.11(a)	0.44
	Untreated	0.01 (b)	0.04	0.0	1.27	1.54(a)	0.90

LSMeans in column and row followed by different letter are significantly different (P=0.05).

Letter in the parenthesis compare column and letter without parenthesis compare row for each life stage and sampling period.

Table 4. Spatial distributions of different life stages of squash bugs within watermelon field across field sections grown under different management systems in 2002. The sampling intervals throughout the growing season were classified as early and late sampling periods. Early sampling period included first 5 sampling intervals and late sampling period included the last 4 sampling intervals.

Life stage	Treatment	Sampling period					
		Early sampling			Late sampling		
		Field sections			Field sections		
		Corner	Edge	Middle	Corner	Edge	Middle
Adult	Trap crop	0.20	0.22(ab)	0.12(b)	0.83	1.28(a)	1.23
	SRP	0.29	0.19(b)	0.13(b)	0.91	1.24(a)	1.06
	Untreated	0.21	0.30(a)	0.35(a)	1.11	0.86(b)	1.04
Egg	Trap crop	0.06	0.17	0.0	1.41	1.43(b)	2.22(b)
	SRP	0.0	0.06	0.0	2.92	3.14(a)	4.41(a)
	Untreated	0.0	0.11	0.25	1.47	0.49(b)	0.53(b)
Nymph	Trap crop	0.0	0.0	0.0	1.44	1.66	1.65
	SRP	0.0	0.0	0.0	1.02	0.70	1.00
	Untreated	0.0	0.0	0.01	0.73	1.24	1.19

LSMeans in column and row followed by different letter are significantly different ($P=0.05$).

Letter in the parenthesis compare column and letter without parenthesis compare row for each life stage and sampling period.

CHAPTER V

DETERMINING THE SPATIAL DISTRIBUTION PATTERN OF

SQUASH BUG ADULTS EGGS AND NYMPHS IN

WATERMELON AND DEVELOPING A

SEQUENTAIL SAMPLING PLAN

ABSTRACT

Spatial distribution patterns of different life stages of squash bugs were determined in watermelon under different pest management systems. Analysis of data using Taylor's power law and Iwao's patchiness regression models indicated that squash bugs were overdispersed (aggregated) in watermelon. Taylor's power law provided a better fit for the data than did Iwao's patchiness model. Analysis of sampling variance revealed that 90% of sampling error was associated with the plant parts or location on the plant. Thus all plant parts should be included as a sampling unit for accurate population estimation in watermelon. Minimum required numbers of samples were determined by substituting a parameter of estimation from both models. To estimate mean adult squash bugs with 80% precision level in watermelon, 47 and 19 samples are required based on Taylor's power law and Iwao's patchiness regression model respectively. Sequential sampling models were developed for adult squash bugs based on 1 squash bug/plant or 2 squash bugs/plant action thresholds in seedless and open pollinated watermelons respectively. The application of these results to pest management research and decision making procedures for producers is discussed.

INTRODUCTION

The squash bug (*Anasa tristis*) is one the most important and widespread native pests of cucurbit crops in North America. It has been found to cause considerable damage especially to plants in the genus Cucurbita such as squash (Quintance 1899, Isley 1927, Beard 1940, Metcalf and Flint 1962, Fargo et al. 1988, Nechols 1987, Bonjour et al.1990). Host plants a have significant effect on development, life span, and reproduction of the squash bug (Bonjour and Fargo 1989, Bonjour et al. 1990). Squash bugs show the greatest preference for pumpkin followed by squash, watermelon and other cucurbits (Bonjour and Fargo 1989).

Unmated adult squash bugs overwinter and emerge from overwintering sites in spring (Beard 1940, Fargo et al. 1988). First generation nymph populations increase in abundance slowly prior to flowering and increase to large numbers during fruit harvest periods (Fargo et al. 1988, Palumbo 1991a).

The seasonal development of squash bug populations varies largely on different geographic locations. The insect is univoltine in northern regions (Nechols 1987), and oviposition occurs from June to September (Beard 1940). However, in more southern regions squash bugs can complete 2-3 generations per year with a prolonged mating and oviposition period (Fargo et al. 1988). In Oklahoma, squash bugs generally complete 2 to 3 overlapping generations (Fargo et al. 1988).

Significantly greater adult squash bug population densities were recorded on early planted squash plants containing greater numbers of larger leaves than on younger plants with fewer leaves (Palumbo et al.1991a). Large leaves may provide better oviposition sites, resulting in less competition for egg laying area and protection from natural

enemies as well (Bonjour et al. 1990). Large leaves near the ground provide better protection and feeding sites for newly hatched nymphs (Palumbo et al. 1991a). Egg masses and nymph populations were also more abundant on older and larger plants. Squash bug populations were more abundant on early planted cucurbits. However, squash bug populations always reach the greatest abundance at the flowering and fruit set stages regardless of planting date (Palumbo et al.1991a).

