DEVELOPMENT OF MANAGEMENT STRATEGIES FOR SQUASH BUG (HETEROPTERA: COREIDAE) POPULATIONS IN SUMMER SQUASH

By

JOHN CHARLES PALUMBO

Bachelor of Science in Agriculture
University of Arizona
Tucson, Arizona
1982

Master of Science
University of Arizona
Tucson, Arizona
1985

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
December, 1989

DEVELOPMENT OF MANAGEMENT STRATEGIES FOR SQUASH BUG (HETEROPTERA: COREIDAE) POPULATIONS IN SUMMER SQUASH

Thesis Approved:

W Scott Fargo
Thesis Adviser

Richard Berberet

Ronald W. McNew

Norman N. Durham
Dean of the Graduate College

PREFACE

Research was conducted from 1986-1988 to quantify the damage potential and distribution of squash bug populations in summer squash for the development of a pest management program. Results of these investigations are presented in four separate and complete manuscripts to be submitted to scientific journals. Each chapter in this thesis was prepared following guidelines for manuscript preparation as established by the Entomological Society of America.

It is necessary to acknowledge several individuals for their contributions to this research. Special thanks and gratitude to Dr. W. Scott Fargo, colleague and friend, for his guidance, support, and assistance throughout my studies and research. I also extend sincere gratitude to the individuals on my graduate committee; Dr. Richard Berberet, Dr. Bob Cartwright, Dr. Gerrit Cuperus, and Dr. Ron McNew, for their guidance in developing the research protocols and critical reviews of the dissertation.

I am sincerely grateful to Edmond Bonjour for his assistance and collaboration with all of the research that was conducted. In addition, thanks to W. David Woodson and Dr. Jim Criswell for their collaboration in several areas of this study.

I would like to acknowledge and thank the following individuals who provided technical services, and research equipment or space; Dr. Jim Motes, Dr. Dean McCraw, Dr. W. Dennis Scott, Bruce Bostien and Ken Karner, Department of Horticulture, OAES; Dr. Robert Burton, Dr. Jim Webster, Dr. Gary Puterka and John Burd, USDA-ARS; Dr. Ken Conway, Department of Plant Pathology; Dr. Jack Dillwith, Dr. Doug Bergman, Paul Neece, Sandra Francis, Renee Bonjour and Heidi Brooks, Department of Entomology. Without their support, the results reported in this manuscript would be incomplete. I would also like to extend my appreciation to Dr. L.A. Crowder for providing me the opportunity to pursue this graduate program.

Finally, I would like extend special thanks and gratitude to my families; Joseph and Joan Palumbo, for providing constant support and motivation, and for teaching me that hard work and honesty will provide the path for achieving my goals ; Harold and Terry Faber, for their support and encouragement throughout my tenure at OSU; and most importantly, I express my deepest appreciation to my wife, K.C., and son Michael, who sacrificed much during my professional endeavors, and yet have always been loving and understanding. To my family I dedicate this manuscript.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

Chapter III

Chapter IV

Chapter V

Chapter VI

LIST OF FIGURES

Figure Page

Chapter III

Chapter IV

Chapter V

Chapter VI

CHAPTER I

INTRODUCTION

Introduction

To be competitive in the vegetable industry, growers must be able to produce a quality crop acceptable to the consumer. However, it is difficult to produce vegetables profitably unless pests are controlled with maximum efficiency at a minimum cost. The squash bug, Anasa tristis (De Geer), has long been considered a key pest to squash and melon producers. Traditional cultural and mechanical control methods, such as hand removal of eggs and nymphs from plants, are time and labor consuming and therefore impractical to utilize on a commercial level. Control with insecticides is often ineffective due to adult tolerance to the active compounds and problems in directing sprays onto eggs and nymphs under leaves. The high cost of insecticide applications relative to the fluctuating market value of the crop may further deter growers from attempting to control high populations. Because infestations of squash bugs occur annually, it is important that efficient control strategies be developed for future management of this pest.

The primary reason for conducting this research was to develop an efficient and economical means of controlling squash bugs based on IPM principles. Cucurbit growers rely almost entirely on insecticides to control squash bugs. Timing of chemical control has typically not been based on quantitative assessments of infestations, but rather the casual observance of nymphs on plants or foliar wilting. These criteria lack a scientific basis and often result in poorly timed applications. More importantly, there is a lack of information concerning cucurbit yield losses in relation to squash bug density levels.

The research reported herein was an attempt to improve summer squash production through the management of squash bug populations. There is a need for defining treatment decision rules based on population assessments where none have previously existed. Because of the pests high potential for population increase and difficulties in control later in the season, a management approach to this problem is requisite. The concept of action thresholds, based on reliable estimates of infestation, offers a feasible solution. Therefore, yield vs. infestation relationships will be important to the outcome of these study. In addition, further investigations of population dynamics of squash bugs in relation to plant phenology are important in defining the critical time to initiate control. Finally, because precise assessments of infestation are required in a management program, a defined sampling program will be necessary based on quantitative analysis of spatial dispersion.

CHAPTER II

LITERATURE REVIEW

Literature Review

The squash bug, Anasa tristis (DeGeer), (Hemiptera: Coreidae) is a native North American pest of cucurbit crops. It is generally recognized as the primary pest responsible for causing crop losses in summer squash and pumpkins, Cucurbita spp., which are it's most preferred hosts (Elliot 1935, Bonjour et al.t al. 1990). The squash bug is commonly found throughout the Western Hemisphere (Britton 1919) and is considered a serious economic pest in Oklahoma.

The seasonal history of the squash bug varies largely on geographic location. In northern areas the insect is univoltine (Beard 1940a), with oviposition beginning in June and continuing until September. In more southern regions, mating and oviposition may be extended, resulting in 2-3 generations per year (Nechols 1987). There are generally 2 generations of squash bugs per year in Oklahoma, but a third generation may be completed prior to overwintering when favorable environmental conditions prevail (Fargo et al. 1988).

Squash bugs overwinter as unmated adults and are believed to find shelter under tree bark, in and around buildings, and in field debris (Weed and Conradi 1902). It was originally believed that they overwintered in a quiescent state, allowing the adults early access to squash crops during mild spring conditions (Wadley 1920). However, recent findings by Nechols (1987) and Fielding (1988) indicates that female squash bugs enter into diapause in late summer, and is terminated prior to seeking host material in the spring. Based on yearly reports, the average first occurrence of adult bugs in squash in Oklahoma is May 18th (Don Arnold, personal communication).

Squash bug and summer squash seasonal development was recently investigated in Oklahoma (Fargo et al. 1988). Results of that study showed that development of squash plants followed a sigmoid-shaped growth curve throughout the season. Similarly, squash bug populations were also shown to increase seasonally in a curve-linear manner. Upon entering squash plots from overwintering sites, female adults oviposited large numbers of eggs early in the season. The F_1 nymphal population increased the overall number of squash bugs in the field. More importantly, the development of F_1 adults caused a dramatic increase in the total population, which appeared to increase at an exponential rate thereafter.

Summer squash plants are very vulnerable to feeding damage. Seedling plants are especially susceptible to damage by overwintering adults and newly-hatched nymphs (Beard 1935). The bugs usually confine their feeding to the undersides of leaves and stems, often resulting in a dried and burned appearance of leaves, wilting of branches and possibly plant death (Pack 1930). Balduf (1950) attributed this plant response to enormous quantities of plant fluid extracted during feeding. Beard (1940a) observed that young seedlings bearing only cotyledon leaves or very few true leaves are easily killed by feeding of large numbers of bugs. As the plants get larger, they become more vigorous and able to withstand feeding damage and are killed only if extremely large numbers of squash bugs are present. However, feeding by nymphs on fruit bearing plants can often result in substantial crop losses, either as a result of leaf wilting or death of plant parts (Eichmann 1945). Fargo et al. (1988) observed that feeding damage by large numbers of squash bugs caused a reduction in potential fruit harvest. They further observed a decline in plant growth coincident to the insect population increase and attributed this to a reduction in plant photosynthesis.

For the commercial squash producer, control of squash bugs is required each season. Control by mechanical and physical practices was first suggested by early researchers (Chittendon 1899, Hoerner 1938), but are mainly practiced in small, home garden plots. On large commercial plantings, control is usually attempted with cultural practices and insecticide applications. However, a reliable and economical pest management approach has not yet been developed for controlling squash bugs in commercial cucurbits.

Cultural control is probably the most ecological and economical sound IPM strategy available to growers (Watson et al. 1976). For example, the time at which squash is planted may influence the eventual damage that squash encounters. Beard (1940a) noted that squash plants which had been planted late in the season suffered severe damage to the seedlings, whereas plants emerging early produced fruit normally. Consequently, Rensner (1986) speculated that early planting of squash may allow plants to complete the majority of development before nymphs reach damaging levels.

Avoiding yield losses by planting two crops of squash in sequence, such that the first crop receives the bulk of the infestation and destroyed when the second crop comes into bearing has been previously suggested (Beard 1940a). It was observed in Connecticut, that squash bug populations were consistently lower in pumpkins, than in summer squash (Beard 1940b). This was attributed to the fact that summer squash is planted earlier than the winter varieties, essentially serving as a trap crop. In addition, because squash is a preferred cucurbit, summer squash has been used successfully as a trap crop to protect cantaloupes, Cucumis melo L., and other less preferred cucurbits (Eichmann 1945).

Chemical control is the primary method of controlling squash bugs by commercial growers. Many early studies (Beard 1938, Elliot 1955, Gould 1951) indicated that successful control of squash bugs with insecticides is quite variable. Adult squash bugs exhibit a high degree of tolerance to most insecticides and are particularly difficult to kill (Harris and Matsumori 1955). In contrast, Watkins (1946) reported that insecticides showed considerably more toxicity to newly-hatched nymphs, but as they matured efficacy was reduced. Similarly, Criswell (1987) determined that first and second instars are the most susceptible life stages to currently registered materials.

Because of the difficulties in killing adults and large nymphs, chemical control can often be unreliable and result in failure to adequately suppress large populations. A number of studies have been reported on field evaluations of insecticides for controlling squash bugs (Beard 1938, Isley 1940, Harries and Matsumori 1955, Wright and Decker 1955). Results from these studies indicated that control was often ineffective. However, the insecticides used in those studies have since become obsolete.

More recently, researchers have reported better success controlling squash bugs with organophosphate and pyrethroid insecticides. Squash plants treated with methomyl had consistently fewer egg masses oviposited on them than any other treatment (Latheef and Ortiz 1982). Beevers and Santaro (1985) reported significant reductions in populations after pumpkin plants were treated with cypermethrin or permethrin. Similarly, Criswell (1987) observed that squash plants treated with cypermethrin and fenvalurate contained significantly fewer numbers of nymphs than those in untreated plots. Recent studies in Arkansas demonstrated that cyfluthrin and esfenvalurate provide excellent control of nymphs and adults (McLeod 1986).

The timing of insecticide applications for controlling squash bugs populations in cucurbits is essential for maximal effectiveness. Eichmann (1945) suggested that chemical control be initiated to protect seedlings when eggs begin to hatch. According to Oklahoma State University recommendations (Motes & Cuperus 1986), it is suggested that commercial cucurbit growers time insecticide applications when egg hatch is at a maximum. Since populations are lowest during the early season (Fargo et al. 1988), it seems logical that applications directed at newly-hatched nymphs during this period would be most effective in suppressing population growth.

Watson et al. (1976) stated that the four elements basic to any IPM program are natural control, knowledge of the ecology and biology of the pest and host, sampling, and economic levels. Natural control, and the biology and ecology of squash bugs in cucurbits is well documented (Beard 1935,1940a, Balduf 1950, Wadley 1920, Worthley 1923, Nechols 1988, Fargo et al 1988). Although squash bug infestations occur annually, economic thresholds and sampling methodologies for this pest in cucurbits have not yet been developed.

The mere presence of an insect pest on some fresh market vegetables may trigger decisive actions, often with insecticides, whether needed or not. The economic threshold (ET), as proposed by Stern et al. (1959), was developed as a partial solution to the problem of the unwarranted use of pesticides. The ET takes into account the potential reduction in crop value as a result of damaging pest densities and the cost required to maintain crop yields at or above profitable levels. Because of the practical limitations in sampling cucurbits (Edelson 1986) and the dynamic fluctuation of the wholesale vegetable market (Motes & Cuperus 1986) development of ET's for squash bug management in cucurbits has been seriously neglected.

Norton (1976) has proposed action thresholds as an alternative decision guideline. The action threshold is very similar to the traditional ET as defined by Stern et al. (1959), but includes the efficacy of control measure. Regardless of method used, these thresholds base management decisions on the level of pest population or injury level at which action tactics will optimize profits. Cancelado and Radcliffe (1979) defined action thresholds in potatoes as the appropriate pest density at which insecticide applications are to be initiated. Furthermore, action thresholds are currently being used in cole crop and cabbage production, where previously insecticide control was based on scheduled applications (Cartwright et al. 1987).

References Cited

Balduf, W.V. 1950. Problems in the bionomics of the squash bug, Anasa tristis (DeGeer) (Coreidae: Hemiptera). Illinois Acad. Sci. Trans. 43:244-248.48.

Beard, R.L. 1935. Further observations on the squash bug in Connecticut, pp 333-339. In Connecticut Agricultural Experiment Station Bulletin 383, New Haven.

Beard, R.L. 1938. Control of the squash bug, pp 243-248. In Connecticut Agricultural Experiment Station Bulletin 248, New Haven.

Beard, R.L. 1940a. The biology of Anasa tristis DeGeer, pp 31-51. In Connecticut Agricultural Experiment Station Bulletin 440, New Haven.

Beard, R.L. 1940b. Control of squash insects, pp 284-287. In Connecticut Agricultural Experiment Station Bulletin 434, New Haven.

Beevers, M.H. & T. Santoro. 1985. Squash Bug Control, p. 210. In Insecticide and acaricide tests, vol 10. Entomological Society of America, College Park, Md.

Britton, W.E. 1919. Insects attacking squash, cucumber, and allied plants in Connecticut, pp 31-23. In Connecticut Agricultural Experiment Station Bulletin 216, New Haven.

Bonjour,E.L., W.S. Fargo & P.E. Rensner. 1989. Ovipositional preference of squash bugs, Anasa tristis, (Heteroptera:Coreidae) in cucurbits. Environ. Entomol. 18: (In Press).

Cancelado, R.E. & E.B. Radcliffe. 1979. Action thresholds for potato leafhopper on potatoes in Minnesota. J.Econ. Entomol. 72:566-569.

Cartwright, B., J.V. Edelson, & C. Chambers. 1987. Composite action thresholds for the control of lepidopterous pests on fresh-market cabbage in the lower Rio Grande Valley of Texas. J. Econ. Entomol. 80:175-181.

Chittenden, F.H. 1899. Some insects injurious to garden and orchard crops. USDA, Div. Entomol., Bull. No. 19:1-99.

Criswell, J.T. 1987. Studies in the control of the squash bug, _Anasa tristis_, De Geer, pp. 109. Ph. D. dissertation, Oklahoma State Univ., Stillwater.

Edelson, J.V. 1986. Comparison of sampling methods for insect pests of cantaloupe. J. Econ. Entomol. 79: 266-270.

Eichmann, R.D. 1945. Squash bug depredations in Washington. J. Econ. Entomol. 38:110-112.

Elliot, D.C. 1935. The squash bug in Connecticut, pp 224-331. _In_ Connecticut Agricultural Experiment Station Bulletin 368, New Haven.

Fargo, W.S., P.E. Rensner, E.L. Bonjour, & T.L. Wagner. 1988. Population dynamics in the squash bug (Heteroptera: Coreidae)-squash plant (Cucurbitales:

Cucurbitaceae) system in Oklahoma. J. Econ. Entomol. 81: 1073-1079.

Fargo, W.S & E.L. Bonjour. 1988. Developmental rate of the squash bug, *Anasa tristis*, (Heteroptera: Coreidae), at constant temperatures. Environ. Entomol. 17: 926-929

Fielding, D.J. 1988. Photoperiodic induction of diapause in the squash bug, *Anasa tristis*. Entomol. exp. appl. 48: 187-193.

Gould, G.E. 1951. Squash bugs in Indiana. Indiana Acad. Sci. Proc. 60:190.

Harries, F.H. & H. Matsumori. 1955. Insecticide tests on the squash bug. J. Econ. Entomol. 48:613-614.

Hoerner, J.L. 1938. Controlling the squash bug, pp 1-8. *In* Colorado Agricultural Experiment Station Press Bulletin 93, Fort Collins.

Latheef, M.A. & J.H. Ortiz. 1982. Effect of insecticides on squash bug oviposition on squash interplanted on other vegetables, p. 117. *In* Insecticide and acaricide tests, vol 7. Entomological Society of America, College Park, Md.

Motes, J. & G. W. Cuperus. 1986. Cucurbit production and pest management, pp. 40. Ok. Agric.Exp. Stn. Circular E-853.

McLeod, P. 1986. Pyrethroids tested for cucurbit insect insect suppression. Ark. Farm Res. 35: 4.

Nechols, J.R. 1987. Voltinism, seasonal reproduction and diapause in the squash bug (Heteroptera:Coreidae) in Kansas. J. Econ. Entomol. 80: 269-273.

Norton, G.A. 1976. Analysis of decision-making in crop protection. Agro-Ecosystems 3: 27-44.

Pack, H.J. 1930. Notes on Miscellaneous Insects of Utah, pp 20-22. In Utah Agricultural Experiment Station Bulletin 216, Logan.

Rabb, R.L. & F.E. Guthrie. 1970. Concepts of pest management. Proc. Inst. of Bio. Sci., North Carolina State Univ., Raleigh, pp. 241.

Rensner, P.E. 1986. An insect survey of select horticultural crops in Oklahoma, emphasizing population dynamics in the squash bug/summer squash system. M.S. thesis, Oklahoma State Univ., Stillwater.

Stern, V.M., R.F. Smith, R. van den Bosch, and K.S. Hagen. 1959. The integrated control concept. Hilgardia. 29:81-101.

Tweeten, L. 1982. Oklahoma Agriculture 2000 Div. of Agric., Oklahoma State Univ., Stillwater, OK. 210 pp.

Wadley, F.M. 1920. The squash bug. J. Econ. Entomol. 13:416-425.

Watkins, C.W. 1946. An evaluation of various sprays to control immature squash bugs. J.Econ. Entomol. 39:255-261.

Watson, T.F., L. Moore, and G.W. Ware. 1978. Practical Insect Pest Management. W.H. Freeman and Company, San Francisco. 196 pp.

Weed, C.M. and A.F. Conradi. 1902. The squash bug. New Hampshire College Agric. Exp. Sta., Bull. 89:13-29.

Worthley, H.N. 1923. The squash bug in Massachusetts. J. Econ. Entomol. 16:73-79.

Wright, J.M., and G.C. Decker. 1955. Laboratory and field tests to control squash bugs. J. Econ. Entomol. 48:250-255.

CHAPTER III

COLONIZATION AND SEASONAL ABUNDANCE OF SQUASH BUGS ON SUMMER SQUASH WITH VARIED PLANTING DATES

Abstract

The effect of summer squash, Cucurbita pepo L. c.v. 'Hyrific', planting dates (PD) on the seasonal abundance of squash bug, Anasa tristis (De Geer), populations and fruit yields was investigated. Studies showed that colonization by overwintered adult squash bugs was directly influenced by planting date. Significantly higher adult population densities developed on older plants containing higher numbers of leaves than on younger plants with fewer leaves. As a result of adult preference for larger plants, egg mass and nymphal populations also reached greater abundance on squash planted earlier. Mean numbers of squash bugs per leaf were correlated with time of planting, number of leaves per plant and physiological plant age. Regardless of planting date, squash bugs were most abundant on plants during flowering and fruit set. Heavy squash bug infestations in the earliest planting resulted in significant reductions in fruit production. Correlation analysis detected negative linear trends in yield responses to squash bug densities. Manipulation of planting date may be a means of managing squash bug populations to avoid yield losses.

Introduction

The squash bug, Anasa tristis (De Geer), is an important economic pest of cucurbits (Cucurbitaceae) throughout North America. Summer squash, pumpkin, and other crop species within the genus Cucurbita are its preferred hosts (Elliot 1935, Paige et al. 1989, Bonjour et al. 1990). In Oklahoma, adults leave overwintering sites and migrate into commercial squash fields soon after seedling emergence in late spring (Fargo et al. 1988). Although seasonal life history varies depending on geographic location (Beard 1940, Eichmann 1945, Nechols 1987, Fielding 1988), squash bugs complete 2-3 generations per year in the southwest (Fargo et al. 1988). Adult and nymphal feeding on young plants causes wilting of leaves, thereby reducing plant vigor and growth. Severe infestations on larger plants can often lead to reduced fruit production and plant death (Beard 1935).

Management of squash bug populations is critical for profitable production of high-quality squash. However, control with insecticides is often ineffective and can increase production costs without increasing returns (Palumbo & Fargo 1989, Criswell 1987, Motes & Cuperus 1986). Destruction of natural and augmented pollinators with foliar insecticide applications is also a significant concern of growers. As concern for food safety in fresh-market vegetables continues to increase, development of alternative management strategies for commercial cucurbit production is requisite.

The manipulation of planting dates has not been investigated as a cultural management strategy for avoiding squash bug infestations. Nechols (1987) indicated that initial colonization by adults occurred in field-seeded plants in mid-June in Kansas, but timing varied with spring temperatures. Overwintered adults occur in Oklahoma squash fields by late-May to early-June (Fargo et al. 1988). Oklahoma growers begin planting squash in early May, and continue to plant throughout the summer. Summer squash reach market maturity about 40 days after direct seeding (Lorenz & Maynard 1980); therefore relatively short delays in squash bug colonization might prevent the occurrence of economic losses. Beard (1940) noted that in the Northeastern United States, squash bugs were consistently less abundant on pumpkin crops planted in July, than on summer squash planted in early June suggesting that infestations might be avoided by manipulating host planting date.

The specific objectives of our studies were to: 1.) investigate the influence of squash planting dates on plant colonization by squash bug adults and subsequent increases in egg mass and nymphal populations; and, 2.) the relationship of planting dates and squash bug infestations with fruit yield.

Materials and Methods

Field studies were conducted in the spring and summer of 1986 at the following three locations in Oklahoma: the Oklahoma State University (OSU) Agronomy Research Station near Perkins, Payne Co., northcentral Okla.; the OSU Landscape and Horticulture Nursery Farm near Stillwater, Payne Co., northcentral Okla.; and the OSU Horticulture Research Station near Bixby, Tulsa Co., northeastern Okla. Study sites were located a minimum of 16 km and a maximum of 112 km from one another.

Differences in plant age and size were created by direct seeding yellow straightneck summer squash, <u>Cucurbita pepo</u> L. c.v. 'Hyrific', into plots on four sequential planting dates (PD). At Stillwater and Perkins, squash was planted on Julian date (JD) 124, 132, 140 and 148. Plots were established on JD 125, 133, 140, and 148 at Bixby. All plots measured 6.5 m in length by six rows with a 1.3 m row spacing and were replicated four times in a randomized complete block design. A preemergence herbicide, ethalfluralin, was applied at a rate of 2.3 kg (AI)/ha 3 days before plots were seeded. Hills were initially planted with four seeds and thinned to one plant per hill after emergence. Each plot contained 30 hills. A nitrogen and phosphorus fertilizer, in the form of monoammonium phosphate, was applied to each plot at planting at a rate of 42.5 and 58.9 kg/ha, respectively. Plots were irrigated weekly with an overhead sprinkler delivery system to ensure uniform seed germination and plant growth within treatments. No insecticides were applied during the course of this study.

Squash bug populations were assessed by counting egg masses, nymphs, and adults on all leaves, petioles and stems on five randomly selected plants in each plot beginning at seedling emergence. Sample sizes were reduced to three plants per plot for JD 182, 196 and 203, after plants began producing fruit. Estimates of squash bug numbers per leaf were calculated by dividing the total number of squash bugs per plant by the total number of leaves per plant. Plant size was measured by counting the number of fully expanded leaves per plant on a weekly basis. Flower production was measured by counting the number of pistilate and staminate flowers on each plant beginning at anthesis. Marketable fruit (fruit > 10 cm long) were harvested and weighed 3-4 times weekly for a total period of about 310 ± 9 degree days above $15.6^{o}C$ beginning about 36-40 days postplanting. Total fruit weights were used in the yield analysis. To account for temperature influences on the physiological development of insects and plants, degree-day accumulations were calculated using daily maximum and minimum temperatures. Degree-days (°C) were calculated using the means method (Arnold 1960) with a lower developmental threshold for both squash bugs and C. pepo of 15.6°C (Fargo & Bonjour 1988).

Analyses were conducted to estimate the effects of planting date on squash bug abundance. A two-way analysis of variance using the SAS (SAS Institute 1985) general linear models (GLM) procedure with Duncan's (1975) multiple range test was used to determine weekly and seasonal differences in squash bug numbers per leaf among the various planting dates. Also, differences in squash bug numbers in relation to phenological development of the squash plant were compared by averaging total squash bugs across three growth stages (seedling, vegetative, and reproductive). Correlation analysis using Proc REG (SAS Institute 1985) was used to describe relationships of squash bug numbers with planting dates, plant sizes, physiological ages, and fruit yields during squash bug colonization.

Results

Temperatures and heat accumulation varied among the experimental locations. Seasonal accumulations of degree-days (°C), from first occurrence of squash bug egg masses through final harvest, were 646.5, 687.9 and 592.2 for Bixby, Perkins and Stillwater, respectively. Using the degree-day requirement of 376.5 for squash bug development (Fargo & Bonjour 1988), it was estimated that 1.71 generations developed at Bixby, 1.82 at Perkins and 1.57 at Stillwater during the growing seasons.

Overall seasonal trends of squash bug abundance on squash among the various planting dates were similar for all locations. However, numbers of overwintered adults were significantly different among locations ($\underline{F}$=10.21; df=2,7;

$\underline{P}<0.01$). Numbers of overwintered adults initially colonizing plots at Stillwater and Perkins were considered relatively high while numbers at Bixby were unusually low.

Overwintered adults were first observed on JD 142, 144 and 154 at Perkins, Stillwater and Bixby, respectively. Average numbers of leaves per plant and degree-day accumulations at initial squash bug colonization varied among planting dates (Table 1). At this time, plants seeded on PD 1 had significantly more leaves than any other planting ($\underline{F}=30.98$; df=3,9; $\underline{P} < 0.0001$ at Bixby; $\underline{F}=18.2$; df=3,9; $\underline{P}<0.0001$ at Perkins; and $\underline{F}=17.5$; df=3,9; $\underline{P}<0.0001$ at Stillwater). Correlation analysis of adult numbers with plant sizes at initial infestation was significant only at Bixby ($\underline{r}=0.56$; $\underline{P}<0.023$;, n=75). Seedling emergence in all planting dates at Bixby had been completed prior to the time squash bugs were first observed in plots. At Perkins and Stillwater, plants in PD 4 had not emerged at the time of adult immigration.

Overwintered adults colonized plots in PD 1 at a greater rate than in other plantings and were subsequently less abundant on the younger plants in PD 2, 3 and 4 (Fig. 1A, 2A, 3A). Densities of overwintered adults peaked in PD 1 on JD 168 at Bixby and Stillwater, and JD 175 at Perkins. This corresponded with a significant differential in numbers of leaves and degree days among the treatments (Table 1). Adult numbers per leaf were highly correlated with number of leaves per plant at that time ($\underline{r}=0.78$; $\underline{P}<0.001$; n=75 at

Bixby; $\underline{r}=0.82$; $\underline{P}<0.0001$; n=80 at Stillwater; $\underline{r}=0.86$; $\underline{P}<0.0001$; n=80 at Perkins). Similarly, physiological age of plants was significantly correlated with adult density ($\underline{r}=0.65$; $\underline{P}<0.0005$; n=75 at Bixby; $\underline{r}=0.75$; $\underline{P}<0.0001$; n=80 at Stillwater; $\underline{r}=0.79$; $\underline{P}<0.0001$; n=80 at Perkins). Following peak population levels, densities of adults tended to decline.

First generation nymphs reached the adult stage 2-3 weeks after numbers of overwintered adults had peaked. Using the degree-day requirement for squash bug development, it was estimated that F_1 adults first occurred in plots on JD 189 at Bixby, JD 184 at Perkins and JD 187 at Stillwater. Following the emergence of F_1 adults, relative population levels increased in all plots, except in Perkins where densities remained nearly constant. Significant differences in adult numbers among planting dates were not observed on the last two sample dates (JD 195 and JD 202) at all locations. Plant senescence in PD 1, coinciding with high densities of squash bugs, caused adults and large nymphs to migrate out of these plots and redistribute among surrounding plots.

Relative abundance of egg masses per leaf among the four plantings are shown in Figures 1B, 2B, and 3B. As expected, egg mass numbers were low in all plots at the time of initial adult colonization. As adult numbers increased in PD 1, a corresponding increase in egg mass density was observed. There were significantly more egg masses per leaf in PD 1 throughout the remainder of the experiment.

Nymphs were first observed on plants about 2 weeks after initial oviposition (Fig. 1C, 2C and 3C). Nymphal densities increased at a significantly greater rate in PD 1 as compared with other plantings, coinciding with increases in egg mass densities. At the termination of the experiment (JD 202), relative densities of both egg masses and nymphs reached high levels in PD 1 and were significantly lower in PD 3 and 4, at all locations. This would be expected as overwintered adults did not heavily colonize younger plantings.

Averaged over all sample dates, squash bugs (adults and nymphs pooled) per leaf were significantly more abundant in the plots seeded on PD 1 than in any other planting date ($\underline{F}$=32.53; df=3,9; $\underline{P}$=0.0001 at Bixby, $\underline{F}$=19.49; df=3,9; $\underline{P}$=0.0003 at Perkins, and $\underline{F}$=28.02; df=3,9; $\underline{P}$=0.0001 at Stillwater). In contrast, squash bug populations in PD 2, 3 and 4 occurred at lower densities and were not significantly different from each other. It was apparent that the lowest numbers of bugs developed on the later planted squash. Seasonal insect abundance was directly correlated with planting date ($\underline{r}$=0.67; $\underline{P}$=0.001; n=423), physiological age ($\underline{r}$=0.70; $\underline{P}$=0.001; n=423) and number of leaves ($\underline{r}$=0.75; $\underline{P}$=0.001; n=423) of summer squash plants. It should be noted that these plant variables are interrelated and highly correlated ($\underline{P}$<0.05) with one another.

The effect of planting date on the seasonal abundance of squash bugs (adults and nymphs pooled) in relation to phenological development of squash plants is reported in Table 2. The squash growing season was partitioned into three distinct phenological growth periods. Squash bug numbers per leaf were averaged within each growth period. During the seedling stage (cotyledon to four leaves per plant), no differences in squash bug densities among planting dates were observed. Migration of overwintered adults into all plots occurred when the older plants had entered the vegetative stage. However, significant differences were observed among planting dates during both vegetative (>4 leaves per plant and prior to flowering) ($\underline{F}$=9.2, df=3,9; $\underline{P}$<0.0001 at Bixby; $\underline{F}$= 11.5; df=3,9; $\underline{P}$=0.0001 at Perkins; $\underline{F}$=17.8; df=3,9; $\underline{P}$=0.0001 at Stillwater) and reproductive (flowering and fruit production) ($\underline{F}$=29.2; df=3,9; $\underline{P}$=0.0001 at Bixby; $\underline{F}$=17.2; df=3,9; $\underline{P}$<0.0001 at Perkins; $\underline{F}$=5.2; df=3,9; $\underline{P}$<0.01) growth.

In most cases, when making comparisons among phenological growth stages, squash bugs were most abundant during the reproductive portion of plant development regardless of planting date (Table 2). However, at Stillwater, there were no significant differences in squash bug densities between phenological periods in PD 3 and 4. A similar situation occurred in PD 3 at Perkins. This may be attributed to the lower seasonal abundance in these later plantings or higher numbers of leaves on plants attained late in the season.

Yield data indicated that variation in fruit production among planting dates corresponded with differences in squash bug density (Table 2). At Bixby, marketable fruit yields (kg/plot) were significantly reduced in the earliest planted squash (F=24.5; df=3,9; P<0.0001). Although yields at Perkins were more variable among treatments, PD 1 had significantly less fruit production (F=67.1; df=3,9; P<0.0001). At Stillwater, no significant differences in yield were observed among the four plantings (F=3.6; df=3,9; P<0.07). Regression analyses indicated that fruit yields were negatively correlated with seasonal mean squash bugs per leaf (R=0.64; P<0.01; df=1,14; at Bixby; R=0.82; P<0.0001; df=1,14; at Perkins; and R=0.57; P<0.02; df=1,14; at Stillwater).

Discussion

This study was designed to investigate interrelationships that occur between squash bugs and factors that influence population dynamics under field conditions. Size and age of squash plants greatly influenced host selection by overwintered adults. It was consistently observed that squash bugs strongly preferred to colonize the earliest planted squash. Greater population levels subsequently developed on these plants, whereas plants seeded 1-2 weeks later attracted fewer bugs. This can be attributed directly to differences in plant size among planting dates, suggesting that leaf area is an important factor in host selection.

Females appeared to have an ovipositional preference for larger leaves located near the ground. Early in the growing season, overwintered adults aggregated primarily underneath large leaves in direct contact with the soil surface. Subsequently, egg masses were frequently observed on the abaxial surface of these leaves. Because adults mate frequently and for prolonged periods of time (Beard 1935), protection from the environment and natural enemies would be advantageous for reproduction. Older plants with larger leaves near the soil surface would presumably offer more shade and protection for squash bugs than younger plants with open canopies. Similarly, these insects have been shown to be more abundant on squash grown in plastic mulch cropping systems where plastic covering the soil provides a protective microenvironment. (Cartwright et al. 1990).

Squash bug populations increased to their greatest abundance during reproductive plant growth, irrespective of planting date. Development of first generation nymphs and adults caused a pronounced increase in total squash bug density, coinciding with flowering and fruit set. These observations concur with results of Fargo et al. (1988) who reported that squash bug population densities reached peak levels as plants were maturing. As a result, fruit production appeared to be affected both by planting dates and squash bug densities. The earliest planted squash became heavily infested during the harvest period and fruit yields were significantly reduced. In contrast, those plots which contained low insect numbers (PD 3 and 4) produced significantly higher yields. Negative correlations between yields and squash bug densities among the planting dates indicate that squash bug infestations left uncontrolled in early planted summer squash may have adverse effects on marketable fruit yields.

In conclusion, overwintered adults migrate into squash fields and select plants that offer protective cover as well as suitable ovipositional sites. Adults prefer to aggregate and reproduce on larger plants when available. Early planted crops emerging in early May are at higher risk from squash bug infestations and economic yield losses than later planted crops which are less likely to be colonized at the same magnitude. Because Oklahoma growers often plant in early May in order to receive high, early market prices (Motes and Cuperus 1986), economic incentives to plant early might outweigh the benefits of delayed planting. However, in areas where management of squash bugs is of primary concern, it may be possible to manipulate plantings of summer squash to lure overwintered adults away from the crops used for market production. By delaying or reducing infestations in subsequent squash plantings, economic losses may be avoided. This would appear to be an attractive alternate strategy for squash bug control because of the ease and low-input required in management as compared with conventional squash production.

References Cited

Arnold, C. Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc. Am. Soc. Hort. Sci. 76: 682-692.

Beard, R. L. 1935. Further observations on the squash bug in Connecticut,pp. 338-339. In Connecticut Agricultural Experiment Station Bulletin 383, New Haven.

Beard, R. L. 1940. The biology of *Anasa tristis* DeGeer, pp. 592-679. In Connecticut Agricultural Experiment Station Bulletin 216, New Haven.

Bonjour, E. L., W.S. Fargo, & P.E. Rensner. 1990. Ovipositional preference of squash bugs (Heteroptera:Coreidae) among cucurbits in Oklahoma. J. Econ. Entomol. 83: (In Press).

Cartwright, B., J. C. Palumbo, and W. S. Fargo. 1990. Influence of crop mulches and row covers on the occurrence of the squash bug (Heteroptera:Coreidae) on summer squash. J. Econ. Entomol. 83: (In Press).

Criswell, J.T. 1987. Studies in the control of the squash bug, *Anasa tristis* DeGeer. Ph.D. dissertation, Oklahoma State Univ., Stillwater.

Duncan, D. B. 1975. *t* Tests and intervals for comparisons suggested by the data. Bionomics 31: 339-359.

Eichmann, R.D. 1945. Squash bug depredations in Washington. J. Econ. Entomol. 38: 110-112.

Elliot, D.C. 1935. The squash bug in Connecticut, pp. 224-231. In Connecticut Agricultural Experiment Station Bulletin 368, New Haven.

Fargo, W.S., P.E. Rensner, E.L. Bonjour, & T.L. Wagner. 1988. Population dynamics in the squash bug (Heteroptera:Coreidae)-squash plant (Cucurbitales: Cucurbitaceae) system in Oklahoma. J. Econ. Entomol. 81: 1073-1079.

Fargo W.S. & E.L. Bonjour. 1988. Developmental rate of the squash bug, Anasa tristis (Heteroptera: Coreidae), at constant temperatures. Environ. Entomol. 17: 926-929.

Fielding, D.J. 1988. Photoperiodic induction of diapause in the squash bug, Anasa tristis. Entomol. exp. appl. 48: 187-193.

Lorenz, O.A. & D.N. Maynard. 1980. Knott's handbook for vegetable growers. Wiley and Sons. New York.

Motes, J. & G. Cuperus. 1986. Cucurbit production and pest management. Oklahoma State University Cooperative Extension Service Circ. E-853, pp. 40.

Nechols, J.R. 1987. Voltinism, seasonal reproduction, and diapause in the squash bug(Heteroptera:Coreidae) in Kansas. Environ. Entomol. 16: 269-273.

Paige, J., W.P. Morrison, J.K. Wangberg, and R.J Whitworth. 1989. Ovipositional host association of Anasa tristis (DeGeer) and various cucurbita cultivars on the Texas high plains. J. Agric. Entomol. 6: 5-8.

Palumbo, J.C. & W.S Fargo. 1989. Control of squash bug in summer squash, 1988, p.60. _In_ Insecticide and acaricide tests, vol 14. Entomological Society of America, College Park, Md.

SAS Institute. 1985. SAS user's guide: statistics, version 5 ed. SAS Institute, Cary, N.C.

Table 1. Plant size and physiological age of summer squash planted on various dates relative to time of overwintered adult colonization.

		Initial adult colonization		Peak adult colonization	
Location	Planting date	Average no. leaves per plant	Degree-days after planting	Average no. leaves per plant	Degree days after planting
Bixby	1	12.1 ±0.2 a	185.7	24.5 ±0.5 a	291.3
	2	6.3 ±0.2 b	128.6	17.4 ±0.3 b	233.4
	3	3.2 ±0.1 c	75.6	8.5 ±0.1 c	181.3
	4	0.5 ±0.1 d	29.0	4.5 ±0.1 d	144.6

Table 1. Continued

Perkins	1	4.2 ±0.1 a	110.9	30.5 ±0.5 a	352.9
	2	1.5 ±0.1 b	70.9	25.8 ±0.3 b	303.8
	3[a]	0.0 ±0.0 c	15.5	22.8 ±0.3 c	279.6
	4[b]	--	--	16.0 ±0.2 d	235.8
Stillwater	1	7.3 ±0.3 a	129.7	25.4 ±0.5 a	268.5
	2	3.0 ±0.3 b	78.9	18.6 ±0.4 b	198.4
	3	0.5 ±0.1 c	35.2	11.7 ±0.3 c	176.8
	4[b]	--	--	7.2 ±0.1 d	142.2

Means within a column followed by the same letter are not significantly different ($P>0.05$; Duncan's [1975] multiple range test).

[a] Only cotyledons were present on seedling plants at time of initial adult colonization

[b] Plants had not emerged.

Table 2. Mean numbers of squash bugs per leaf in relation to phenological development of summer squash at various planting dates in Oklahoma, 1986.