Determination of spatial and temporal distribution of a pest is important in accurate pest population density estimation for successful pest management. A study of spatial distribution and development of a sequential sampling protocol for squash bugs in squash was conducted by Palumbo et al. (1991b). However, spatial distribution of squash bugs in other host plants such as watermelon has not been conducted. Studies have shown that host plants influence spatial distribution and colonization of insect pests (Pires et al. 2000, Jones and Peruyero 2002). Although squash bugs mainly feed on pumpkin and squash (Bonjour et al. 1990), large populations of the pest were found on watermelon (Pair 1997, Edelson et al. 2002, 2003). Thus, it is expected that the spatial distribution and colonization of squash bugs would be different in watermelon as compared to summer squash. Therefore, the objectives of this study were (1) to determine the spatial distribution of different stages of squash bugs in watermelon, and (2) to determine an efficient means of sampling for squash bugs in watermelon.

MATERIALS AND METHODS

Spatial distribution pattern of squash bugs in watermelon was determined in 2001 and 2002. Experiments were conducted in 2001 at the Wes Watkins Agricultural Research and Extension Center (WWAREC) at Lane, OK, the USDA ARS Grazinglands Research facilities at El Reno and with a commercial producer at Caney, Oklahoma, and in 2002 at the Wes Watkins Agricultural Research and Extension Center at Lane and with two commercial production farms at Bennington, and Leon, Oklahoma.

To evaluate the effects of management systems on the spatial distribution of squash bugs, we used data from another study which was conducted to compare squash bug management practices. Two squash bug management practices were included in the study.

The treatments were as follows:

1- Standard recommended practice (SRP) - Furadan® 4F, carbofuran (2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) FMC, Philadelphia, PA, applied at a rate of 0.249 kg (AI)/ 1000 linear meters in a 18 cm band over the seed furrow, with monitoring of plants to detect pests followed with foliar applications of Thiodan® EC, endosulfon (hexachloro hexahydromethano-2,4,3-benzodloxathlepin-3-oxide)LLC, Eagan, MN, or Capture®2EC, bifenthrin ((2 methyl[1,1-biphenyl]-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl) 2,2-dimethyl propanecarboxylate) FMC, Philadelphia, PA, if pest populations exceed thresholds of 1 adult squash bug adult per plant at seedling stage (Edelson et al. 2002).

2- Trap crop system – summer squash transplanted around the perimeter of the watermelon field prior to emergence or transplanting of watermelon, with monitoring of

pests in the trap crop and watermelon, followed by foliar applications of Thiodan or Capture when pests occur in the trap crop or exceed thresholds of 1 adult squash bug per plant.

3- Untreated – watermelon planted without a perimeter trap crop and not treated with insecticides.

To control weeds and diseases, herbicide and fungicide were applied to watermelon fields as it was needed. Fields were hoed and cultivated to control weeds. Soil from all the fields was tested and fertilizer was applied at-planting based on Oklahoma Cooperative Extension Service recommendations (Motes and Roberts 1994).

Fields of similar size (approximately 0.4 ha) and cultural practices were established each year at 3 locations. In 2001, six fields were located at Lane, three fields at Caney and three fields at El Reno. In 2002, three fields were located at each of Lane, Bennington and Leon, Oklahoma. Watermelons were planted in the first week of May at Caney, in the third week of May at Lane, and in the second week of June at El Reno in 2001. In 2002, at all locations watermelons were transplanted in the last week of April.

Fields were evenly divided into 16 sub-sampling plots. Each of these plots was 11 x 20 meters in size and consisted of three 20 m long watermelon rows that were spaced apart. For each sub-sampling unit, three randomly selected plants were visually inspected for eggs, nymphs and adults of squash bugs at least once a week. Examination began at the seedling stage and continued until watermelon fruits reached maturity. During early stages of watermelon growth, all plant parts (leaf, stem and petioles) and the soil surface immediately underneath of each plant within a 20 cm radius of the stem, were examined for the presence of squash bugs. In the later plant growth stages (after the fifth

sampling interval) when plants were intertwined with one another, we confined our per area sampling unit to all foliage centered on the base stem of the plant within an area encompassing one half the distance between neighboring plants and rows (0.9×3.7m, plant by row space).

Data analysis:

The sample unit; data were sorted by location, sampling plots, plants and plant parts for each field and date. NANOVA (SAS Inst. 1997) was used to test variance components among strata. NANOVA can be used for the partitioning of the variation within each stratum to determine the number of divisions necessary and allow optimum allocation of a sampling program within each stratum (Pedigo and Buntin 2000). The sampling unit for the study was determined according to the greater variance component within the division. The determination of sampling units was based on data from untreated watermelon fields.