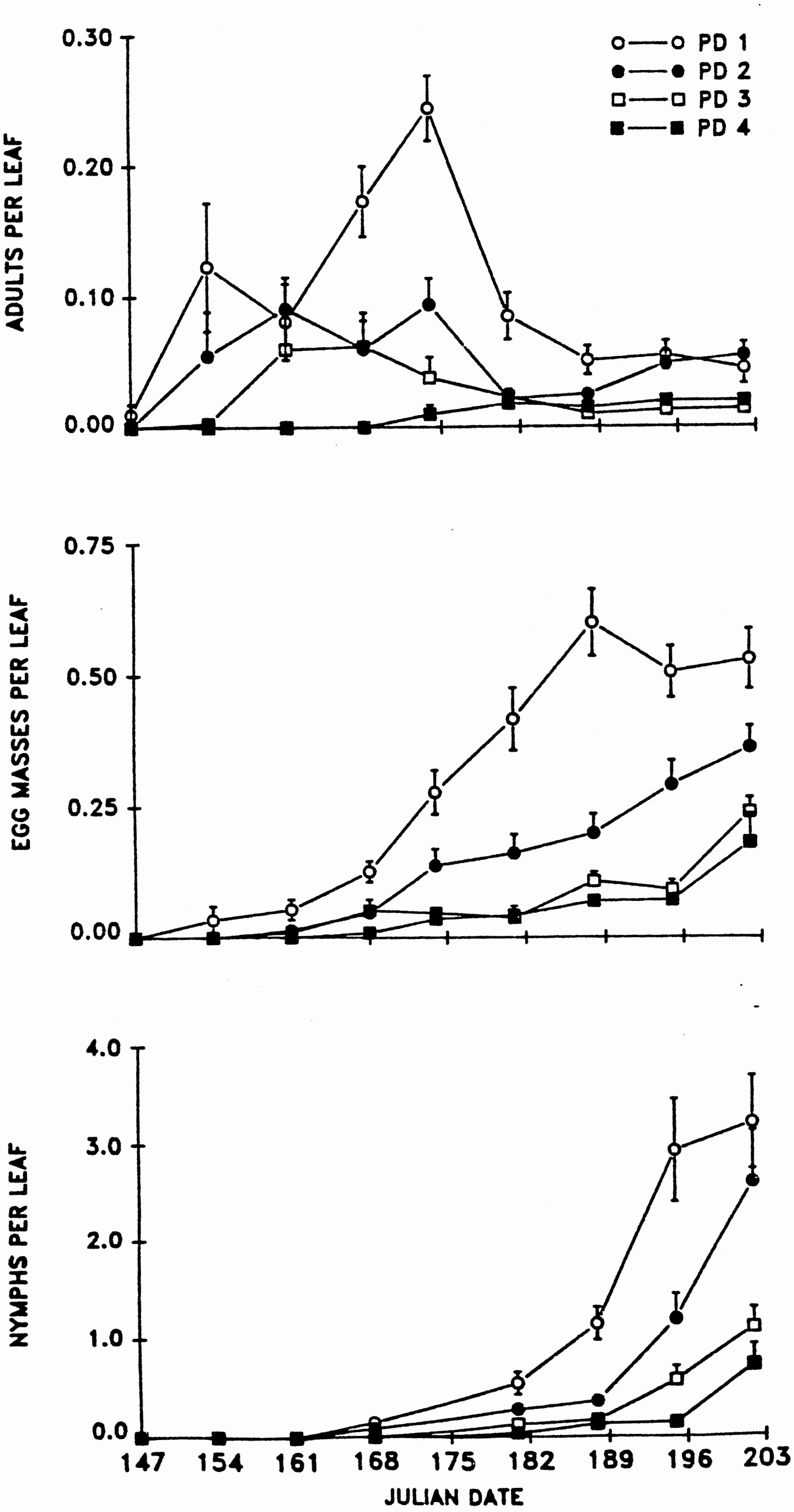
		Mean squash bugs per leaf			
Location	Planting Date	Seedling	Vegetative	Reproductive	Yield (kg/plot)
Bixby	1	0.00 aB	0.07 aB	0.49 aA	12.9 a
	2	0.00 aB	0.01 bB	0.08 bA	23.8 b
	3	0.00 aB	0.01 bB	0.06 bA	27.9 b
	4	0.00 aB	0.00 bB	0.04 bA	25.7 b
Perkins	1	0.06 aB	0.28 aB	1.88 aA	9.5 a
	2	0.04 aB	0.19 abB	0.62 bA	25.1 b
	3	0.05 aA	0.13 bA	0.26 bA	35.7 bc
	4	0.06 aB	0.04 cB	0.24 bA	37.5 c

Table 2. Continued

Stillwater	1	0.00 aB	0.08 aB	0.85 aA	40.7 a
	2	0.00 aB	0.05 abB	0.29 bA	51.8 a
	3	0.02 aA	0.07 aA	0.22 bA	48.8 a
	4	0.02 aA	0.01 bA	0.12 bA	49.5 a

Means within a column by location followed by the same lowercase letter or means among columns by location followed by the same uppercase letter are not significantly different ($P>0.05$; Duncan's [1955] multiple range test).

Figure 1. Average number (± SEM) of squash bug (A) adults per leaf, (B) egg masses per leaf and (C) nymphs per leaf, on four ages of squash (=planting dates, PD 1, PD 2, PD 3, and PD 4) determined from weekly counts at Perkins, Oklahoma, 1986.



○—○ PD 1
●—● PD 2
□—□ PD 3
■—■ PD 4
ADULTS PER LEAF
0.30
0.20
0.10
0.00
EGG MASSES PER LEAF
0.75
0.50
0.25
0.00
NYMPHS PER LEAF
4.0
3.0
2.0
1.0
0.0
147
154
161
168
175
182
189
196
203
JULIAN DATE

Figure 2. Average number (± SEM) of squash bug (A) adults per leaf, (B) egg masses per leaf, and (C) nymphs per leaf, on four ages of squash (=planting dates, PD 1, PD 2, PD 3, and PD 4) determined from weekly counts at Stillwater, Oklahoma, 1986.

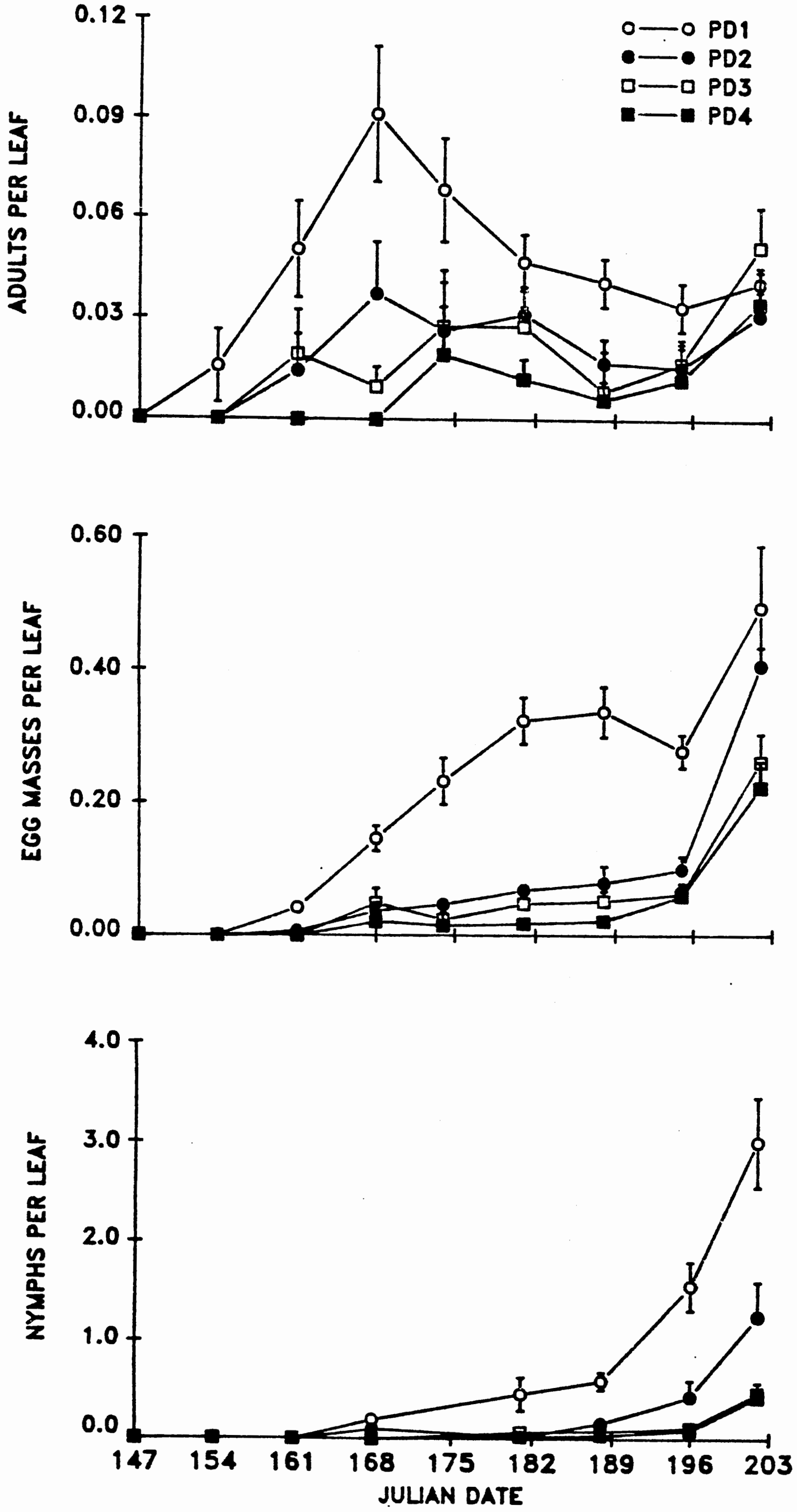
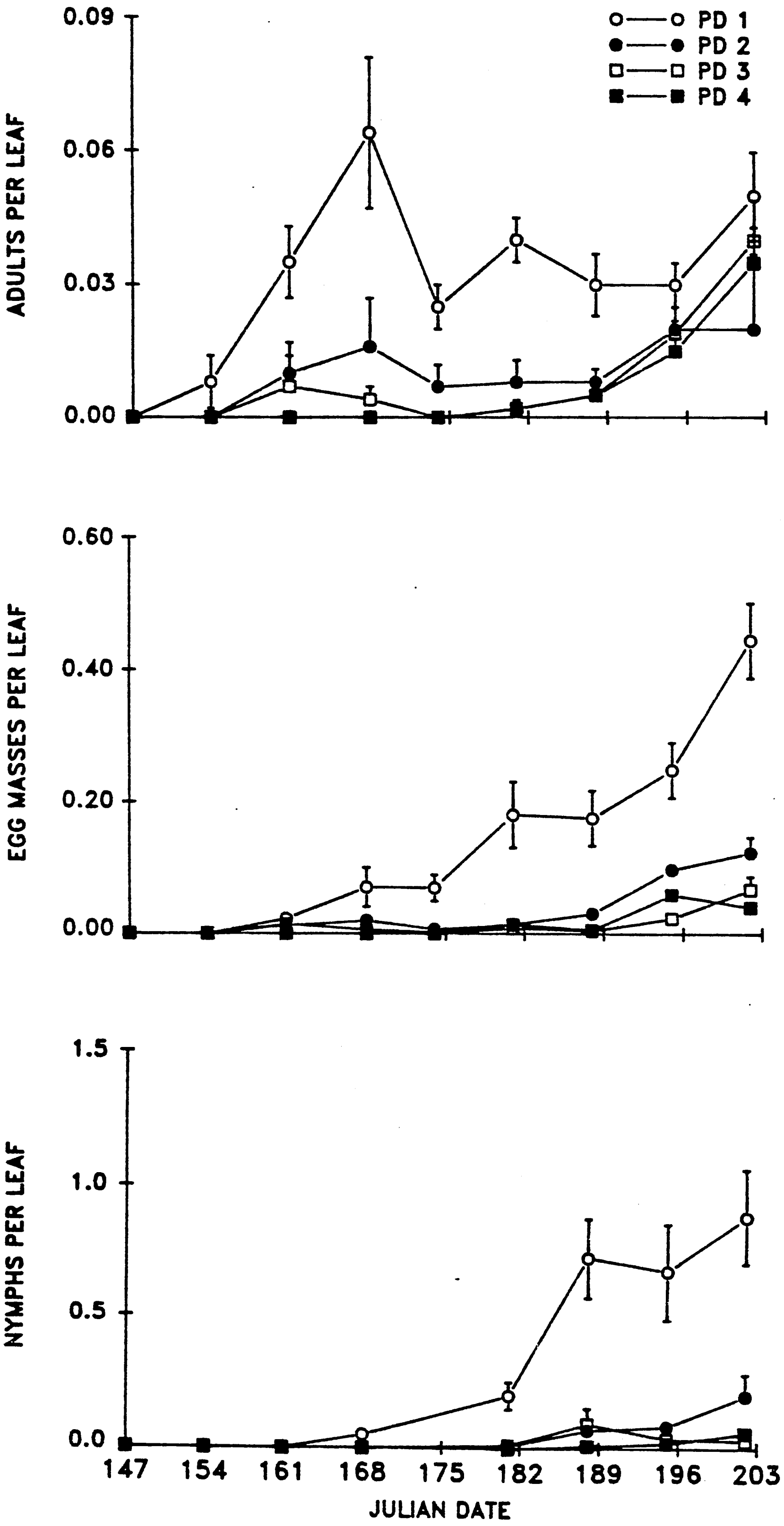

0.12
0.09
0.06
0.03
0.00
ADULTS PER LEAF
○—○ PD1
●—● PD2
□—□ PD3
■—■ PD4
0.60
0.40
0.20
0.00
EGG MASSES PER LEAF
4.0
3.0
2.0
1.0
0.0
NYMPHS PER LEAF
147
154
161
168
175
182
189
196
203
JULIAN DATE

Figure 3. Average number (± SEM) of squash bug (A) adults per leaf, (B) egg masses per leaf, and (C) nymphs per leaf, on four ages of squash (=planting dates, PD 1, PD 2, PD 3, and PD 4) determined from weekly counts at Bixby, Oklahoma, 1986.



PD 1
PD 2
PD 3
PD 4
ADULTS PER LEAF
0.09
0.06
0.03
0.00
EGG MASSES PER LEAF
0.60
0.40
0.20
0.00
NYMPHS PER LEAF
1.5
1.0
0.5
0.0
147
154
161
168
175
182
189
196
203
JULIAN DATE

CHAPTER IV

YIELD LOSS RELATIONSHIPS OF SQUASH BUG INFESTATIONS ON SPRING PLANTED SUMMER SQUASH IN OKLAHOMA

Abstract

Five insecticide schedules were applied to plots of spring-planted summer squash Cucurbit pepo L., cv. 'Hyrific', in 1987 and 1988 to investigate yield losses in response to variations in timing and density of squash bug, Anasa tristis (De Geer), infestations. Natural populations of adults and nymphs did not increase to damaging levels prior to flowering of squash plants. However, feeding by insects for long durations during flowering and fruit set significantly reduced fruit production. As a result, yield losses were directly related to the duration and magnitude of infestation. Numbers of nymphs and adults during harvest were greatest in untreated plots, inducing high rates of plant mortality and reducing yields by more than 50%. Insecticide applications based on estimates of egg mass numbers prior to harvest, were effective in maintaining populations below damaging levels. Regression of yield reduction with egg mass density during early flowering provided a consistent description of the relationship between infestation and yield for determining action thresholds for management of squash bugs.

Introduction

The squash bug, Anasa tristis (DeGeer), is an important native pest of cucurbits crops (Cucurbitaceae) throughout much of North America. In the southwestern United States, squash bugs are considered serious pests of summer squash, Cucurbita pepo var. melopepo L., though they complete less than two generations during the growing season (Palumbo et al. 1990). Overwintered adults enter fields soon after seedlings emerge in the spring and commence ovipositing on young plants (Nechols 1987, Fargo et al. 1988). Females continue to oviposit throughout the growing season, depositing egg masses of 15-20 eggs on undersides of lower leaves (Bonjour et al. 1990, Chapter 4). Subsequently, nymphal populations often increase to high densities causing damage to plants by removing plant assimilates and reducing the plants photosynthetic capacity because of leaf destruction. Excessive damage to leaves can result in wilting and death of plants (Beard 1940). Although the insects are capable of causing substantial crop losses, the effects of squash bug infestations on summer squash fruit yields have not been quantitatively demonstrated.

Growers in the Southwest annually attempt to control squash bugs and prevent crop losses in cucurbits. Insecticidal control is most commonly employed but, adequate suppression of insects is seldom achieved at high population densities during harvest (Criswell 1987). However, control measures have been shown to be effective when directed at low numbers of small nymphs (Criswell 1987). Population dynamics studies of squash bugs in summer squash have shown that nymph populations begin increasing rapidly after plants begin flowering (Fargo et al. 1989). In addition these authors observed decreases in plant productivity during fruit set coinciding with large insect densities. Isley (1940) suggested that control of squash bugs with contact insecticides should be initiated soon after nymphs hatch. Thus, in theory, control directed at egg masses and newly hatched nymphs prior to emergence of first generation adults may prevent infestations from reaching damaging levels.

In Oklahoma, control with insecticides by growers is often attempted with weekly sprays after nymphs become numerous or plant damage becomes excessive. This timing is not based on scientific research and often results in poor control. Although the biology and ecology of squash bugs are well understood, there is a lack of information regarding it's damage potential and management requirements in cucurbits. Therefore, the objective of this research was to investigate temporal and quantitative relationships between squash bug infestations and summer squash fruit production for the development of action thresholds for use in cucurbit management programs.

Materials and Methods

Experiments were conducted in 1987 and 1988 on the Oklahoma State University Agricultural Experiment Stations at Perkins, and Stillwater, Payne Co. In each of the four experiments, summer squash cv. 'Hyrific' was seeded into plots consisting of four rows, 9 m long with a 1.2 m spacing. Plots were separated by two guard rows and a 2.5 m alley. Within each row, 4-5 squash seeds per hill were planted at 0.9 m intervals and later thinned to one plant per hill immediately following seedling emergence. Planting dates in 1987 were 11 May at Stillwater and 5 June at Perkins, and in 1988 were 25 May at Stillwater and 5 May at Perkins.

Experimental plots were arranged in a randomized complete block design with treatments replicated four times. Treatments consisted of five insecticide application schedules and untreated plots. Schedule 1 was the pest-free standard maintained by weekly applications of cypermethrin beginning when nymphs were first detected on plants. Sprays were applied eight times during the season except at Stillwater in 1987, where seven applications were made. Schedules 2-5 received two closely timed applications of cypermethrin, the first initiated when egg mass numbers exceeded densities of $\geq$ 1, 3, 5 and 7 per plant, respectively. Although spray timing was based on egg mass levels, currently available insecticides have no ovicidal activity (Beevers & Santoro 1985) and control was primarily directed at small nymphs. A second spray was applied to these treatments approximately 98 degree-days (above 15.6°C) later to suppress late hatching nymphs. Each foliar application of cypermethrin was delivered at a rate of 68 g (AI)/ha, using a boom sprayer at 21 kg/cm^2 pressure and delivering 388 liters/ha. The rationale for this methodology was twofold: (1) to manipulate populations with insecticides throughout the season in order to create gradations in nymphal density for development of infestation vs. yield relationships, and (2) to apply insecticides at various stages in plant and insect growth to determine the critical timing for management.

Cultural techniques were similar to those used for commercial plantings in this region. At Stillwater in 1987, carbaryl insecticide was foliar applied at a rate of 810 g (AI)/ha to all plots at the seedling and 4 leaf stage of squash growth to prevent seedling damage by cucumber beetles, Diabrotica undecimpunctata howardi Barber, and Acalymma vittalum (Fabricious). These beetles can cause significant plant mortality to summer squash early in squash plant development (Brewer et al. 1987). Carbaryl was selected because it is highly efficacious for cucumber beetles and has produced little mortality in populations of squash bug adults (Palumbo and Fargo 1989, Criswell 1987). In 1988 at Stillwater, data collected from plants in one block were not included in the analyses because plants were severely stunted as a result of flooding injury and seedling disease (Pythium spp.).

Squash bug numbers were monitored twice weekly from plant emergence to first flowering. Thereafter, insects were sampled weekly until harvest was completed. Egg masses, nymphs (by instar), and adults were counted on all leaves, petioles and vines. Initial sample sizes were 16 and 20 plants per plot in 1987 and 1988, respectively. Samples sizes were reduced to 5 and 10 plants per plot in 1987 and 1988 respectively, when plants began producing fruit.