To determine spatial distribution of squash bugs in watermelon, means and variance for counts of adults, eggs and nymphs per plant were calculated for every treatment on each sample date. Data were analyzed (1) to compare data with known discrete distribution models and (2) to calculate indices determining distribution. Observed frequency of counts for each life stage of squash bugs for each sampling date were tested against three distribution models, Poisson (random), positive binomial and negative binomial using descriptive statistics (SAS Inst. 1997). Chi-square analysis was used to test the fit of each distribution. The model fitness was rejected when chi-square probability level was higher than 0.05.

The mean (m) and variance (s^2) of squash bugs were used to determine the spatial

distribution of squash bugs. Iwao's patchiness (1968) and Taylor's power law regression [log(s^2)=log(a) +b log (m)] (1961) were used to calculate indices of dispersion. Iwao's patchiness regression expresses mean crowding, $x^*=m + (s^2 / m)-1$, and the mean (m) using linear regression as $x^*=\alpha+\beta m$. The intercept of the regression α is defined as the index of basic contagion, and β is defined as the slope of the regression that indicates the density contagiousness coefficient and measures spatial distribution of populations. Dispersion estimate indices (β) can be used to classify dispersion patterns as random (β = 1), aggregated ($\beta > 1$) or regular ($\beta < 1$). Taylor's power law regression model expresses the relationship between variance (s^2) and means (m). The model express the relationship such that $s^2 = am^b$, where a is a function of sample size and b is the index of aggregation. Populations can be classified as aggregated ($b > 1$), random ($b = 1$) or uniform (b < 1). The probability of encountering the expected number of squash bugs for each sampling period and year was calculated using ECOSTAT software program (Young and Young 1998). The Pearson chi-square test was used for the "Goodness of Fit" test for each distribution to each set of counts. The fit was rejected if the probability of a chi-square test was higher than 0.05. Data were tested against three discrete distributions (Binomial, poisson and negative binomial).

The general linear model regression procedure (GLM) (SAS Institute 1997) was used to compute the regression of means and variances for Iwao's patchiness and Taylor's power law models. The student t-test was used to determine whether the intercept was significantly different than zero and if the slope was significantly different than 1 (α=0.05). The coefficients from Iwao's patchiness and Taylor's power law regression models were used to determine fixed-precision-level sampling numbers for

different stages of squash bugs in watermelon.

Development of a sequential sampling plan.

The minimum required sample size for different stages of squash bugs was determined by solving $n \geq \beta\text{-}1/ C^2$ for Iwao's patchiness regression (Young and Young 1998). β is the degree of the slope of Iwao's patchiness regression model, and C is predetermined level of precision of mean density. The mean density of squash bug populations with a specified coefficient of variation CV (*m*), were determined with the value of C. A minimum sample size for Taylor's power law was determined by solving Green's (1970) formula for $n = am^{b\text{-}2} /D^2$ where n is the number of plants required to be sampled to estimate population means with fixed levels of precision, *a* and *b* are coefficients from Taylor's power law regression, *m* is the squash bug density and D is the precision of population estimation. Average mean squash bug density across two years (2001 and 2002) was used in determination of minimum required number of samples when Green's (1970) formula used based on parameter of estimate from Taylor's power law regression.

Sequential sampling plans were developed by substituting Taylor's power law's parameter of estimate *a* and *b* or Iwao's patchiness' parameter of estimate α and β into Iwao's (1975) formula: $T_n = qm \pm t[q([a+1]m + [b-1]m^2)]^{1/2}$ (Boeve and Weiss 1998) where T_n is the upper and lower limit of the confidence interval for the cumulative number of squash bugs found, q is the number of samples required, *m* is the action threshold.

Prior to determining an action threshold for squash bugs in watermelon, hypothetical action thresholds were set for different stages of squash bug in watermelon.

For relatively expensive seedless watermelon at seedling stages, 1 adult squash bug/plant was set as action threshold while for open pollinated watermelon varieties at seedling stages 2 squash bugs/plant were assumed as action thresholds. Management of squash bug eggs and nymphs are assumed not to be critical for watermelon yield. However squash bug egg and nymph populations may effect the overwintering populations which are important for the following year's crops.

RESULTS

The results of analysis of variance for abundance of adult squash bugs in watermelon indicated that 6.18% of the variance was due to experimental blocks which were locations. 3.36% of the variance was related to plots within each field. Variance across plants within sampling plots was 0, indicating that plants have no effect on total variance components. The highest variance component of the total variance was for plant parts which had a variance of 90.45% (Table 1). When data were pooled across plant parts and analyzed, variance associated with watermelon plants was 70.59% of total variance, 19.04% of the variance was associated fields and 10.35% of the variance associated with plots. Analyze of variance indicated that there is a significant proportion of variance across plants in the field. Therefore, number of plants to be sampled is also important and minimum required number of samples should be followed.

The fact that the highest variance component was associated with plant parts indicating that no single plant part provides a good sample unit. Thus, all plant parts must to be examined for best estimation of population density. A sampling unit is the proportional area of the entire sampling field where arthropod counts are made (Pedigo and Buntin 2000). Due to large squash bug abundance (variability) across plant parts, all

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the plant parts were examined for squash bugs. The sampling unit was a watermelon plant until the fifth sampling interval. Later due to physical difficulties in separating one plant from another the sampling unit was confined to the area per plant (0.9×3.7m, plant by row space).

Squash bug densities in watermelon in 2002 were significantly (F= 67.53; df=1, 2709; P < 0.0001) higher than in 2001. However, the distribution of squash bugs within watermelon fields and across field sections was similar (F=0.66; df= 2, 2709; P=0.5189) for both years. Squash bug mean abundance and variance for each sampling date were compared with the Poisson distribution and the distributions fit to the model when squash bug mean abundance per plant was =< 0.1. However, at higher densities, the distribution did not fit to random (Poisson) distribution, indicating aggregated (negative binomial) distribution.

Adult squash bug mean abundance and associated variance were regressed as described by Iwao's patchiness and Taylor's power law regressions models for each year. Iwao's patchiness regression model provided a poor fit when compared with Taylor's power law for all the tests. The coefficients of determination (R^2) were 0.96 for Taylor's power law and 0.73 for Iwao's patchiness regression model when adult squash bugs were tested across 2001 and 2002. Taylor's power law provided a better fit for both years and with combined years as compared to Iwao's model. Squash bug densities did not affect the fit for Taylor's power law when squash bug populations increased. In 2001, adult squash bug densities were low when compared to 2002. The fit of Taylor power law was 0.97 in 2001 while in 2002 the fitness was 0.95 indicating adult squash bug density did not increased the fit of the model. Although Iwao's patchiness model provided a poor fit,

the model indicated aggregated adult squash bug distribution for 2001, 2002 and combined years (Table 2).

There were no significant differences in b and β values between data collected in 2001 and 2002. Therefore, data were pooled for Taylor's power law and Iwao's patchiness model across years to develop a general regression model for adult squash bugs. When data were tested across years using Taylor's power law and Iwao's model the fit of the models corresponded average fit of 2001 and 2002. Taylor's power law and Iwao's patchiness parameters of estimate, intercept and slope, were greater than 0 and 1 respectively indicating the pest aggregation.

Taylor's power law and Iwao's patchiness model indicated aggregated adult squash bugs distribution pattern. Therefore, to test fit of adult squash bug distribution pattern with the predicted distribution pattern, observed numbers of adult squash bugs for each year were compared with the expected number of squash bugs for negative binomial distribution models. Pearson's chi-square tests indicated a highly significant p-value (P=0.0001) for adult squash bug (Fig. 1 - 2) indicating lack of fit for negative binomial distribution. All stages of squash bugs were tested with the predicted model and no significant fit was obtained. Observed and expected numbers of all stages of squash bug were tested with other distribution models such as Poisson and binomial distribution. Squash bugs did not fit to any predicted model of distribution.

The observed numbers of adult squash bugs were not found to fit to the expected numbers of squash bugs as predicted by the theoretical distribution models. For all samples the numbers of observed 0's were similar to expected number of 0's for the negative binomial distributions. However, the numbers of observed and expected

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observations of 1 squash bug did not fit. Numbers of observations of 1 or 2 squash bugs were similar and sometimes the number of observed 2 squash bugs per sample were higher than number of observed 1 squash bug. Therefore, adult squash bug dispersion did not fit any model of distribution.

Analysis using Taylor's power law and Iwao's patchiness index models indicated that squash bug eggs were aggregated in watermelon when individual egg counts were analyzed. Similar to the result of adult squash bugs, Iwao's patchiness provided a poor fit as compared to Taylor's power law model when distribution of squash bug eggs was tested. The coefficient of determination for Iwao's patchiness regression model (R^2) was 0.15 and 0.41 in 2001 and 2002 respectively. In general, Taylor's power law provided a good fit for egg data were tested in 2001 and 2002. Iwao's patchiness index indicated the data fit a Poisson distribution in 2001 and aggregated distribution for 2002. However the coefficient of determination in 2001 was very low. Taylor's power law indicated data fit an aggregated distribution in 2001 and 2002 and the coefficient of determination was 0.95 and 0.94 respectively (Table 3).