Plant parameters were measured on a weekly basis. Growth was described by counts of fully expanded leaves per plant. Flower production was tabulated from counts of pistilate and staminate flowers on each plant. Plant mortality data were taken by recording the number of dead plants per plot. Marketable fruit (fruit > 10 cm long) were picked and weighed 3-4 times weekly, beginning about 36 d after planting and continuing for a 4-wk period.

To account for temperature influences on insect development, degree-day accumulations were calculated. Estimates were based on daily maximum and minimum temperatures with a lower developmental threshold of 15.6°C (Fargo & Bonjour 1988). To estimate adult and nymphal feeding as a function of the intensity and duration of the infestation, squash bug feeding days (SBD) were calculated on a weekly and cumulative basis (Ruppel 1983), by the equation:

$$\begin{aligned} SBD_{i+1} &= [(SB_i + SB_{i+1}) / 2] (D_{i+1} - D_i) \\ CumSBD_{i+1} &= CumSBD_i + SBD_{i+1} \end{aligned} \tag{1}$$

where D_i and D_{i+1} are adjacent points of time and SB_i and SB_{i+1} are corresponding numbers of squash bug nymphs and adults.

Data were analyzed by analysis of variance and linear regression with the Proc GLM from Statistical Analysis Systems (SAS Institute 1985). Two-way analyses of variance were conducted on seasonal means for squash bug numbers, mean SBD, plant variables and yields of summer squash fruit. Separate analyses were performed on data from each site in both years. Means were compared using Duncan's multiple range test ($\underline{P}$=0.05). Linear regressions of yield with SBD, were conducted separately for each experiment. Plots of data points for egg masses vs. yield showed that similar relationships prevailed in all replications within each year and location. Based upon the results that regression lines for replicates have the same slopes but not similar intercepts, a common regression (Berberet et al. 1979) was formed for each year and location by using the model:

$$\underline{Y}_{ijk} = \alpha_i + \underline{p}_{ij} + \beta_{ic} X_{ijk} + \underline{e}_{ijk} \tag{2}$$

where: α_i = intercept for $i^{\underline{th}}$ year & location (i= Perkins '87, '88, Stillwater '87, '88)

$\underline{p}_{ij}$ = effect due to j^{th} replication in i^{th} year and location (j=1,2,3,4)

β_{ic} = common regression coefficient for i^{th} year

X_{ijk} = egg masses per plant for the k^{th} plot in the j^{th} replicate in the i^{th} year

$\underline{e}_{ijk}$ = random error associated with the (i,j,k) plot

Y_{ijk} = kg of summer squash per ha in the (i,j,k) plot

A linear regression equation for each of the 4 studies was generated from this model. Analysis of covariance using Proc GLM were conducted to test for similarity of regression coefficients (Freund & Minton 1979) to determine if a valid common regression combining both locations and years could be formed.

Results

Overwintered adults entered the plots in these studies shortly after seedling emergence and began ovipositing within 4-7 days. As a result, the treatment receiving weekly insecticide applications was initiated about 2 weeks postplanting. Insecticide treatments significantly influenced seasonal mean numbers of squash bug adults, egg masses, and nymphs per plant in both years and locations (Table 1). Averaged over the growing season, untreated plots contained significantly greater numbers of insects than did any other treatment. Insecticide application treatments, regardless of timing, significantly reduced mean numbers of squash bug adults and large nymphs (third-fifth instars) relative to the untreated plots. Numbers of small nymphs (first and second instars) were generally lowest in plots sprayed on a weekly schedule or at the 1 egg mass treatment level.

Seasonal differences in squash bug (adult and nymphs pooled) infestations among treatments were measured by comparing mean cumulative SBD per plant on various dates (Tables 2-5). The sampling dates reported correspond to plant phenological events occurring throughout each season. Vegetative plant growth was defined as the time period between seedling emergence and flowering, with reproductive growth occurring thereafter. Population trends were consistent within experiments and only varied slightly between years and locations.

Squash bug infestations developed relatively slowly in all plots during vegetative growth and consisted primarily of overwintered adults, egg masses and low numbers of small nymphs. No significant differences in mean SBD were observed among treatments during this period. Plots receiving weekly applications of insecticide had been sprayed at least 2-3 times during this period. At the beginning of squash flowering ($\bar{x}=285\pm11, n=4$, degree days(°C) postplanting), differences in SBD among treatments were observed only at Stillwater in 1988, where cumulative numbers were relatively low in plots sprayed weekly. The 1 egg mass treatment level was exceeded prior to flowering in all experiments except at Perkins in 1988, where this level was exceeded shortly thereafter.

Based on the untreated plots, SBD accumulated more rapidly during plant reproductive growth than was observed prior to flowering (Table 2-5). At first fruit harvest ($\bar{x}$=348±15,n=4, degree days(°C) postplanting), mean numbers of cumulative SBD differed significantly among treatments. Untreated plots had accumulated the greatest numbers of SBD. Fruit were continually harvested over a period of 28-30 days ($\bar{x}$=335±32,n=4, degree days (°C) from first fruit production). At completion of harvest, untreated plots had accumulated significantly more total SBD per plant than did any sprayed plot. Because of the large variation in SBD accumulated between treated and untreated plots, differences in SBD among the five insecticide regimes were not detected at final harvest.

Plant growth measured during the vegetative growth stage did not differ among treatments. Similarly, squash bug-induced plant mortality was not observed prior to fruit production. However, plant mortality during fruit harvests was significantly greater in untreated plots than in all other treatments (Tables 2-5). In both years and locations, large accumulations of SBD during the reproductive stage caused excessive wilting and plant damage to leaves and vines. At Perkins, squash bug feeding in untreated plots caused mortality of plants in excess of sixty percent. Conversely, squash bug-induced plant mortality was relatively low in sprayed plots. Correlation analysis indicated that percent plant mortality was significantly correlated with SBD ($R=0.75$; $n=90$; $P=0.0001$ for SBD).

Fruit yields (kg/plot) differed significantly among treatments in all studies (Tables 2-5). Mean total yields from the "pest-free" plots did not differ significantly from plots sprayed at 1 egg mass per plant. Initiating applications of cypermethrin at a mean of 1 egg mass per plant prior to flowering was consistently more effective in preventing significant yield reductions than at any other egg mass treatment level. Untreated plots produced significantly less total fruit yield than any other treatment in both years and locations.

Differences in timing of insecticide applications provided a gradation of yields and infestation levels. Yields of summer squash fruit showed a significant negative relationship with total seasonal cumulative SBD. These relationships were best estimated using a non-linear exponential function ($Y=e^{a+bx}$), with slightly more yield(Y) loss per cumulative SBD(x) at low insect numbers than at high numbers ($Y=e^{3.87-0.0002x}$; $R^2=0.73$; df=1,22; $P<0.0001$ at Perkins 1987; $Y=e^{3.93-0.0002x}$; $R^2=0.66$; df=1,22; $P<0.001$ at Perkins 1988; $Y=e^{3.78-0.0003}x$; $R^2=0.63$; df=1,22; $P<0.0001$ at Stillwater 1987; and $Y=e^{3.92-0.0003x}$; $R^2=0.78$; df=1,22; $P<0.0001$ at Stillwater 1988). Analysis of covariance for regressions of treatment means for SBD with yields showed that slopes were not significantly different among the location and years ($F=2.87$; df=3,16; $P>0.10$). However, regression intercepts for this relationship did significantly differ among the experiments.

As expected, a positive linear relationship ($\underline{Y}$=a+b$\underline{x}$) between egg masses and cumulative SBD was observed. Analysis of covariance showed that regression of egg masses($\underline{x}$) with SBD($\underline{Y}$) among locations and years resulted in one model ($\underline{Y}$= -250 + 268±22.3$\underline{x}$; R^2=0.78; df=1,88; $\underline{P}$=0.0001). This relationship indicates that assessment of egg mass numbers can be used as a reliable estimate of potential squash bug infestations. Therefore, a yield reduction index based on egg mass density was estimated for the development of action thresholds. Calculation of thresholds based on egg masses is more desirable because of the practical limitations in sampling and calculating SBD in the field.

Based on above relationships, early flowering appears to be the critical time for control of squash bug infestations. Linear regression analyses of total fruit yields (kg/ha) with egg mass numbers per plant, averaged from one week prior to flowering to one week into harvest ("early flowering"), are shown in Figure 1-4. Despite the fact that egg mass infestation and yield varied among the 4 studies, analysis of covariance indicated that regression resulted in coefficients with similar slopes, but different intercepts. Furthermore, a highly significant (R^2=0.75; df=3,79; $\underline{P}$<0.0001) common linear and quadratic relationship existed between egg mass infestation during early flowering and yield reduction.

Yield values were adjusted for years and locations, and replications by subtracting from each observation corresponding estimated intercept and replicate effects. The adjusted yield values were plotted against egg mass numbers averaged over early flowering (Fig. 5). In general, the common regression line which resulted from pooling data over both years and locations, showed a curvelinear trend for yield reduction with increasing levels of egg masses. However, the coefficients for this equation ($Y=1009-924\underline{x}+23\underline{x}^2$) reflected slight increases in yield when egg mass numbers were less than 1 per plant (Fig. 5).

Action thresholds were computed by using the general economic injury level formula described by Mumford & Norton (1984):

$$AT=(C/P\cdot D\cdot K) \qquad (3)$$

where At is the action threshold, C is the cost of chemical control ($/ha), P is the market value of squash ($/kg), D is the pest damage expressed as yield reduction per pest (kg/ha), and K is a "killing efficiency" function expressed as the percentage reduction in pest attack following application of a control measure. A range of purchase and application costs for insecticides and market values for summer squash were substituted for C and P, respectively. The damage function D, was assigned the value of the coefficients from the common regression between egg masses per plant and yield reduction. K was assigned a value of

0.90, signifying a 90% reduction of squash bug attack after application (Criswell 1987, Beevers & Santoro 1985).

The resulting matrix of action thresholds are shown in Table 6. Depending on expected squash fruit market values and control costs, foliar insecticide applications are not justified for nymphal squash bug control unless the average number of egg masses per plant prior to or during early flowering exceeds 1.17-1.45 masses.

Discussion

Several studies have reported that squash bug injury can cause yield losses in cucurbits, however this study is the first to quantitatively demonstrate the relationship of squash bug densities with fruit yields of summer squash. Yield losses were directly related to the duration and magnitude of infestation during flowering and fruit set. Large numbers of insects accumulating during harvest caused significant damage to plants and were correlated with losses in fruit production. Consequently, it was consistently observed that significant yield reductions occurred in plots accumulating greater than 300 SBD after flowering. Although squash bugs completed less than 2 generations during the growing season, infestations attained in untreated plots caused greater than 50% reductions in yield.

In contrast, feeding by squash bugs during vegetative growth may not be as damaging to summer squash planted in May and June in Oklahoma as observed by researchers in

Connecticut and Washington (Beard 1935, Elliott 1935, Eichmann 1945). Squash bug numbers were relatively low in both treated and untreated plots. Feeding was comparatively minimal prior to flowering and probably did not contribute to yield losses. This is concluded from the fact that differences in plant growth and maturity were not detected between treated and untreated plants. Thus, damage to flowering and fruiting plants should be the primary concern in management of this pest in spring planted crops. However, this relationship is most important when considering overwintered populations in spring plantings. Seedling summer squash planted in August and September can suffer significant reductions in plant growth and increases in seedling mortality by feeding from migrating populations of second-generations adults and large nymphs (Criswell 1987).

The plant's ability to produce fruit under varying feeding pressures was obviously affected. As indirect pests, squash bugs injure plants by feeding on leaves, removing plant assimilates and causing cellular necrosis (Beard 1935). Variation in yield responses among treatments can be largely attributed to the amount of plant feeding by nymphs and adults. Although feeding damage to leaves was not quantitatively measured, leaf necrosis and wilting were generally more noticeable as SBD accumulations increased. Under extreme feeding pressures, such as observed in some untreated plots, squash bug-induced plant mortality appeared to contribute more to yield losses than any other factor.

Thus, leaf damage and plant mortality resulting from squash bug feeding during harvest, appears to be an important factor in yield reductions of summer squash in relation to squash bugs.

Fargo et al. (1988) speculated that timing control measures early in the season prior to completion of the first generation adults would be essential for maintaining squash bugs below damaging levels. Data from my studies concur with that assumption and showed that timing of insecticide application is critical for successfully avoiding crop losses. Preventing the establishment of large squash bug infestations during harvest is important for avoiding yield losses. Delaying control until after harvest commences when populations are rapidly increasing, may not sufficiently protect yields.

Conversely, weekly applications of insecticide maintained plants essentially pest-free throughout the season and produced high yields. In practice this management approach may not be feasible due to high costs and disruption of harvests resulting from pre-harvest and re-entry intervals required after insecticide applications. However, spray timing based on egg mass densities during "early flowering" consistently provided adequate suppression of nymphs and produced similar yields as plots sprayed weekly. At low egg mass numbers, densities of nymphs are low and consist of first and second instars which are most susceptible to insecticides. In most cases, initiating control based on egg mass densities prior to harvest prevented nymphs from accumulating to damaging levels later. Thus, the critical time for determining management decisions in spring plantings appears should be during early flowering.

The consistent relationship of egg mass infestation and yield reduction has practical management applications. Egg mass numbers can be accurately estimated with few plant samples relative to the numbers required for sampling nymphs (Chapter 5 & 6). More importantly, the common regression of egg mass numbers and yield reduction (Fig 6) provides a reliable index of infestation on which to develop management guidelines.

An effective management strategy based on egg mass action thresholds was derived from this study. These action thresholds provide Oklahoma squash growers with a practical alternative to routine application of insecticides, but growers should be aware of the following limitations and recommendations before using them. First, egg mass densities should be monitored weekly prior to and during early flowering on a field-by-field basis. Information derived from chapters 5 & 6 regarding sampling precision should be utilized for assessing egg mass populations prior to reaching decisions. Also it is recommended that these thresholds be considered preliminary guidelines rather than absolute decision rules in cucurbit production outside of Oklahoma. Validation under other regional environmental conditions and crop production practices will be necessary for use in different cropping systems and locations. Finally, the threshold values reported are valid only for the control costs, market values and insecticide efficacy shown in Table 6. However, based on equation 3, any combination of control costs and market values can be substituted for calculation of individual thresholds. This information is currently being integrated within a knowledge-based management delivery system for use by growers and extension personnel.

References Cited

Beard, R. L. 1935. Further observations on the squash bug in Connecticut, pp 333-339. In Connecticut Agricultural Experiment Station Bulletin 383, New Haven.

1940. The biology of Anasa tristis De Geer, pp 31-51. In Connecticut Agricultural Experiment Station Bulletin 216, New Haven.

Beevers, M.H. & T. Santoro. 1985. Squash Bug Control, p. 210. In Insecticide and acaricide tests, vol 10. Entomological Society of America, College Park, Md.

Bonjour, E. L., W.S. Fargo, and P.E. Rensner. 1989. Ovipositional preference of squash bugs (Heteroptera:Coreidae) among cucurbits in Oklahoma. Environ. Entomol. 18: (In Press).

Brewer, M.J., R.N. Story, and V.L. Wright. 1987. Development of summer squash seedlings damaged by striped and spotted cucumber beetle (Coleoptera: Chrysomelidae). J. Econ. Entomol. 80: 1004-1009.

Criswell, J.T. 1987. Studies in the control of the squash bug, Anasa tristis DeGeer. Ph.D. dissertation, Oklahoma State Univ., Stillwater.

Duncan, D. B. 1975. t Tests and intervals for comparisons suggested by the data. Bionomics 31: 339-359.

Eichmann, W. 1945. Squash bug depredations in Washington. J. Econ. Entomol. 32: 110-112.

Elliot, D.C. 1935. The squash bug in Connecticut, pp 224-231. In Connecticut Agricultural Experiment Station Bulletin 383, New Haven.

Fargo, W.S., P.E. Rensner, E.L. Bonjour, and T.L. Wagner. 1988. Population dynamics in the squash bug (Heteroptera:Coreidae)-squash plant (Cucurbitales:Cucurbitaceae) system in Oklahoma. J. Econ. Entomol. 81: 1073-1079.

Fargo W.S. and E.L. Bonjour. 1988. Developmental rate of the squash bug, Anasa tristis (Heteroptera: Coreidae), at constant temperatures. Environ. Entomol. 17: 926-929.

Fruend, R.J. & P.D. Minton. 1979 . Regression methods: a tool for data analysis. Marcel Dekker, Inc., New York.

Isley, D. 1940. Control of the squash bug by calcium cyanide. J. Econ. Entomol. 33:475-477.

Motes, J. and G.W. Cuperus. 1986. Insect management, pp.40, In Cucurbit production and pest management. Oklahoma State University, Cooperative Extension Service Circular E-853.

Mumford,J.D. & G.A. Norton. 1984. Economics of decision making in pest management. Annu. Rev. Entomol. 19: 157-174.

Nechols, J.R. 1987. Voltinism, seasonal reproduction, and diapause in the squash bug (Heteroptera: Coreidae) in Kansas. Environ. Entomol. 16:269-273.

Palumbo, J.C, W.S. Fargo,and E.L. Bonjour. 1990. Colonization and seasonal abundance of squash bugs (Heteroptera: Coreidae) on summer squash with varied planting dates. J.Econ. Entomol. (Submitted)

Palumbo, J.C. and W.S Fargo. 1989. Control of squash bug in summer squash, 1988, p.60. In Insecticide and acaricide tests, vol 14. Entomological Society of America, College Park, Md.

Ruppel, R.F. 1983. Cumulative insect-days as an index of crop protection. J. Econ. Entomol. 76: 375-377.

SAS Institute. 1985. SAS user's guide: statistics, version 5 ed. SAS Institute, Cary, N.C.

Table 1. Seasonal mean number of squash bugs per plant with several insecticide regimes in Oklahoma, 1987-1988.

	Perkins 1987			
Treatment level	Adults	Egg masses	Small [a] nymphs	Large [b] nymphs
Weekly	0.1 a	0.3 a	0.1 a	0.1 a
1 egg mass	0.4 a	1.3 b	0.9 ab	0.1 a
3 egg mass	0.1 a	1.8 b	1.5 b	0.3 a
5 egg masses	0.5 a	3.3 b	3.0 b	0.9 a
7 egg masses	0.3 a	3.0 b	4.6 b	1.3 a
Untreated	2.6 b	13.4 c	47.5 c	22.6 b
_F_ statistic	45.5	24.5	34.8	12.9
_P_ value	0.0001	0.0001	0.0001	0.0001

Table 1. Continued

Treatment level	Stillwater 1987			
	Adults	Egg masses	Small [a] nymphs	Large [b] nymphs
Weekly	0.1 a	0.1 a	0.1 a	0.0 a
1 egg mass	0.2 a	1.3 b	0.7 ab	0.1 a
3 egg mass	0.3 a	2.1 b	2.3 b	0.2 a
5 egg masses	0.2 a	2.2 b	2.0 b	0.3 a
7 egg masses	0.5 a	3.0 b	4.1 b	1.8 a
Untreated	1.5 b	7.7 c	20.2 c	15.3 b
F statistic	3.1	2.7	3.2	3.1
P value	0.04	0.06	0.04	0.04

Table 1. Continued

	Perkins 1988			
Treatment level	Adults	Egg masses	Small [a] nymphs	Large [b] nymphs
Weekly	0.2 a	0.4 a	0.3 a	0.1 a
1 egg mass	0.4 a	1.4 b	1.6 ab	0.3 a
3 egg mass	0.6 a	2.2 b	3.2 b	0.4 a
5 egg masses	0.5 a	2.9 b	4.5 b	0.4 a
7 egg masses	1.0 a	3.9 b	7.7 b	3.5 a
Untreated	3.3 b	10.6 c	25.7 c	13.7 b
F statistic	15.7	28.8	49.6	29.7
P value	0.0001	0.0001	0.0001	0.0001

Table 1. Continued

Treatment level	Stillwater 1988 Adults	 Egg masses	 Small [a] nymphs	 Large [b] nymphs
Weekly	0.1 a	0.2 a	0.2 a	0.1 a
1 egg mass	0.4 a	1.5 b	1.8 ab	0.1 a
3 egg mass	0.3 a	2.1 b	2.6 b	0.2 a
5 egg masses	0.4 a	2.8 b	3.7 b	0.4 a
7 egg masses	0.6 a	3.2 b	5.3 b	2.1 a
Untreated	2.3 b	8.9 c	28.1 c	14.1 b
F statistic	45.5	24.5	34.8	12.9
P value	0.0001	0.0001	0.0001	0.0001

Means in the same column followed by the same letter are not significantly different (*P*>0.05; Duncan's [1975] multiple range test; df=5,15 for each column except Stillwater 1988, df=5,10).