Distribution pattern of squash bug egg mass was tested using Taylor's power law and Iwao's patchiness model. Iwao's patchiness model provided a poor fitness as compared to Taylor's power law. The coefficient of determination (R^2) was 0.0028 and 0.96 for Iwao's patchiness and Taylor's power law respectively. Thus the result from Iwao's patchiness model was ignored. The slope of Taylor's power law regression was less than 1 indicating regular egg mass distribution in watermelon (Table 4). Egg masses were obtained by dividing individual eggs using a divider of 15 (average number of egg

mass in watermelon). However, the transformation of individual egg may not correspond to actual egg mass.

Analysis using Taylor's power law and Iwao's model indicated aggregated squash bug nymph distribution in 2001, 2002 and combined years (Table 5). Slope of the regression model for Taylor's power law were higher when squash bug nymphs were tested as compared to adult squash bugs indicating nymph populations are more aggregated than adults in watermelon.

A common k value was calculated using a procedure described by Young and Young (1998). The value of the common k was 0.43 based on mean values and variance of data in 2002. The validity of the common k was tested using Pearson's chi-square test and the p value for the test was 0.0024. Therefore, the common k was rejected indicating lack of fit for a common k value for squash bug populations in watermelon. Estimation of a common k is desirable for developing a sampling program for over-dispersed populations (Southwood 1978).

Sampling plans

Based on analysis using Taylor's power law and Iwao's patchiness index a minimum required sample size for adult squash bug is 47 and 19 sample units based on 80% precision. Higher number of samples is required when a sequential sampling plan is developed based on Taylor's power law as compared to Iwao's patchiness. However, Iwao's patchiness model provided a poor fit when adult squash bug distribution pattern was determined. To estimate squash bug eggs in watermelon with 80% precision, 87 samples are necessary based on Taylor's power law and 39 samples are necessary based on Iwao's patchiness regression model. Minimum required number of samples for squash

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bug nymphs was 93 based on Taylor's power law and was 55 based on Iwao's patchiness regression. The greater aggregation of nymph populations in watermelon as compared to adult squash bugs increased minimum required number of samples to estimate nymph abundance with 80% precision.

Sequential sampling plans based on counting the number of adult squash bugs per plant and using two hypothetical action thresholds for seedless and open pollinated watermelon were developed. The sequential sampling plans (Appendix A-B) were developed by substituting the parameters of estimate from Taylor's power law and Iwao's patchiness regression into Iwao's (1975) formula. According to sequential sampling plan based on Taylor's power law, after sampling 47 (minimum required) plants for adult squash bugs and setting the action threshold at 1 squash bug/plant for seedless watermelon at the seedling stage insecticide treatment is warranted if > 64 adult squash bugs were tallied and no treatment is warranted if < 30 squash bugs were tallied. Sampling will continue if 30 < > 64 squash bugs were tallied. For open pollinated watermelons, setting the action threshold at 2 squash bugs / plant, after sampling 59 plants, insecticide treatment is warranted if > 129 squash bugs were tallied and no treatment is warranted if < 59 squash bugs were tallied. Based on the sequential sampling plan calculated using Iwao's power law regression for seedless watermelon plants at the seedling stage, after sampling 19 watermelon plants (minimum required samples) insecticide treatment is warranted if >31 squash bugs were tallied and no insecticide treatments is warranted if <7 squash bugs were tallied. Sampling will continue if 7< > 31 squash bugs were tallied. For open pollinated watermelons, insecticide treatment is warranted if >58 squash bugs were tallied and no insecticide treatment is warranted if

<18 squash bugs were tallied. The sampling will continue if 18 < >58 squash bugs were tallied.

DISCUSSION

Analysis of data using Taylor's power law and Iwao's patchiness models revealed that squash bugs are aggregated in watermelon as was reported for summer squash (Palumbo 1991b). However, adult squash bugs are less aggregated in watermelon as compared to squash. Taylor's power law provided a better fit for data than Iwao's patchiness regression. Similar results have been found for a wide range of organisms (Taylor et al. 1978; Taylor 1984).

Although Iwao's patchiness and Taylor's power law regression models indicated an aggregated regression pattern for squash bug adults, squash bug distribution at high density did not fit exactly to any theoretical distribution models. All prediction models assume a gradual level of decrease in the probability of finding 1, 2, 3, and so on individuals. However, our data indicated that observed numbers of 2 squash bugs per sample were greater or equal to observed numbers of 1 squash bug. Therefore, squash bug distribution did not fit to the theoretical distribution models. It seems that squash bugs have a unique distribution pattern. Squash bug adults tend to stay in the mating position (2 individuals coupled) for a prolonged period of time while feeding on the host plants. Thus mating behavior of squash bugs may results in the described aggregated pattern.

Squash bug egg and nymph distribution had a similar distribution pattern as with adult squash bugs. Adults more frequently lay eggs on the abaxial surface of host plants (Palumbo et al 1991a). Early instar nymphs tend to stay together up to the third and

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fourth instars and feed on leaves where egg masses were laid. Therefore, squash bug eggs and nymphs were likely found on the host plants in an aggregated pattern. However, when egg masses were tested using Taylor's law regression, the distribution pattern was a regular distribution.