[a] first and second instar nymphs pooled and averaged.

[b] third, fourth and fifth instar nymphs pooled and averaged.

Table 2. Mean accumulated SBD, percent plant mortality and yield of summer squash at Perkins, 1987.

		Date (degrees days postplanting)					
Treatment level	Spray timing (degree days postplanting)	26 JUN [a] (198)	7 JUL [b] (298)	13 JUL [c] (344)	10 AUG [d] (721)	% plant [e] mortality	Fruit yield (kg/plot)
Weekly	135-655	0.1 a	0.4 a	1.0 a	7.5 a	0.0 a	55.0 a
1 egg mass	286,388	0.9 a	8.6 a	19.6 ab	73.3 a	0.0 a	51.4 ab
3 egg masses	339,449	1.7 a	7.1 a	24.1 ab	113.6 a	3.1 ab	47.4 ab
5 egg masses	423,521	0.4 a	8.5 a	25.2 ab	232.1 a	7.8 b	44.9 ab
7 egg masses	491,583	0.8 a	9.3 a	17.2 ab	653.3 a	14.1 b	41.8 b
Untreated	--	0.5 a	14.2 a	41.1 b	3649.8 b	64.5 c	25.9 c

Table 2. Continued

F statistic	0.7	0.9	3.2	47.7	12.9	9.2
P value	0.62	0.50	0.05	0.0001	0.0001	0.001

Means in the same column followed by the same letter are not significantly different (*P*>0.05; Duncans [1975] multiple range test; df=5,15 for each column).

a Mid-vegetative growth; average plant size = 10.2 leaves per plant.

b Flowering initiated

c Harvest initiated

d Harvest completed

e Data transformed before analysis(arcsine /*P*)

Table 3. Mean accumulated SBD, percent plant mortality, and yields of summer squash at Perkins,1988.

		Date (degrees days postplanting)					
Treatment level	Spray timing (degree days postplanting)	30 MAY [a] (119)	11 JUN [b] (262)	18 JUN [c] (329)	17 JUL [d] (695)	% plant [e] mortality	Fruit yield (kg/plot)
Weekly	92-542	1.1 a	3.9 a	8.7 a	29.7 a	0.0 a	51.2 a
1 egg mass	271,355	1.0 a	4.7 a	24.6 ab	126.3 a	0.0 a	49.2 a
3 egg masses	326,420	0.8 a	3.8 a	45.1 b	370.6 a	6.3 a	38.2 b
5 egg masses	359,463	0.9 a	4.6 a	48.9 b	376.1 a	6.3 a	36.4 bc
7 egg masses	403,509	0.8 a	4.0 a	49.9 b	924.3 a	15.4 b	30.1 c
Untreated	--	1.0 a	6.8 a	80.2 c	2655.8 b	64.2 c	16.2 d

Table 3. Continued

F statistic	2.3	1.5	6.6	14.1	28.4	29.6
P value	0.10	0.20	0.002	0.0001	0.0001	0.0001

Means in the same column followed by the same letter are not significantly different ($P>0.05$; Duncans [1975] multiple range test; df=5,15 for each column).

[a] Mid-vegetative growth; average plant size = 8.5 leaves per plant.

b Flowering initiated

c Harvest initiated

d Harvest completed

e Data transformed before analysis(arcsine /*P*)

Table 4. Mean accumulated SBD, percent plant mortality and yields of summer squash at Stillwater, 1987.

		Date (degrees days postplanting)					
Treatment level	Spray timing (degree days postplanting)	1 JUN [a] (168)	15 JUN [b] (286)	21 JUN [c] (352)	10 AUG [d] (680)	% plant [e] mortality	Fruit yield (kg/plot)
Weekly	154-653	0.2 a	4.9 a	5.1 a	9.2 a	0.3 a	60.7 a
1 egg mass	269,362	0.9 a	10.6 a	25.9 a	53.0 a	1.6 a	62.1 a
3 egg masses	362,462	1.3 a	21.2 a	78.5 ab	359.6 a	6.3 a	53.2 b
5 egg masses	394,498	1.9 a	14.6 a	55.2 ab	326.1 a	6.3 a	51.4 b
7 egg masses	442,540	1.5 a	19.5 a	70.2 ab	395.3 a	7.8 a	49.5 b
Untreated	--	1.8 a	17.5 a	124.1 b	3068.8 b	42.4 b	29.4 c

Table 4. Continued

F statistic	1.9	2.1	2.9	12.8	4.8	28.4
P value	0.22	0.10	0.05	0.005	0.008	0.0001

Means in the same column followed by the same letter are not significantly different (P>0.05; Duncans [1975] multiple range test; df=5,15 for each column).

[a] Mid-vegetative growth; average plant size = 9.3 leaves per plant.

[b] Flowering initiated

[c] Harvest initiated

[d] Harvest completed

[e] Data transformed before analysis(arcsine /P)

Table 5. Mean accumulated SBD, percent plant mortality and yields of summer squash at Stillwater, 1988.

		Date (degrees days postplanting)					
Treatment level	Spray timing (degree days postplanting)	15 JUN [a] (144)	27 JUN [b] (284)	4 JUL [c] (366)	2 AUG [d] (709)	% plant [e] mortality	Fruit yield (kg/plot)
Weekly	89-611	0.5 a	1.5 a	6.0 a	18.1 a	0.0 a	56.6 a
1 egg mass	231,337	0.9 a	7.1 b	18.2 ab	62.0 a	0.0 a	50.1 ab
3 egg masses	353,457	0.8 a	6.1 b	56.1 ab	197.6 a	0.0 a	47.9 b
5 egg masses	415,507	0.9 a	7.2 b	62.1 ab	257.1 a	2.0 a	44.8 bc
7 egg masses	469,570	0.7 a	6.7 b	69.2 ab	553.3 a	9.3 b	41.1 c
Untreated	--	0.9 a	8.2 b	88.2 b	2439.8 b	43.1 b	22.9 d

Table 5. Continued

F statistic	1.8	5.8	3.6	10.8	43.7	30.1
P value	0.27	0.01	0.04	0.001	0.0001	0.0001

Means in the same column followed by the same letter are not significantly different ($P>0.05$; Duncans [1975] multiple range test; df=5,10 for each column).

[a] Mid-vegetative growth; average plant size = 10.0 leaves per plant.

b Flowering initiated

c Harvest initiated

d Harvest completed

e Data transformed before analysis(arcsine /*P*)

Table 6. Action thresholds[a] for squash bug management with foliar insecticides at 90% efficacy (K=0.90).

Market [b] value ($/kg)	Cost of squash bug control ($/ha) [c]			
	24.71	49.42	74.13	98.84
0.40	1.20	1.29	1.37	1.45
0.45	1.20	1.27	1.35	1.42
0.50	1.19	1.25	1.32	1.39
0.55	1.18	1.24	1.30	1.37
0.60	1.17	1.23	1.28	1.35

[a] Average number of egg masses per plant prior to or during early flowering

[b] Market values for fruit yields correspond to $ 0.18, 0.20, 0.22, 0.24, 0.26 per pound, respectively.

[c] Control costs are $ 10, 20, 30, and 40 per acre, respectively.

Figure 1. Relationship between mean yield of summer squash fruit(Y) and number of squash bug egg masses(x) at Perkins, Oklahoma, 1987.

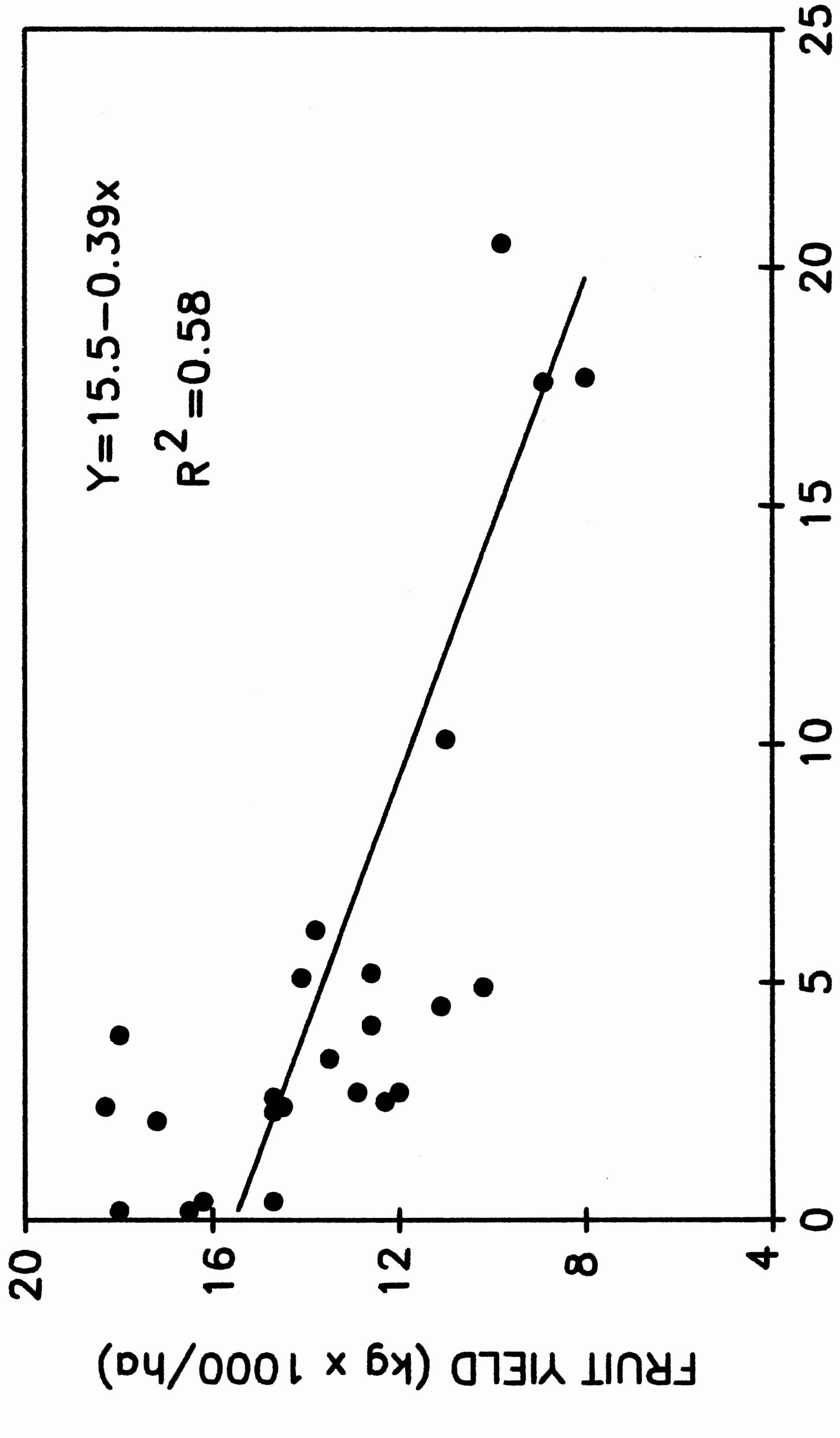

Y=15.5−0.39x
R^2=0.58
FRUIT YIELD (kg x 1000/ha)
20
16
12
8
4
EGG MASSES PER PLANT
0
5
10
15
20
25

Figure 2. Relationship between mean yield of summer squash fruit(_Y_) and number of squash bug egg masses(_x_) at Perkins, Oklahoma, 1988.

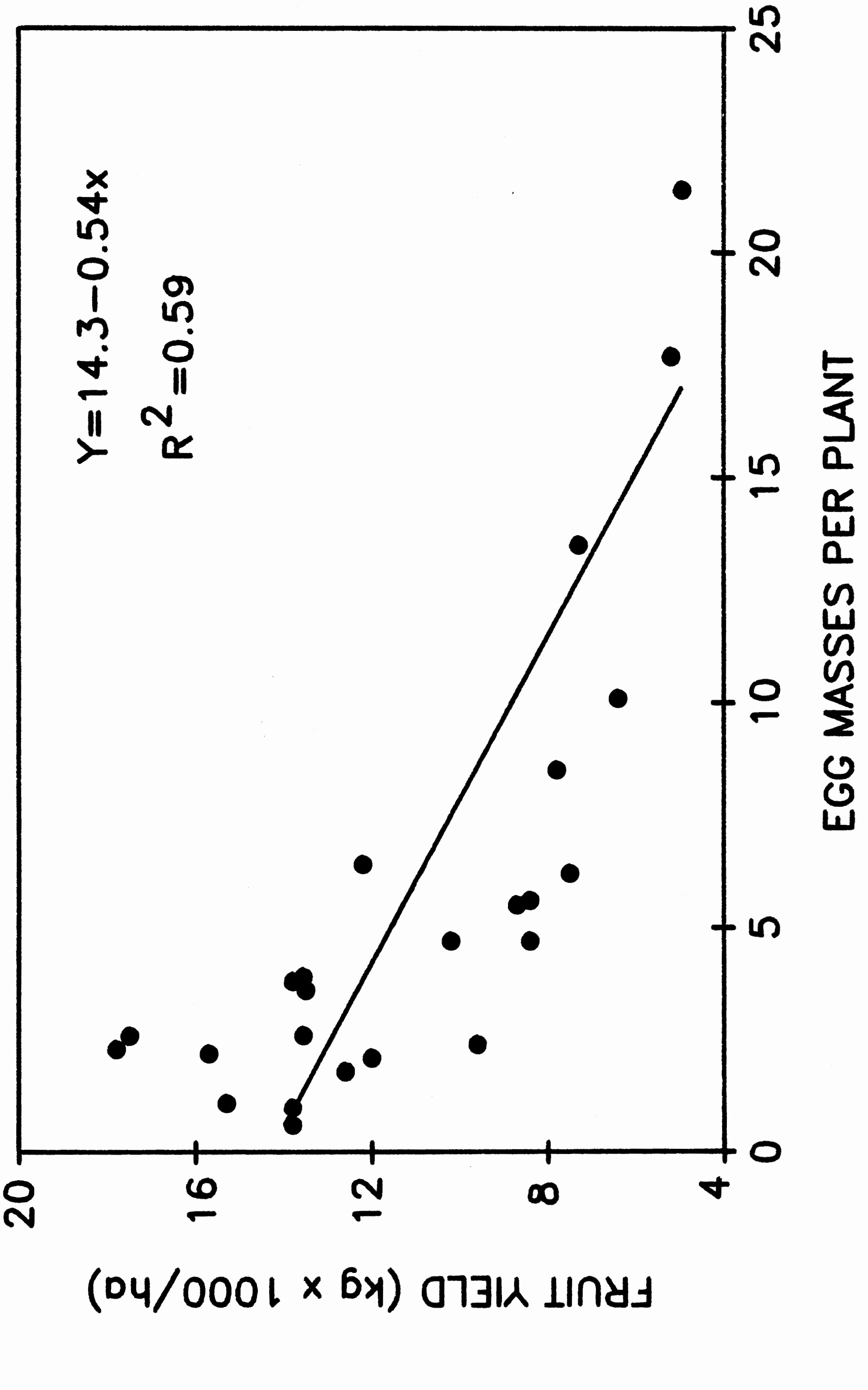

Y=14.3−0.54x
R^2=0.59
FRUIT YIELD (kg x 1000/ha)
EGG MASSES PER PLANT
20
16
12
8
4
0
5
10
15
20
25

Figure 3. Relationship between mean yield of summer squash fruit(_Y_) and number of squash bug egg masses(_x_) at Stillwater, Oklahoma, 1987.

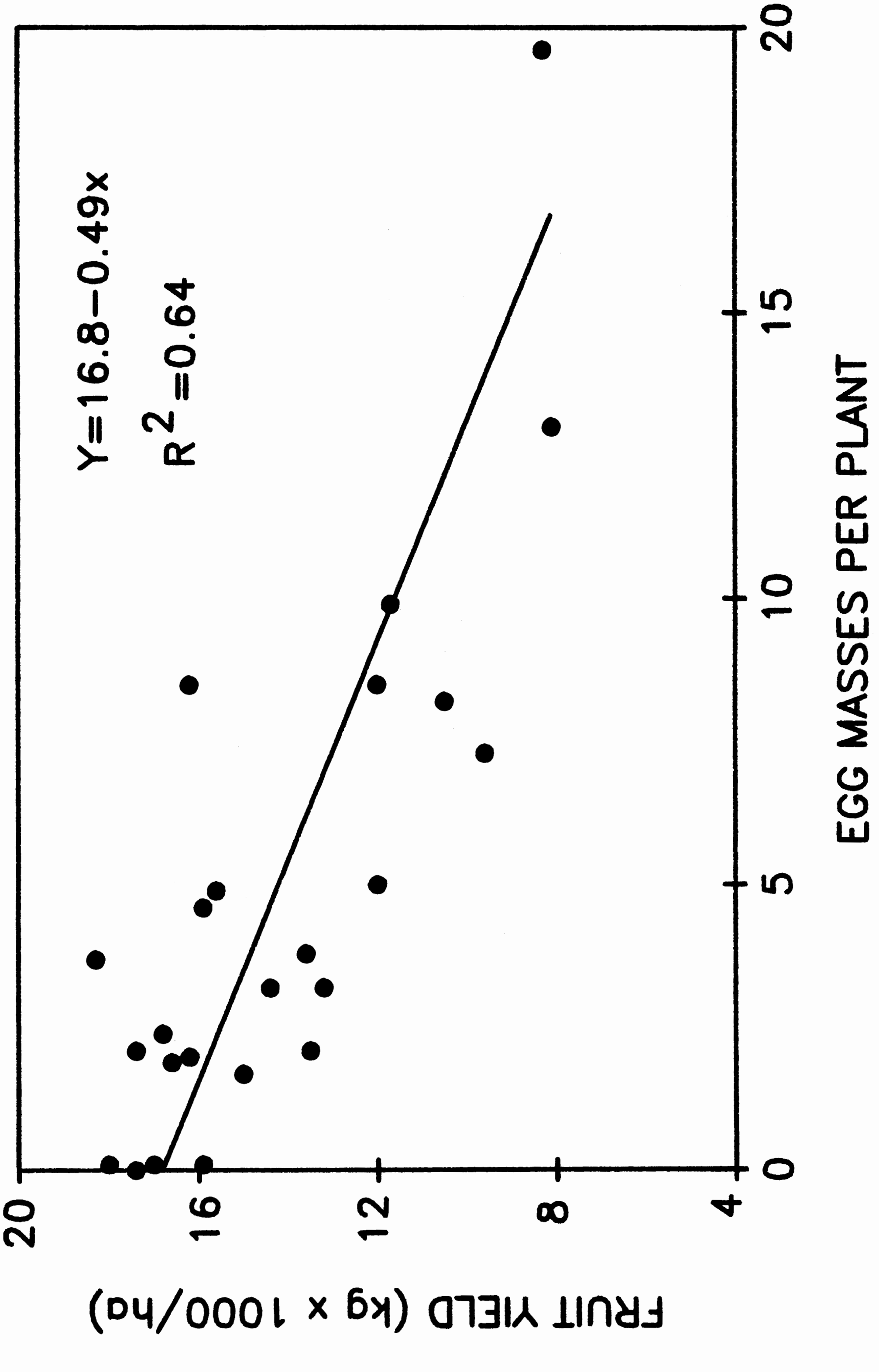

Y=16.8−0.49x
R^2=0.64
EGG MASSES PER PLANT
0
5
10
15
20
FRUIT YIELD (kg x 1000/ha)
4
8
12
16
20

Figure 4. Relationship between mean yield of summer squash fruit(<u>Y</u>) and number of squash bug egg masses(<u>x</u>) at Stillwater, Oklahoma, 1988.