Analysis using Taylor's power law and Iwao's patchiness models provided similar sampling plans. The minimum required number of samples for adult squash bugs in watermelon was less than Palumbo's (1989) findings in squash. In our studies with watermelon the minimum required number of samples was 47 based on Taylor's power law model in watermelon while in squash the minimum number of samples was 64 based on the same model (Palumbo 1989) with less precision. Palumbo's numbers were estimated with 75% precision while our results were based on 80% precision. The greater degree of aggregation and the greater numbers of samples are required estimating a pest population with a desired level of precision. Therefore, indications are that squash bugs are more aggregated in squash than in watermelon.

The sampling plans presented in this study were developed to be used by researchers, growers, and field scouts. The plans provide an estimated minimum sample size based on a set risk level. The sample numbers provided here are based on 80% precision of the mean. Depending on specific needs, the precision level could be increased to 90% precision of the mean for research purposes by increasing minimum required number of samples. In general for management purposes 75-80% precise estimate of mean density is acceptable. Information acquired in this study should aid watermelon growers in decision making procedures that will help to determine appropriate timing of insect control measures and increased pesticide resource use

efficiency. The sampling plan will be an important guideline for growers and decision makers to standardize adult squash bug management during early watermelon growth stages. The action thresholds used in the sampling plan are based on our best judgment. In the future should action threshold experimentally is determined then the sampling plan can be adapted to experimentally determined action threshold.

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Table 1. Nested Random effects analysis of variance component for adult squash bugs on watermelon in untreated fields. The smallest unit was a plant part.

Variance source	Mean square	Variance component	Percent of total
Total	0.47	0.50	100.00
Field	4.90	0.03	6.19
Plot	0.50	0.02	3.36
Plant	0.35	-0.03	0.00
Plant part	0.46	0.46	90.45
Error	--------	0.00	0.00

Table 2. Nested Random effects analysis of variance component for adult squash bugs on watermelon in untreated fields. Watermelon parts were removed from the model by combining adult squash bugs across plant parts as per plant. The smallest unit was a plant

Variance source	Mean square	Variance component	Percent of total
Total	0.47	0.48	100.00
Field	14.71	0.28	19.04
Plot	1.50	0.15	10.35
Plant	1.04	1.04	70.59
Error	--------	0.00	0.00

Table 3. Results of analysis using Taylor's power law and Iwao's patchiness regression methods to determine required plant samples for adult squash bugs taken from watermelon grown under different management systems.

Year	Taylor's power law			Iwao's patchiness		
	Intercept	Slope	R-Square	Intercept	Slope	R-Square
2001	0.98±0.07	1.20±0.03	0.97	0.76±0.14	1.65±0.13	0.79
2002	0.94±0.05	1.19±0.03	0.95	0.73±0.17	1.86±0.16	0.68
Pooled	0.96±0.04	1.19±0.02	0.96	0.76±0.11	1.76±0.10	0.73

Table 4. Results of analysis using Taylor's power law and Iwao's patchiness regression methods to determine required plant samples for squash bug eggs taken from watermelon grown under different management systems.

Year	Taylor's power law			Iwao's patchiness		
	Intercept	Slope	R-Square	Intercept	Slope	R-Square
2001	2.94±0.07	1.36±0.05	0.95	24.59±6.24	3.16±1.51	0.15
2002	3.18±0.08	1.32±0.06	0.94	18.12±1.77	2.00±0.44	0.41
Pooled	3.05±0.05	1.35±0.04	0.95	21.01±3.03	2.57±0.74	0.17

Table 5. Results of analysis using Taylor's power law and Iwao's patchiness regression methods to determine required plant samples for adult squash bug egg taken from watermelon grown under different management systems. Egg numbers were divided by 15 (average number of eggs per egg cluster) to obtain approximate number of egg mass per plant.

Year	Taylor's power law			Iwao's patchiness		
	Intercept	Slope	R-Square	Intercept	Slope	R-Square
2001	-1.22±0.08	0.68±0.03	0.96	-0.12±0.43	0.05±0.16	0.0046
2002	-1.47±0.06	0.61±0.02	0.97	-0.15±0.04	0.03±0.05	0.0014
Pooled	-1.35±0.05	0.64±0.02	0.96	-0.14±0.03	0.04±0.11	0.0028

Table 6. Results of analysis using Taylor's power law and Iwao's patchiness regression methods to determine required plant samples for adult squash bug nymphs taken from watermelon grown under different management systems.