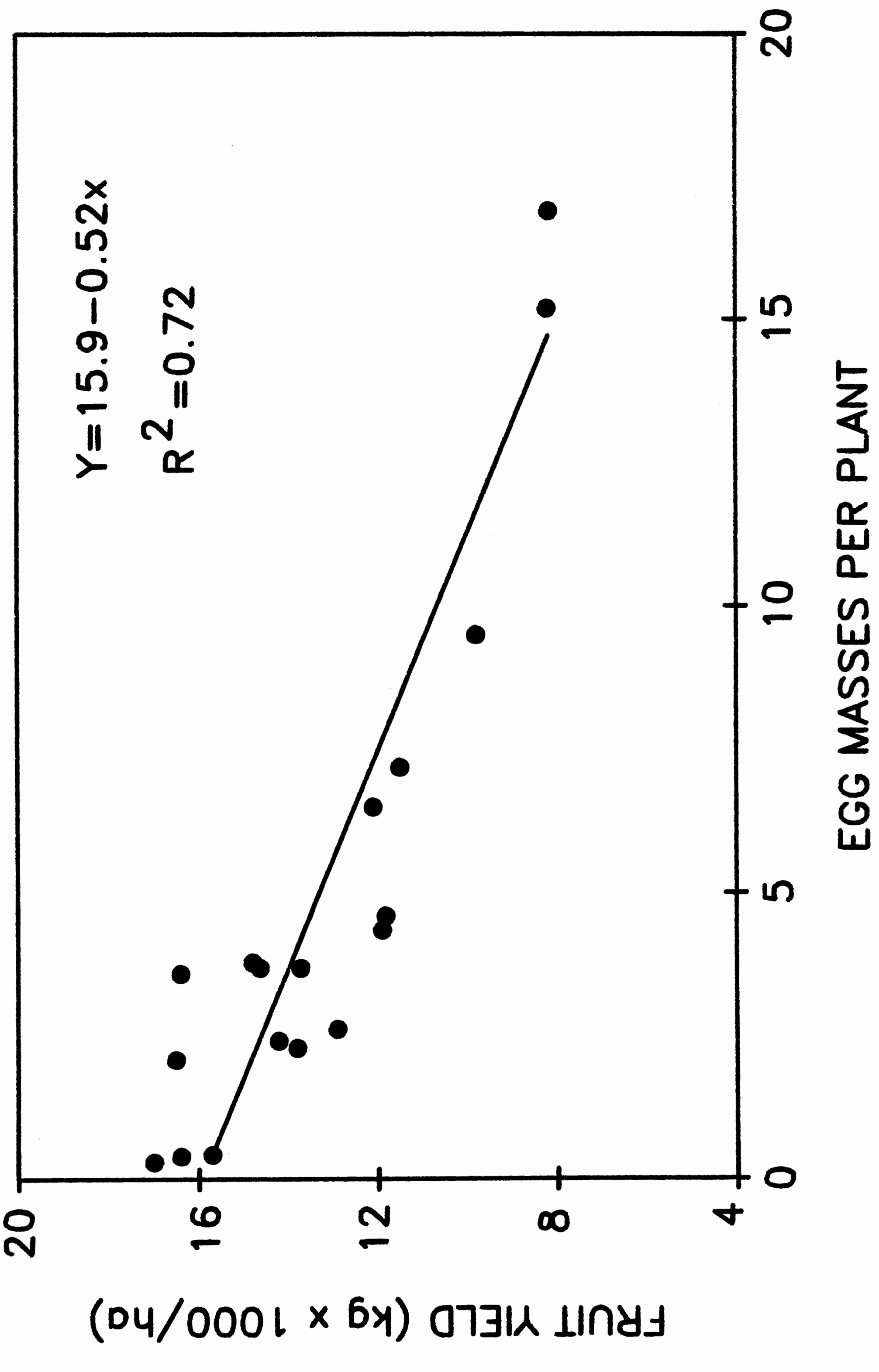
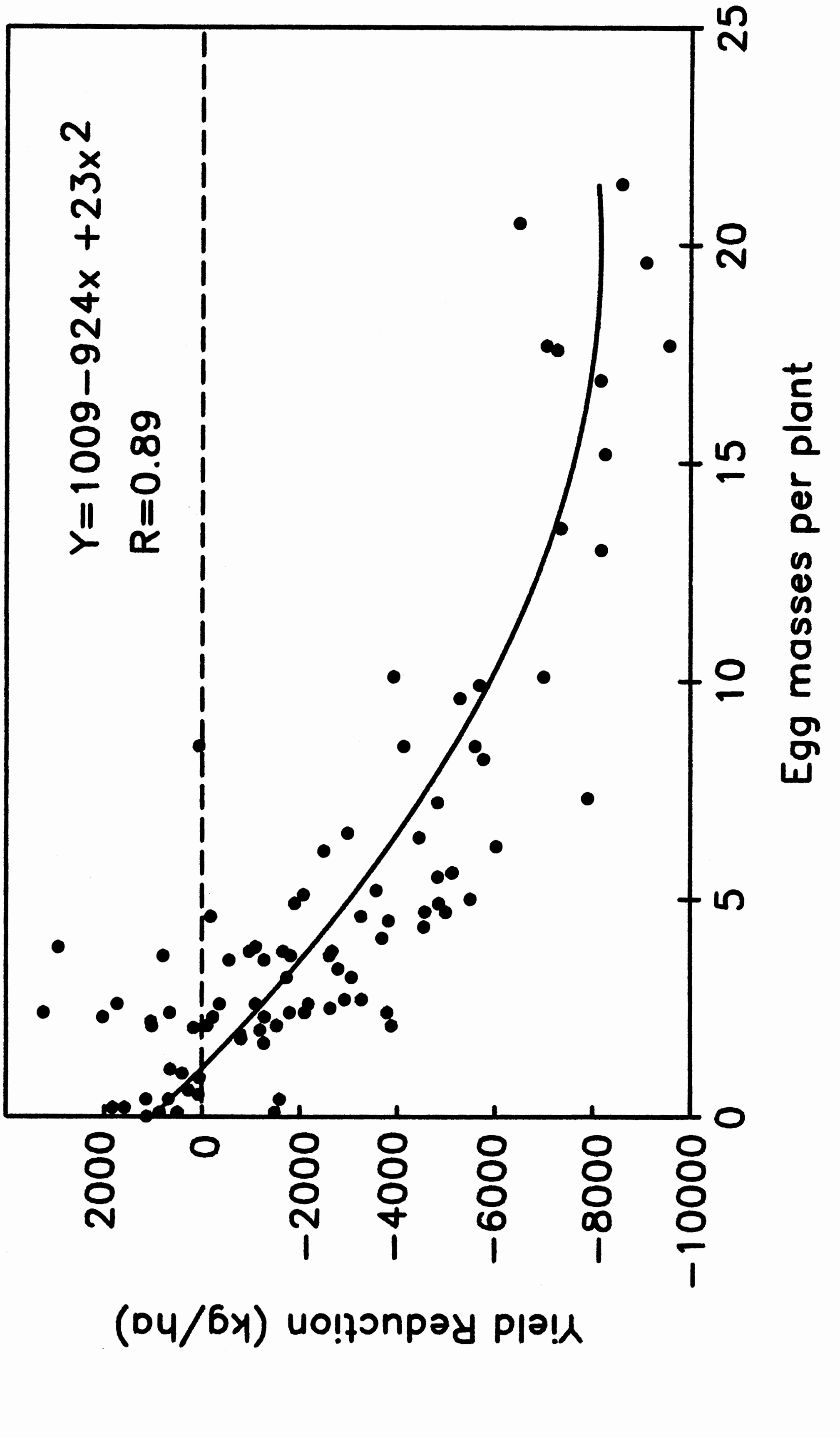

Y=15.9−0.52x
R^2=0.72
FRUIT YIELD (kg x 1000/ha)
20
16
12
8
4
EGG MASSES PER PLANT
0
5
10
15
20

Figure 5. Common regression for squash bug egg mass infestation vs. yield reduction in Summer squash in Oklahoma.


Y=1009−924x +23x2
R=0.89
Yield Reduction (kg/ha)
2000
0
−2000
−4000
−6000
−8000
−10000
0
5
10
15
20
25
Egg masses per plant

CHAPTER V

SPATIAL DISPERSION PATTERNS AND FIXED-PRECISION-LEVEL SAMPLING PLANS FOR SQUASH BUGS IN SUMMER SQUASH

Abstract

Squash bugs, Anasa tristis (De Geer), were intensively sampled in summer squash plots from three locations in Oklahoma in the spring and summer of 1987 and 1988. Data collected from whole plant samples for adults, egg masses, and nymphs were fitted to the Poisson, negative binomial, and positive binomial frequency distributions, as well as Taylor's power function and Iwao's patchiness regression. None of the three theoretical distributions fit the squash bug populations on all sample occasions. Taylor's power law provided a better fit to the count data than did Iwao's patchiness regression. All life stages exhibited aggregated patterns of spatial dispersion; small nymphs exhibiting the largest degree of aggregation, followed by large nymphs, adults and egg masses in decreasing magnitude of aggregation. Fixed-precision-level sequential sampling plans for squash bugs were developed using estimated variance-mean relationships derived from Taylor's power function. Because small nymphs tended to be highly aggregated, greater numbers of plant samples were required to estimate population means of nymphs with fixed levels of precision than was needed for adults or egg masses.

Introduction

Squash bug, Anasa tristis (De Geer), is a major insect pest of commercial squash and pumpkins, Cucurbita spp., grown in the mid- and southwestern United States (Nechols 1987, Fargo et al. 1988). Adult bugs overwinter near fields and emerge in the spring soon after squash is planted. Populations of nymphs develop gradually prior to flowering, increasing to large numbers during fruit harvest periods (Fargo et al. 1988). Feeding injury caused by squash bug adults and nymphs can result in substantial plant losses (Beard 1935, Eichmann 1945). Relationships between squash bug density and squash fruit yield losses have recently been determined, providing damage functions necessary for the development of an action threshold (Chapter 3). However, no statistically verified sampling program has been developed for estimating squash bug populations. Although an understanding of the spatial dispersion of an insect population is essential for developing valid sampling procedures (Southwood 1978), information regarding the distribution of squash bugs within summer squash is not available.

Several statistical techniques have been used to determine dispersion characteristics of insect pests. The parameter $\underline{k}$ of the negative binomial distribution is measure of aggregation that can be used for insect species having clumped or aggregated spatial patterns. This parameter is useful in providing an estimate of the degree of aggregation of a population in a specific habitat area (Southwood 1978). Two other statistical methods that use modifications of the mean-variance relationships as indices of aggregation are Taylor's power law (Taylor 1961) and Iwao's patchiness regression (Iwao 1968). Both methods produce information useful in understanding the overall mean-variance relationship when developing sampling procedures for insects (Taylor 1984). Sampling plans based on these indices of aggregation (Green 1970, Kuno 1969) often minimize sampling effort while providing constant levels of sampling precision.

The objective of this study was to quantify spatial dispersion patterns of squash bug egg masses, nymphs and adults between summer squash plants and use the information to develop fixed-precision-sampling plans for assessing squash bug populations.

Materials and Methods

Experiments were conducted in 1987 and 1988 on the Oklahoma State University Agricultural Experiment Stations at Perkins, and Stillwater, Payne Co. and at a cooperating growers field near Crescent, Logan Co., Oklahoma in 1988. At Stillwater and Perkins, a 0.15-ha field (16 rows by 55 m) of straightneck summer squash, *Cucurbita pepo* var. *melopepo* L.

'Hyrific', was sub-divided into 20 plots of equal size. Each plot was 4 rows wide (122 cm per row width) by 11 m long. Squash bug counts were made in the middle two rows of each plot. Plots were established in 1987 on 11 May at Stillwater and 5 June at Perkins, and in 1988 on 25 May at Stillwater and 5 May at Perkins. Plots were managed similarly to commercial plantings in this region and were irrigated weekly with a drip-irrigation system.

At the Crescent site, a 0.9-ha field (8 rows by 200 m long) of 'Hyrific' straightneck summer squash was planted adjacent to watermelon fields on 15 June, 1988. Each row was subdivided into 3 plots, 75 m long with a 302 cm spacing between rows, for a total of 24 plots. These plots were managed similarly to the Stillwater and Perkins plots with the exception that no irrigation was applied.

Numbers of squash bug egg masses, small nymphs (first and second instars), large nymphs (third-fifth instars) and adults per plant were recorded 2-3 times weekly by visual examination of all plant parts. Sixteen and twenty plants were examined on each sample date from the middle of each plot in 1987 and 1988, respectively. Sampling began at seedling emergence and continued until plant flowering. This is the time period in which squash bugs should be monitored to make decisions on chemical control (Chapter 3). Sampling was conducted on 10 dates at Perkins in 1987 (6 June-7 July) and 1988 (24 May-27 June), 12 dates at Stillwater in 1987

(21 May- 24 June), 9 dates at Stillwater in 1988 (9 June-11 July) and 8 dates at Crescent in 1988 (20 June-1 August).

Means and variances for counts of adults, egg masses and nymphs per plant were calculated for each field on each sample date. Two approaches were used in analyzing the count data: (1) comparing the data with known discrete distributions and (2) calculating indices which are measures of aggregation. Observed frequency distributions of count data for each squash bug life stage were tested at each sample date against three theoretical frequency distributions: Poisson (random distribution), positive binomial (uniform distribution) and negative binomial (clumped distribution). The data were tested by a customized BASIC (Quick BASIC, Microsoft Corp., Redmond, WA.) program developed by the authors and based on statistical procedures presented in Southwood (1978) (Appendix A). Chi-square analysis was used to test the fit of each distribution to observed sample data. Fit of model was rejected if the probability level fell below 0.05.

The negative binomial parameter $\underline{k}$ was calculated for each sample occaision and plotted against the mean to test the effects of density and to justify the calculation of a common $\underline{k}$ (Taylor et al. 1979. Curves were fit with the general linear model (GLM) procedure of SAS (SAS Institute 1982).

Spatial dispersion indices were calculated using Taylor's power law (Taylor 1961) and Iwao's patchiness regression (Iwao 1968). Taylor's power law expresses the relationship between the variance (s^2) and mean (x) such that $\log s^2 = b \log x + \log a$. The slope ($b$) is a measure of aggregation where values of $b > 1$ indicate an aggregated or clumped distribution , $b=1$ indicates a and random distribution, and $b < 1$ indicates a regular or uniform distribution. The intercept (a) is a scaling factor related to the environment, sampling procedure, and sample unit employed (Southwood 1978, Taylor 1984). Iwao's patchiness regression relates mean crowding, $^{*}m=m+[(s^2/m)-1]$ (Lloyd 1967), and the mean (m) using linear regression as $^{*}m=\alpha+\beta m$. The intercept (α) is an index of basic contagion, and the slope (β) is interpreted the same as (b) in Taylor's regression.

The general linear model procedure (GLM) of SAS (SAS Institute 1982) was used to conduct linear regression analyses for the dispersion indices. Students t-tests were conducted to determine if the slopes (b) of the regression lines were significantly > 1 ($P=0.05$). Comparison of the slopes and intercepts among squash bug life stages and among fields and years for each lifestage were made using analysis of covariance (Freund and Minton 1979).

The coefficients from Taylor's power law regression were used to develop fixed-precision-level sampling plans for squash bug egg masses, adults and nymphs. To determine critical stoplines for fixed-precision-level sequential sampling plans, the following formula from Green (1970) was used:

$$\log \underline{Tn} = \frac{\log (\underline{Do}^2/a)}{\underline{b} - 2} + \frac{\underline{b} - 1}{\underline{b} - 2} \underline{n} \qquad (1)$$

where Tn is the cumulative number of individuals in a sample size of n; a and b are the intercept and slope respectively from Taylor's power law regression; and Do is the fixed level of precision. Estimates of population density within 10 and 25% of the mean are usually sufficiently accurate for intensive and extensive sampling, respectively (Southwood 1978). Therefore, we chose Do= 0.10, 0.15, and 0.25 for use in this study. The number of summer squash plant samples required at various squash bug densities with fixed precision was determined by solving for n in Equation 1 (Finch et al. 1975):

$$\log \underline{n} = (\log \underline{a} - 2 \log \underline{Do}) - (2 - \underline{b}) \log x \qquad (2)$$

Results and Discussion

No single frequency distribution described squash bug populations through the entire range of densities, though sample counts fit the aggregated distribution of the negative binomial more frquently than any other (Table 1). None of the data for squash bug life stages fit the positive binomial distribution. Egg masses and adults fit the negative binomial on 91 and 83 % of the samples, respectively. Nymph populations tended to fit the negative binomial at all but high population densities. Values of k for the negative binomial ranged from 0.14-5.43 for egg masses and never exceeded a value of 2.00 for adults or nymphs, indicating that populations tended to be highly aggregated in spatial pattern. The Poisson distribution tended to fit the data fewer occaisions and only at lower population densities.

When the inverse $\underline{k}$ was plotted against mean density, a type-I curve as described by Taylor et al (1979) resulted for both adults and nymphs. This curve response is expected when the slope of the power function is between 1 and 2. This relationship indicates that $\underline{k}$ varies in a linear trend with increasing density, although some $\underline{k}$ values may fit at more than one density. Because of this relationship, coupled with the fact that the negative binomial did not describe squash bug distribution on all sample dates, calculation of a common k was not attempted. A common k is desirable for developing sampling programs using the negative binomial (Southwood 1979).

Estimates of indices of aggregation are shown in Table 2. Both Taylor's and Iwao's regressions significantly ($\underline{P} < 0.001$) accounted for variation in egg mass, nymph, and adult population counts in all fields. Taylor's power function generally provided a better description of spatial dispersion of all life stages than did Iwao's method. The coefficients of determination (R^2) for Taylor's power law regressions ranged from 0.95-0.98, whereas values of R^2 ranged from 0.28-0.93 for Iwao's patchiness regression.

Iwao's method described a similar trend in aggregation, but this method did not provide as good a fit to the data as Taylor's regression. Poor fits to Iwao's method have also been reported for pickleworm, Diaphania nitidalis (Stoll) on summer squash (Brewer & Story 1987). Therefore, parameters from Taylor's power law were used to model the functional relationship between mean and the variance for use in determining constant-precision-level sampling plans.

The interpretation of Taylor's regression followed the same general pattern of fit as the discrete negative binomial distribution. All b values from Taylor's power law were significantly ($P<0.05$) greater than 1, indicating that all lifestages exhibited aggregated spatial distributions at all but low densities. Aggregation was greatest among small nymphs, followed by large nymphs, adults and egg masses (Table 2). The life history of the squash bug further suggests that the counts would conform to an aggregated distribution. Overwintered adults entering fields in the spring mate frequently and for prolonged intervals (Beard 1940). Eggs are laid on leaves in masses or clusters of 15-20, and small nymphs remain aggregated near the egg mass. Large nymphs and adults have greater mobility, and interplant movement results in a less aggregated dispersion pattern. Nymphs may also be limited in their interplant movement because of the bushy nonoverlapping growth of individual summer squash plants prior to fruit set.

Results of analysis of covariance indicated that at least some of the slopes (b) or intercepts (log a) of the Taylor's power law regressions differed among squash bug life stages (F=5.67; df=4,208; $P<0.01$). This suggests that spatial dispersion patterns differed among some life stages. However, pairwise t-test comparison of data for small and large nymphs showed that intercepts and slopes were not different ($P<0.05$) and could be pooled in calculating sampling plans. Therefore adults, egg masses, and total nymphs were considered separately in determining the sampling sizes and sequential sampling stop lines. Results of analysis of covariance comparing slopes and intercepts among samples pooled across years and locations indicated no significant differences ($P>0.05$) for any of the three lifestages. These results showed similar patterns of dispersion for squash bugs from one year to the next. Furthermore, dispersion patterns of squash bugs were not influenced by differences in location or management practices. This is supported by the fact that the field in Crescent was grown under dryland conditions, and was planted at a wider row spacing.

Constant-precision-level stoplines for each lifestage (Fig. 1-3) were calculated using Equation 1 based on Taylor's regression coefficients (a) and (b). Use of these stop lines provides a time-efficient method of estimating population densities of each lifestage at desired levels of precision. Plant samples are taken sequentially until the cumulative number of squash bugs sampled exceeds the stopline. When this occurs, mean squash bug density per plant can then be estimated by dividing the cumulative number by the number of plant samples taken. Because of the greater tendency of small nymphs to exist in an aggregated distribution among plants, more samples are needed to estimate mean densities for nymphs than for adults and egg masses. However, using these sequential sampling plans should result in observed levels of precision.