Year	Taylor's power law			Iwao's patchiness		
	Intercept	Slope	R-Square	Intercept	Slope	R-Square
2001	2.70±0.13	1.55±0.08	0.96	11.46±3.28	3.89±1.06	0.46
2002	2.62±0.11	1.54±0.05	0.97	8.25±1.81	2.78±0.51	0.54
Pooled	2.66±0.08	1.54±0.54	0.97	9.81±1.72	3.18±0.52	0.45

Figure 1. Expected and observed adult squash bugs based on negative binomial
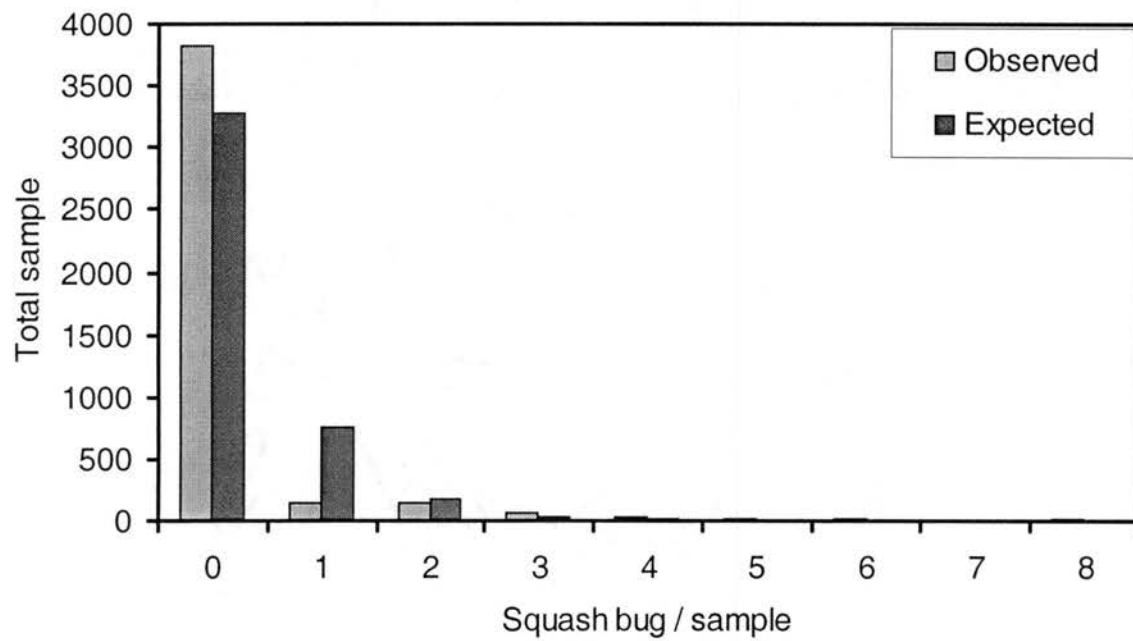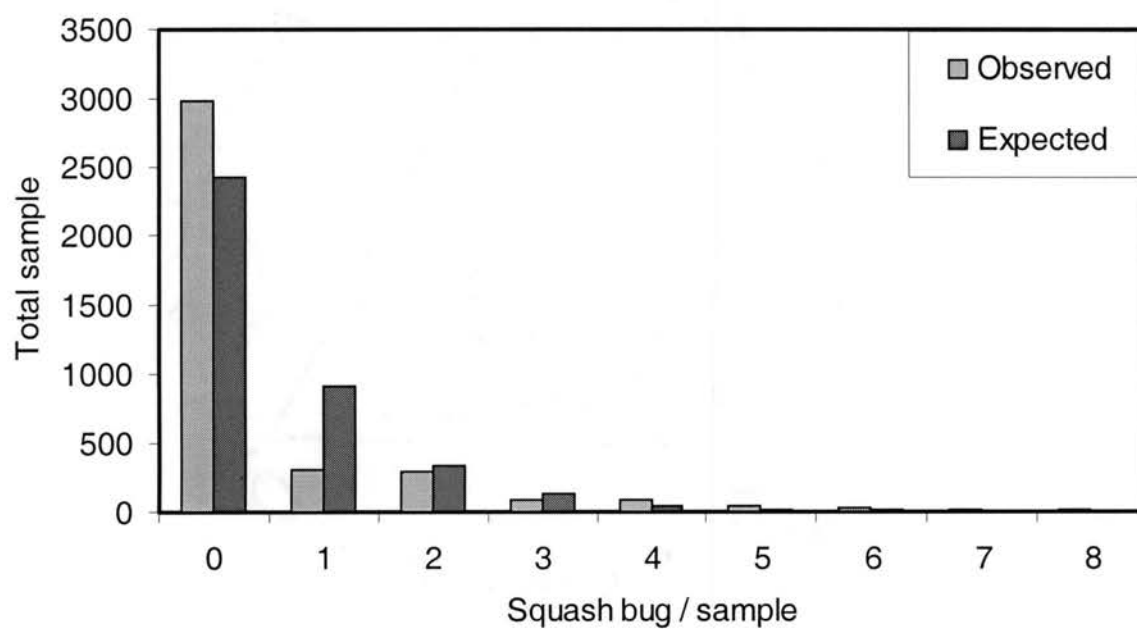
distribution in watermelon in 2001.