The variance-mean relationship described by Taylor's power law is also useful in determining the minimum number of samples required to estimate squash bug numbers at fixed-levels of precision. Taylor's slope and intercept values are inserted into Equation 2, and the sample size ($\underline{n}$) for any mean value ($\underline{x}$) can then be calculated at the desired level of precision ($\underline{Do}$). Sample size curves for fixed levels of precision are shown in Fig. 4-6. The fewest samples are required for estimating population densities of egg masses and the highest numbers are required for estimates of nymphal densities. To estimate a mean density of one squash bug per plant at a level of precision of $\underline{Do}=0.25$, a total of 38, 64, and 120 samples would be necessary for egg masses, adults and nymphs, respectively. However, sample size is also influenced by the value of the intercept ($\underline{a}$). When squash bug densities are low, numerous samples are required to estimate population density with a high degree of precision (ie. $\underline{Do}=.10$). For pest management purposes

(Do=0.25), fewer numbers of samples are required for precise estimates of mean density.

The consistent variance-mean relationships observed in this study indicated that squash bug populations tend to disperse among squash plants in an aggregated manner, largely as a reflection of this species life history. These relationships also provided indices for developing efficient sampling methods to precisely estimate population numbers of squash bugs on summer squash. Use of sequential sampling will allow squash bug management decisions to be made based on accurate estimates of population numbers at various plant growth stages. The use of whole plant examinations as sample units provide a precise estimation of squash bug numbers and are adequate in a monitoring program for determining the need for squash bug control. Functional relationship between summer squash yield losses and squash bug densities at early flowering showed that management of this pest should be initiated at low egg mass and nymphal populations (Chapter 4). Information acquired in that study, in conjunction with the above sequential sampling procedures, should allow squash growers to make critical management decisions at the appropriate time, perhaps resulting in reduced inputs of insecticide.

References Cited

Beard, R. L. 1935. Further observations on the squash bug in Connecticut, pp 333-339. In Connecticut Agricultural Experiment Station Bulletin 383, New Haven

1940. The biology of Anasa trisitisDeGeer, pp 31-51. In Connecticut Agricultural Experiment Station Bulletin 216, New Haven.

Brewer, M.J. & R.N. Story. 1987. Larval spatial patterns and sequential sampling for pickleworm, Diapania nitidalis (Stoll) (Lepidoptera: Pyralidae), on summer squash. Environ. Entomol. 16: 539-544.

Eichmann, W. 1945. Squash bug depredations in Washington. J. Econ. Entomol. 32: 110-112.

Fargo, W.S., P.E. Rensner, E.L. Bonjour, & T.L. Wagner. 1988. Population dynamics in the squash bug (Heteroptera:Coreidae)-squash plant (Cucurbitales: Cucurbitaceae) system in Oklahoma. J. Econ. Entomol. 81: 1073-1079.

Fruend, R.J. & P.D. Minton. 1979 . Regression methods: a tool for data analysis. Marcel Dekker, Inc., New York.

Green, R.H. 1970. On fixed precision level sequential sampling. Res. Popul. Ecol. 12: 249-251.

Iwao, S. 1968. A new regression method for analyzing the aggregation pattern of animal populations. Res. Popul. Ecol. 10: 1-20.

Kuno, E. 1969. A new method of sequential sampling to obtain the population estimates with a fixed level of precision. Res. Popul. Ecol. 11: 127-136.

Lloyd, M. 1967. Mean crowding. J. Anim. Ecol. 36: 1-30.

Nechols, J.R. 1987. Voltinism, seasonal reproduction, and diapause in the squash bug (Heteroptera: Coreidae) in Kansas. Environ. Entomol. 16:269-273.

SAS Institute. 1985. SAS user's guide: statistics, version 5, ed. SAS Institute, Cary, N.C.

Southwood, T.R.E. 1978. Ecological methods with particular reference to the study of insect populations. Chapman & Hall, London.

Taylor, L.R. 1961. Aggregation , variance, and the mean. Nature (London) 189: 732-735.

1984. Assessing and interpreting the spatial distribution of insects. Annu. Rev. Entomol. 29: 321-357.

Taylor, L.R., I.P. Woiwod & J.N. Perry. 1979. The negative binomial as an ecological model and the density dependance of *k*. J. Anim. ecol. 48: 289-304.

Table 1. Percentage of sample occasions with a good fit between observed and theoretical frequency distributions of squash bugs on summer squash plants in Oklahoma in 1987 and 1988.

Distribution	Stage	Sample [a]	% Fit [b]
Poisson	Adults	38	28.9
	Egg masses	39	30.8
	Nymphs	33	15.4
Negative binomial	Adults	36	83.3
	Egg masses	34	91.2
	Nymphs	31	80.6

[a] Number of data sets that had sufficient degrees of freedom for all distributions to be tested.

[b] Percentage of data sets not significantly different from distribution (Chi-Square; $P<0.05$).

Table 2. Taylor's power law and Iwao's patchiness regression statistics for plant samples of squash bug life stages taken from summer squash at Perkins, Stillwater, and Crescent, Oklahoma in 1987-1988.

		Taylor			Iwao		
Stage	$\underline{n}$ [a]	Log $\underline{a}$±SEM	$\underline{b}$±SEM [b]	R^2	α ± SEM	β ± SEM [b]	R^2
Egg masses	46	0.38±0.03	1.28±0.05	0.95	-0.08±0.22	2.06±0.08	0.93
Adults	48	0.61±0.03	1.38±0.04	0.95	0.55±0.19	4.04±0.32	0.89
Small nymphs	40	1.02±0.03	1.43±0.04	0.98	6.08±1.20	3.30±1.06	0.28
Large nymphs	34	0.890.05	1.40±0.05	0.97	5.95±0.56	3.36±0.30	0.80
Total nymphs	40	0.85±0.04	1.41±0.05	0.96	7.53±1.87	2.45±0.25	0.78

[a] The number of $\bar{x}$ and s^2 or $^*m$ pairs used to calculate regression statistics.

[b] All b and β values significantly greater than 1; Students t test ($\underline{P}$=0.05).

Figure 1. Stoplines for fixed-precision-level sequential sampling for squash bug adults at three levels of precision (_Do_)

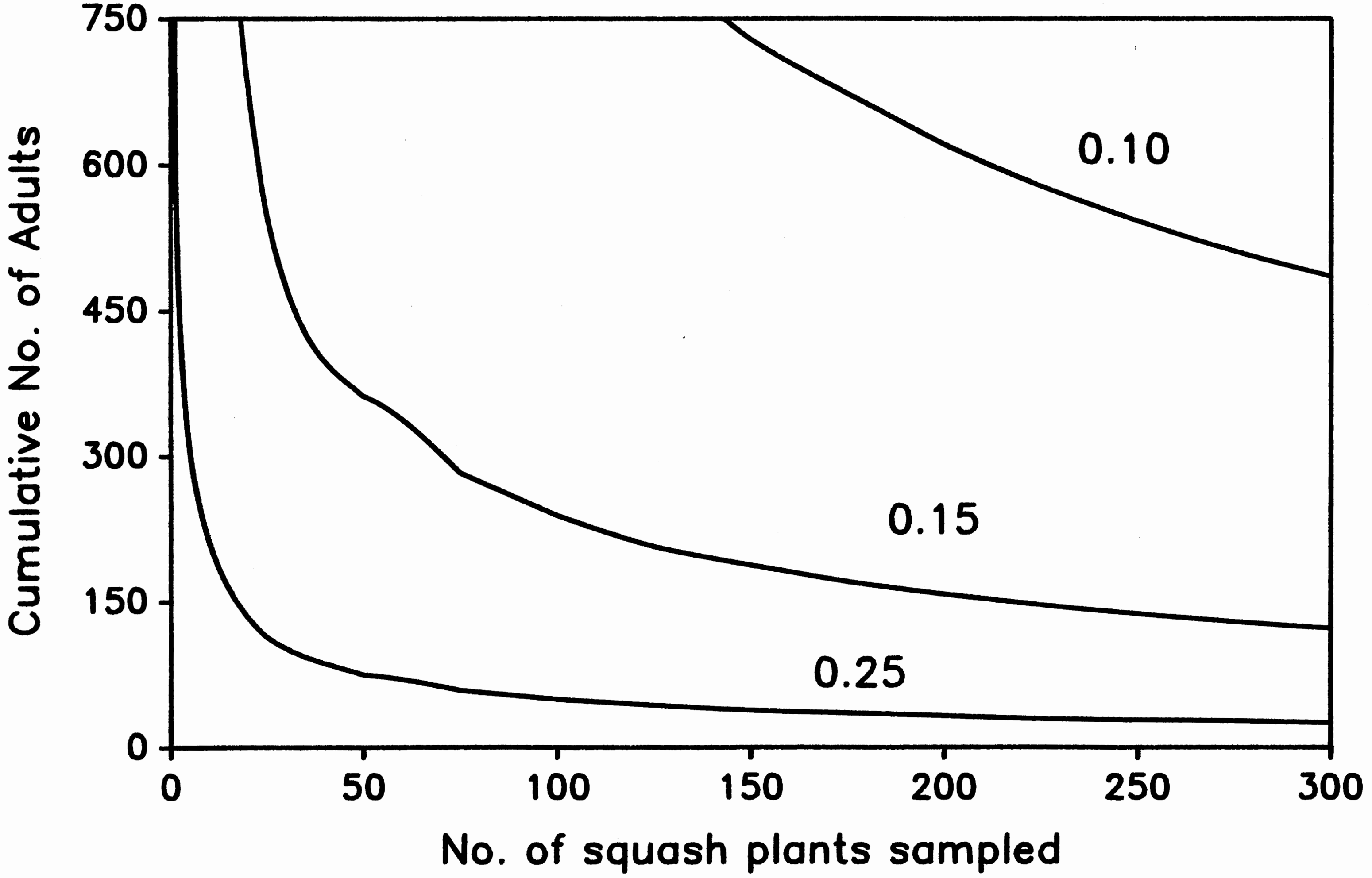

Cumulative No. of Adults
750
600
450
300
150
0
0
50
100
150
200
250
300
No. of squash plants sampled
0.10
0.15
0.25

Figure 2. Stoplines for fixed-precision-level sequential sampling for squash bug egg masses at three levels of precision (_Do_)

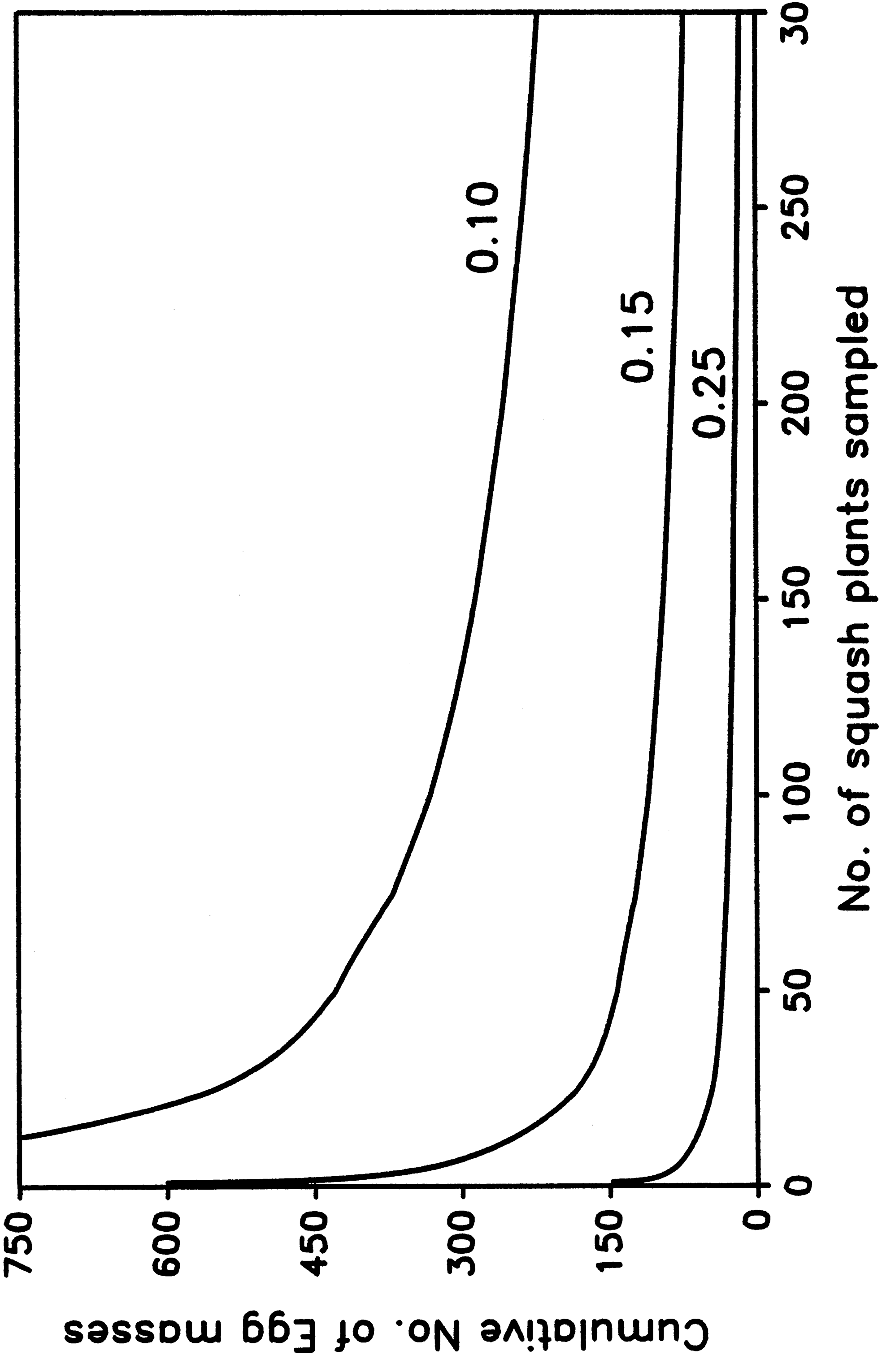

Cumulative No. of Egg masses
750
600
450
300
150
0
No. of squash plants sampled
0
50
100
150
200
250
300
0.10
0.15
0.25

Figure 3. Stoplines for fixed-precision-level sequential sampling for squash bug nymphs at three levels of precision (_Do_)

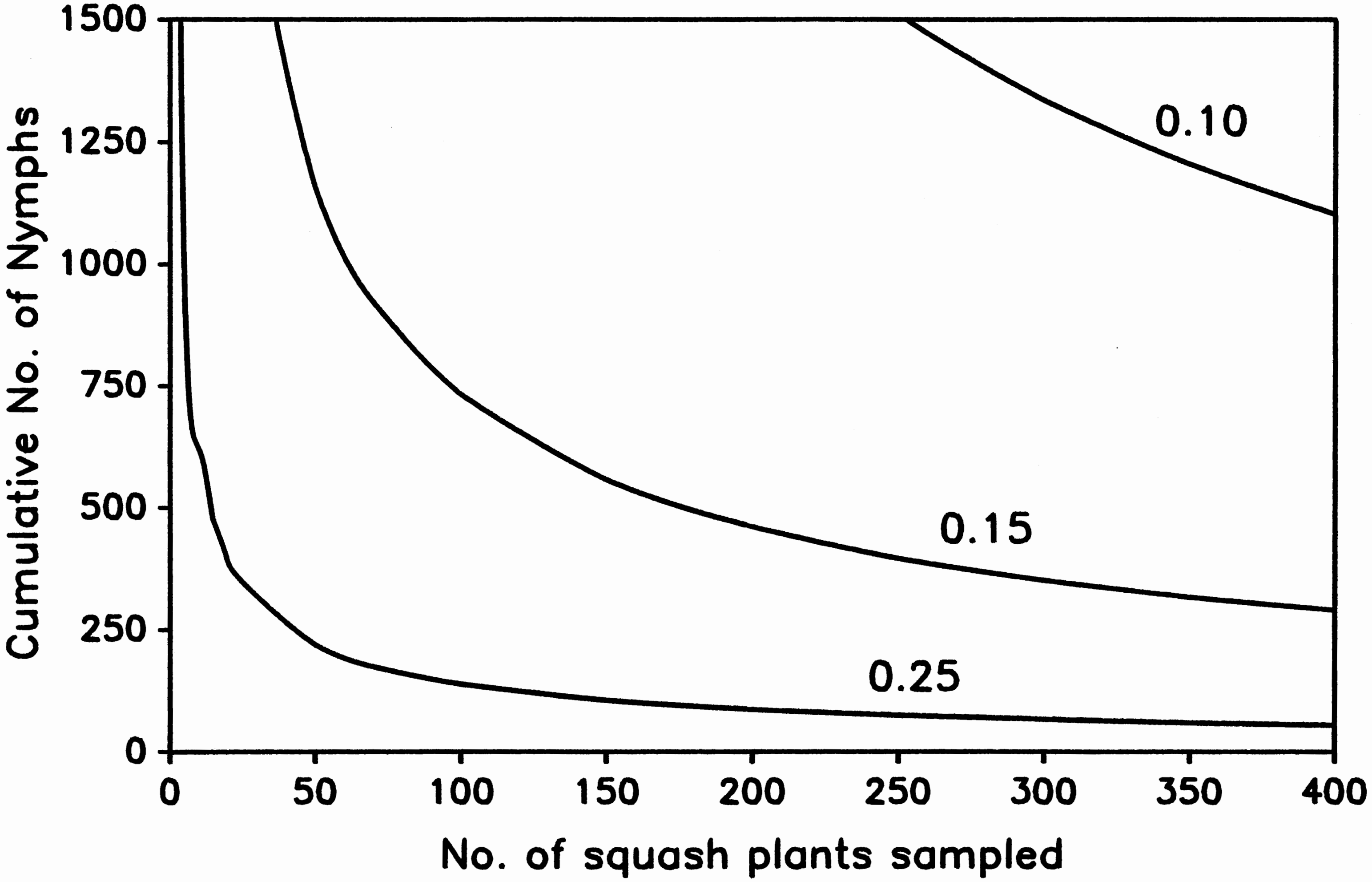

1500
1250
1000
750
500
250
0
Cumulative No. of Nymphs
0
50
100
150
200
250
300
350
400
No. of squash plants sampled
0.10
0.15
0.25

Figure 4. Number of squash plant samples required for various squash bug adult population densities with precision levels of _Do_=0.10, 0.15 and 0.25

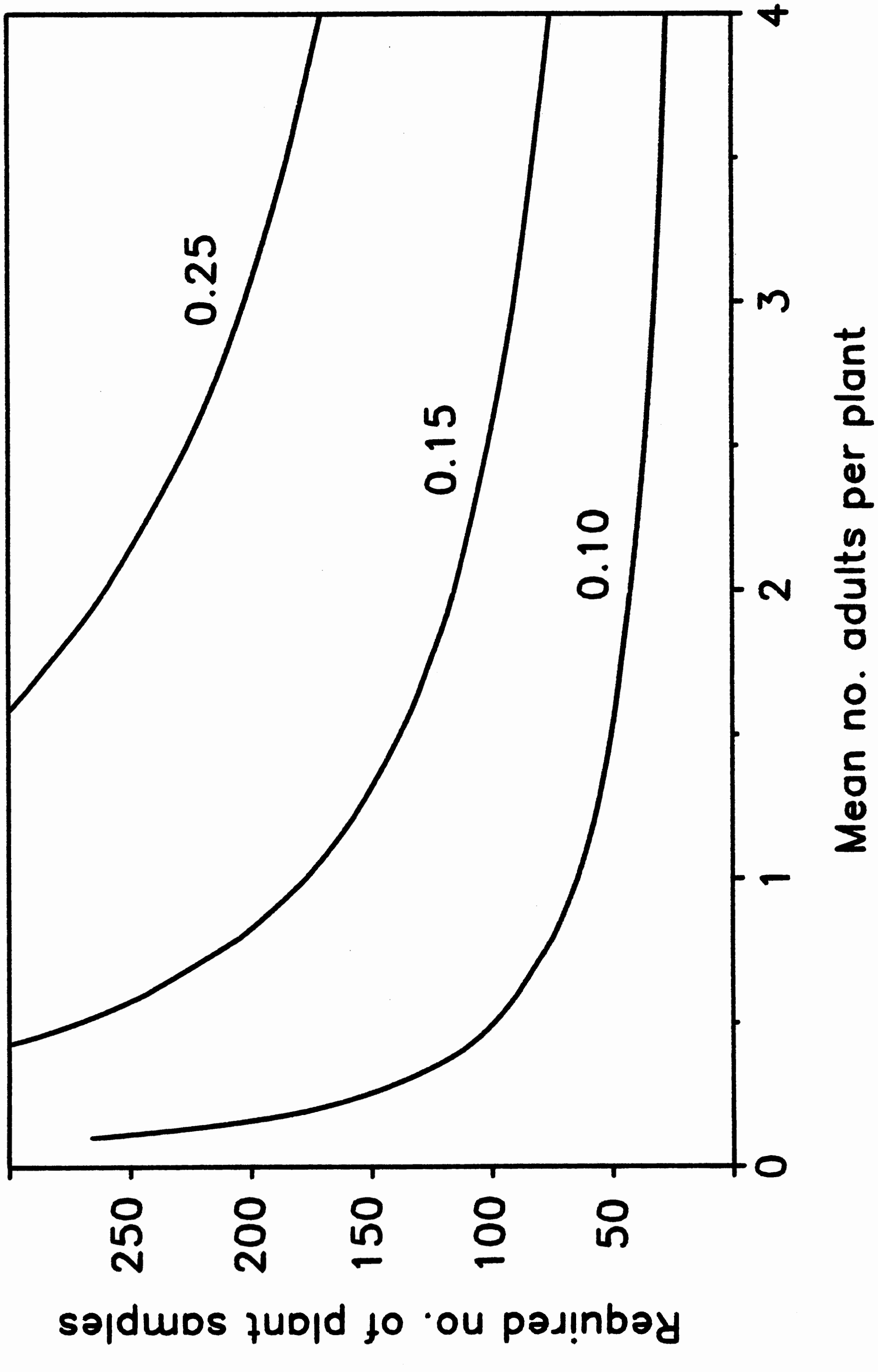

Required no. of plant samples
250
200
150
100
50
0
1
2
3
4
Mean no. adults per plant
0.25
0.15
0.10