Figure 2. Expected and observed adult squash bugs based on negative binomial

distribution in watermelon in 2002.

APPENDIXES

Appendix A. Sequential sampling decision plans based on Taylor's power law for

squash bugs in watermelon and the setting action threshold at 1 squash bug/plant for

seedless and 2 squash bugs/plant for open pollinated watermelons.

Sample number	Cumulative number of adult squash bugs present			
	Action threshold= 1 SB/plant		Action threshold= 2 SB/plant	
	Lower limit	Upper limit	Lower limit	Upper limit
47	30	64	59	129
48	31	65	61	131
49	32	66	62	134
50	32	68	64	136
51	33	69	66	138
52	34	70	67	141
53	35	71	69	143
54	36	72	71	145
55	37	73	72	148
56	37	75	74	150
57	38	76	76	152
58	39	77	77	155
59	40	78	79	157
60	41	79	81	159
61	42	80	82	162
62	43	81	84	164
63	43	83	86	166
64	44	84	87	169
65	45	85	89	171
66	46	86	91	173
67	47	87	92	176
68	48	88	94	178
69	48	90	96	180
70	49	91	97	183
71	50	92	99	185
72	51	93	101	187
73	52	94	103	189
74	53	95	104	192
75	54	96	106	194
76	54	98	108	196
77	55	99	109	199
78	56	100	111	201
79	57	101	113	203
80	58	102	114	206
81	59	103	116	208
82	60	104	118	210
83	61	105	120	212
84	61	107	121	215
85	62	108	123	217
86	63	109	125	219
87	64	110	127	221
88	65	111	128	224
89	66	112	130	226

90	67	113	132	228
91	67	115	133	231
92	68	116	135	233
93	69	117	137	235
94	70	118	139	237
95	71	119	140	240

The sampling plan is based on Iwao's (1975) formula using Taylor's power law parameters (a=0.96 and

b=1.19) and confidence level of 90%. Sampling should be terminated if squash bug numbers are below the

lower limit or above the upper limit. Sampling should be continued when cumulative squash bug numbers

are between lower and upper limits. Squash bug management will be necessary when squash bugs above

the upper limit.

Appendix B. Sequential sampling decision plans based on Iwao's patchiness model for squash bugs in watermelon and setting the action threshold at 1 squash bug/plant for seedless and 2 squash bugs/plant for open pollinated watermelons.

Sample number	Cumulative number of adult squash bugs present			
	Action threshold= 1 SB/plant		Action threshold= 2 SB/plant	
	Lower limit	Upper limit	Lower limit	Upper limit
19	7	31	18	58
20	8	32	19	61
21	9	33	21	63
22	9	35	22	66
23	10	36	24	68
24	11	37	25	71
25	11	39	27	73
26	12	40	28	76
27	13	41	30	78
28	14	42	31	81
29	14	44	33	83
30	15	45	35	85
31	16	46	36	88
32	17	47	38	90
33	17	49	39	93
34	18	50	41	95
35	19	51	43	97
36	20	52	44	100
37	21	53	46	102
38	21	55	47	105
39	22	56	49	107
40	23	57	51	109
41	24	58	52	112
42	25	59	54	114
43	25	61	56	116
44	26	62	57	119
45	27	63	59	121
46	28	64	61	123
47	29	65	62	126
48	29	67	64	128
49	30	68	66	130
50	31	69	67	133
51	32	70	69	135
52	33	71	71	137
53	33	73	72	140
54	34	74	74	142
55	35	75	76	144
56	36	76	77	147
57	37	77	79	149
58	38	78	81	151
59	38	80	83	153
60	39	81	84	156
61	40	82	86	158

62	41	83	88	160
63	42	84	89	163
64	43	85	91	165
65	43	87	93	167
66	44	88	95	169
67	45	89	96	172
68	46	90	98	174
69	47	91	100	176
70	48	92	101	179
71	48	94	103	181
72	49	95	105	183
73	50	96	107	185
74	51	97	108	188
75	52	98	110	190
76	53	99	112	192
77	54	100	114	194
78	54	102	115	197
79	55	103	117	199
80	56	104	119	201

The sampling plan is based on Iwao's (1975) formula using parameters ($\alpha=0.76$ and $\beta=1.76$) and confidence level of 90%. Sampling should be terminated if squash bug numbers are below the lower limit or above the upper limit. Sampling should be continued when cumulative squash bug numbers are between lower and upper limits. Squash bug management will be necessary when squash bugs above the upper limit.

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