Figure 5. Number of squash plant samples required for various squash bug egg mass densities with precision levels of <u>Do</u>=0.10, 0.15 and 0.25

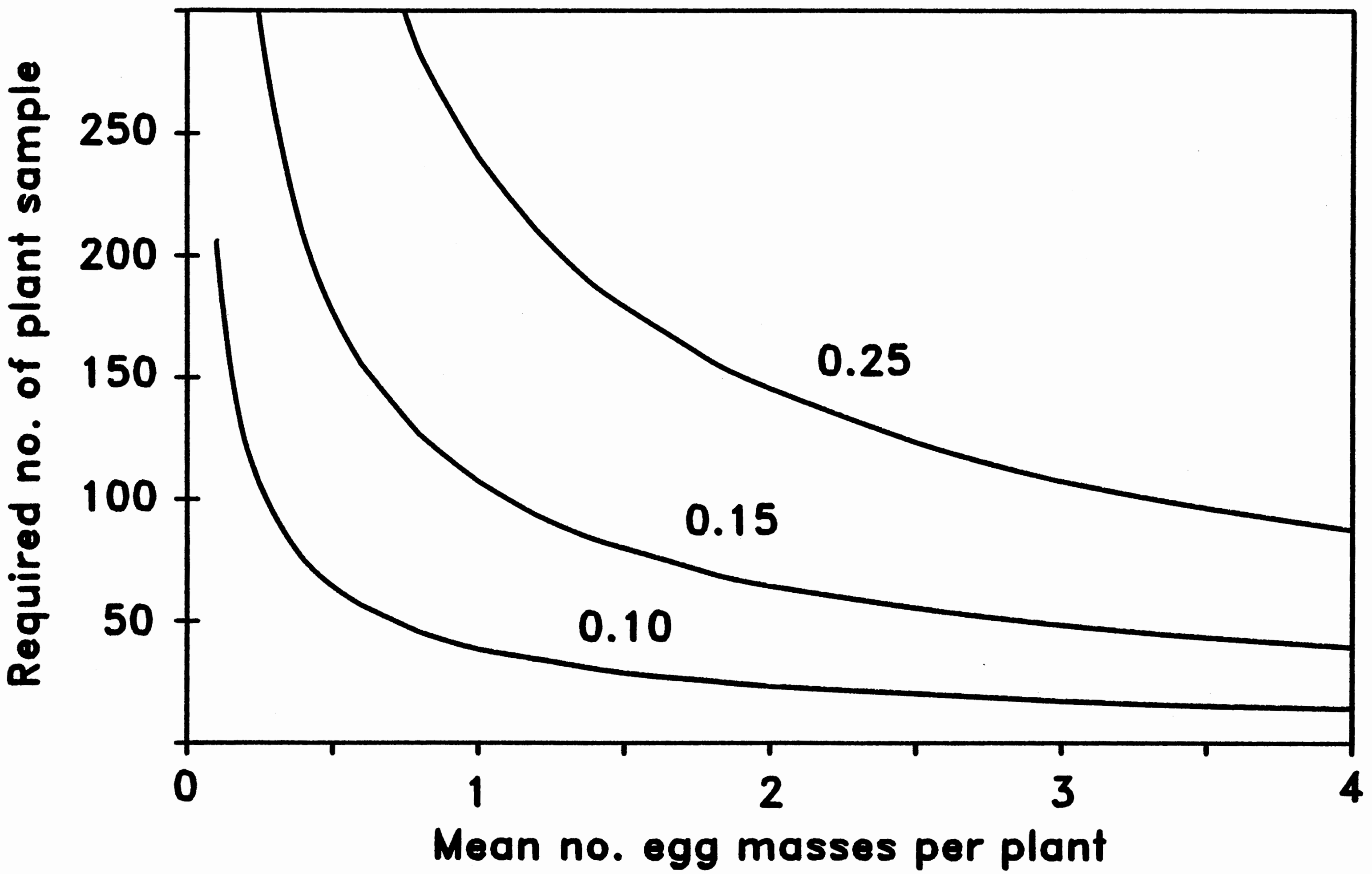
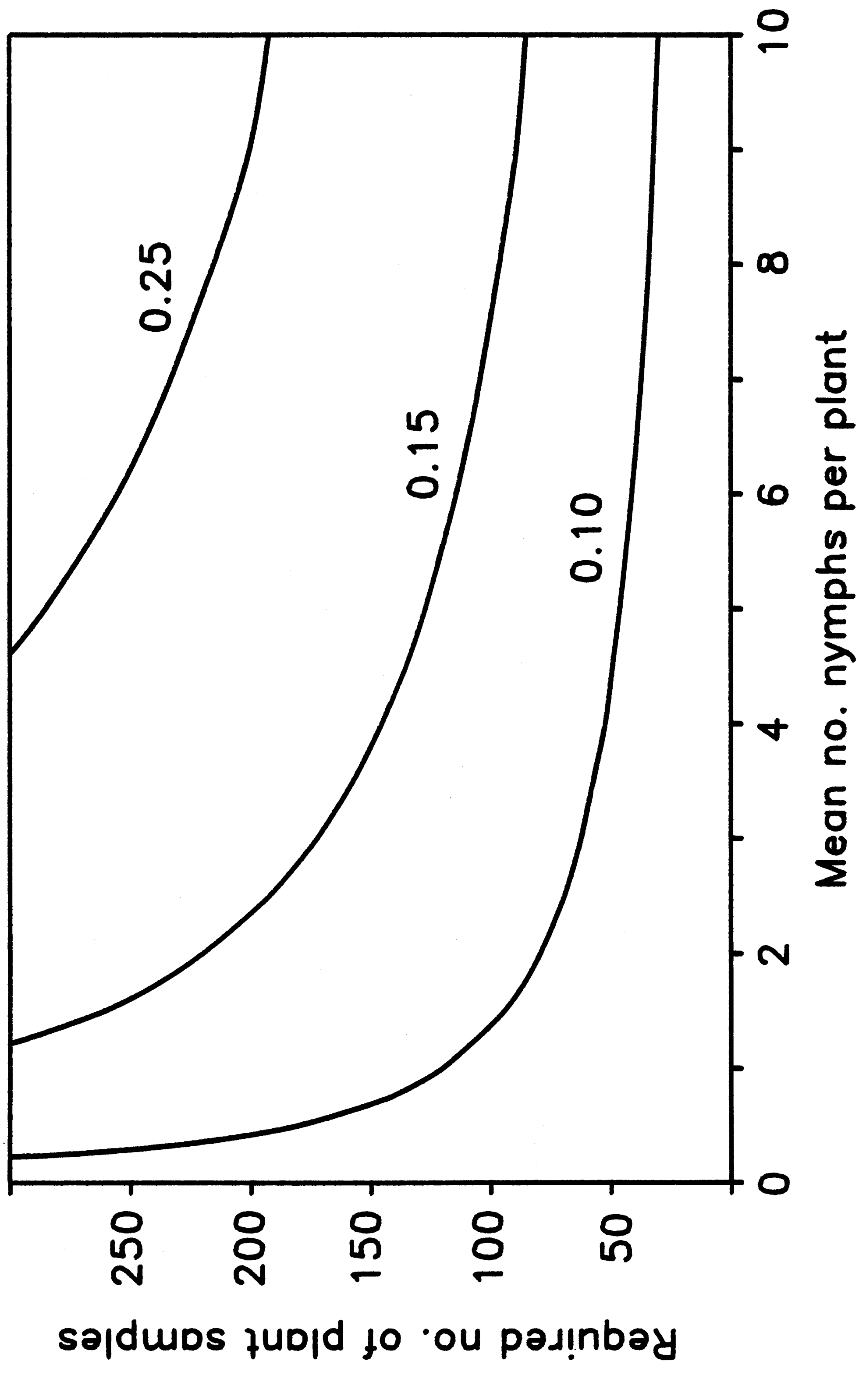

Required no. of plant sample
250
200
150
100
50
0
1
2
3
4
Mean no. egg masses per plant
0.25
0.15
0.10

Figure 6. Number of squash plant samples required for various squash bug nymph population densities with precision levels of _Do_=0.10, 0.15 and 0.25


0.25
0.15
0.10
Required no. of plant samples
250
200
150
100
50
Mean no. nymphs per plant
0
2
4
6
8
10

APPENDIX A

BASIC PROGRAMS FOR FITTING DATA TO NEGATIVE BINOMIAL AND POISSON DISTRIBUTIONS

```
 10 REM  CALCULATION OF PROBABILITIES OF THE NEGATIVE
        BINOMIAL DISTRIBUTION
 20 X=2
 30 INPUT "DATE=";D
 40 PRINT "      DATE:=";D
 50 INPUT "NUMBER OF SAMPLES=";N
 60 PRINT "      N=";N
 70 INPUT "ENTER K ";K
 80 PRINT "      K=";K
 90 INPUT "MEAN = ";XBAR
100 PRINT "    MEAN=";XBAR
110 PRO=((K/(K+XBAR))^K)
120 EXPECT =PRO*N
130 PRINT TAB(15)"PR(0)=";PRO TAB(40)"EXP(0)";EXPECT
140 M=(XBAR/(XBAR+K))
150 PR=K*MPRO
160 EXPEC=PR*N
170 PRINT TAB(15)"PR(0)=";PR TAB(40)"EXP(0)";EXPEC
180 Q=((X+K-1)/X)*M
190 PR=Q+PR
200 OBS=PR*N
210 PRINT TAB(15)" PR(";X;")";PR TAB(40)"
    EXP(";X;")";OBS
220 X=X+1
230 IF PR>0.0001 THEN GOTO 180
```

```
 10 REM CALCULATIONS FOR PROBABILITY OF POISSON
    DISTRIBUTION
 20 DIM X(100), PROB(100)
 30 INPUT "ENTER THE VALUE OF LAMBDA :";LAMBDA
 40 PRINT "      LAMBDA=";LAMBDA
 50 INPUT "N=";N
 60 PRINT "      N=";N
 70 XFACT=1
 80 INPUT "ENTER THE MAXIMUM VALUE OF X :";XMAX
 90 PRINT "X PROBABILITY"
100 PRINT "      THE PROBABILITY OF X"
110 FOR X=0 TO XMAX
120 IF (X=0) THEN XFACT=1 ELSE XFACT=XFACT*X
130 PROB(X)=EXP(-LAMBDA)*LAMBDA^X)/XFACT
140 EXPECT(X)=PROB(X)*N
150 EXPVAL=EXPVAL+PROB(X)*100
160 PRINT X;EXPECT (X)
170 PRINT "       EXPECTED VALUE OF (";X;")=";EXPECT(X)
180 NEXT X
```

CHAPTER VI

WITHIN-PLANT DISTRIBUTION OF SQUASH BUG ADULTS AND EGG MASSES IN VEGETATIVE STAGE SUMMER SQUASH

Abstract

Within-plant distribution of squash bug, Anasa tristis (De Geer), adults and egg masses on spring plantings of summer squash was determined by making whole-plant visual examinations. A significantly greater percentage of adults were found on the soil surface than on plants in early stages of crop phenology (<10 leaves per plant). On plants with greater numbers of leaves, the squash bugs were found predominantly on plants. Averaged throughout vegetative growth of squash, numbers of adults on plants and on the soil surface did not differ significantly. Studies of distribution of egg masses indicated that > 90% of squash bug oviposition occurred on abaxial leaf surfaces. A significantly greater percentage (90%) of egg masses were deposited on leaves in the lower one-half of the plant during vegetative plant growth. Results from this study suggest that sampling procedures should be developed separately for adults and egg masses. Monitoring adults populations should include examination of both the plant and soil surface, while sampling for egg masses should concentrate primarily on the lower foliar canopy.

Introduction

Fresh market cucurbits are important crops throughout the United States and in particular Oklahoma, where production was valued at $ 13.7 million dollars in 1981 (Tweeten 1982). Squash bug, Anasa tristis (De Geer), is among the most important pests associated with these crops (Davidson & Lyon 1979), but is especially damaging to summer squash and other cultivated species within the genus, Cucurbita. Adult squash bugs have been shown to cause significant mortality to seedling squash plants (Beard 1935, Eichmann 1945). Damage to fruiting plants caused by nymphal feeding can cause significant reductions in fruit yields (Chapter 4). As a result, control strategies are most effective when directed at populations of egg masses and small nymphs prior to plant flowering.

Although the basic ecology and biology of this pest have been studied intensively (Beard 1935, 1940, Nechols 1987, 1988, Fargo et al. 1988, Fargo and Bonjour 1988, Fielding & Ruesink 1988, Bonjour et al. 1990), information regarding population assessment of squash bugs is lacking. Interplant spatial patterns of squash bugs on summer squash has previously been described for the development of sequential sampling plans (Chapter 5). However, a basic component in deriving a reliable sampling program is the determination of the within-plant location of squash bug adults and egg masses during various growth stages. If squash bugs disperse on squash plants in a predictable pattern, then specific plant structures can be used as sample units. Therefore, the primary objective of this study was to determine the spatial pattern of squash bug adults and egg masses within summer squash plants during vegetative growth.

Materials and Methods

The study was conducted during 1988 at two locations in Northcentral Oklahoma: the Oklahoma State University (OSU) Horticultural Research Station near Perkins, Payne Co., Okla.; and the OSU Landscape and Horticulture Nursery Farm near Stillwater, Payne Co., Okla. At each location, a 0.15-ha field of straightneck summer squash, Cucurbita pepo L. 'Hyrific', was sub-divided into 20 plots of equal size. Each plot was 4 rows wide (122 cm per row width) by 11 m long. Each row contained hills spaced at 0.9 m intervals. Planting dates were 25 May at Stillwater and 13 May at Perkins. Plots were maintained using normal horticultural practices for this region. No insecticides were applied to the plants during the studies.

Plants were sampled at 4-5 day intervals, beginning at seedling emergence and continuing until plants began to flower. Sampling was conducted by randomly selecting five plants from each plot (100 total plants per site and sample date) and visually examining all plant structures (leaves, stems, and petioles) for incidence of squash bug adults and egg masses. In addition, the soil surface immediately underneath each plant within a 0.3 m radius of the stem was examined for the presence of adults. Sampling was conducted on 8 separates dates at Stillwater (6 June-4 July) and on 7 dates at Perkins (24 May-21 June). Sampling data was collected between 0700 and 1100 hours. On each sampling occasion the following information was recorded for each plant: number of cotyledons and fully expanded leaves; total egg masses and adults per leaf, petiole, and stem; and location of each adult and egg mass on the plant. Each leaf, petiole, and internode was numbered with respect to its position on the plant, relative to the hypocotyl.

All analyses were performed with the Statistical Analysis System (SAS Institute 1985). Linear regression analysis using the GLM procedure was used to describe correlations between numbers of squash bugs on various locations within the plant and soil. Regressions were performed for each location independently and were tested with analysis of covariance for homogeneity of slopes and intercepts and whether data could be pooled across locations.

A two-way analysis of variance using the SAS (SAS Institute 1985) general linear models (GLM) procedure with Duncan's (1975) multiple range test was used to test for mean differences in squash bug numbers among the various plant structures. Data consisting of percentages of squash bug adults and egg masses located within plants were transformed using an arcsine transformation (arcsine$\sqrt{P}$) prior to analysis. Student's *t* tests ($P<0.05$) were also used to compare mean differences in the percentages of total insects inhabiting plant structures. Regression analysis using Proc REG (SAS Institute 1985) was used to describe relationships of total egg mass numbers with numbers located on leaf surfaces.

To describe the relative abundance and position of egg masses on leaves, weighted mean leaf positions were calculated for each plant on each sample occasion using the formula: $L_m=\Sigma l_i m_i/\Sigma m$, where L_m=weighted mean leaf position on the plant; l_i=leaf position i on the plant, where $i=1,...,n$ and position 1 is closest to the hypocotyl; m_i=number of egg masses on leaf l_i, and Σm = total number of egg masses summed across all leaf positions for each plant. These weighted mean leaf positions were subjected to regression analysis with mean leaves per plant using plot means as replicates.

Results and Discussion

Adult distribution. Trends in distribution of adults within plant hills are presented in Table 1. Throughout vegetative growth (1-23 leaves per plant), the greatest mean percentage of adults were located either on leaf surfaces or the soil surface below plants. Early in the season when there was an average of 2-8 leaves per plant, a significantly greater proportion of adults were located on the soil surface. As numbers of leaves per plant increased (>15 leaves), more adults were found on leaves than on the soil. A lower percentage of adults were found among the, cotyledons, petioles, and stems.

On many occasions when plants were small, mating adults were observed hiding in cracks in the soil or under field debris near plants. As plants size increased, adults were observed more frequently on leaves and petioles (Table 2), correlating with an increase in egg mass abundance. However, averaged over all sample dates, no significant difference between mean percentages of adults located the soil surface (56.6%) and plant (43.4%) was observed. Other heteropteran insects have been reported to distribute similarly on both plant and soil surfaces at various stages of plant growth (Hoffman et al. 1987). Because adults mate frequently and for prolonged periods (Beard 1940), protective cover is important when adults first enter fields. Seedling plants with few leaves may not provide sufficient cover, as compared to plants with 15-20 leaves. This may partially explain why adults are frequently found on the soil. In addition, adults have been reported to congregate underneath the plastic near the base of summer squash plants grown in plastic mulched soil. (Cartwright et al. 1990).

Therefore, because distribution of adults on and around plants varies during vegetative growth stages, selection of a specific plant structure as a standard sample unit for monitoring purposes can not be derived from these results. More importantly, in order to accurately assess adult population densities, examination of the soil surface beneath the plant must be considered when developing a sampling methodology.

Egg mass distribution. Egg masses were found on plants on all sample dates. The total number of egg masses laid by squash bug females did not differ significantly between experimental sites. A total of 1276 egg masses was observed on the plants at both locations during the study; 94.5% of which were deposited on leaves, 3.6% on cotyledons, 1.2 % on petioles and 0.7% on vines. Of the total number of egg masses deposited on leaves, an average of 92.2% were located on abaxial surfaces. The mean percentage of egg masses found on the abaxial surfaces of leaves was significantly greater than that found on other plant structures throughout the vegetative growth period (Table 3). These results corroborate the findings of Bonjour et al. (1990) and earlier workers who reported the abaxial surface of leaves as preferred oviposition sites of squash bug.

Regression analysis of total egg mass numbers per plant($\underline{Y}$) with the number of egg masses on abaxial leaf surfaces($\underline{x}$) was highly significant ($\underline{Y}=0.15\pm0.10 + 1.07\pm0.02\underline{x}$; $R^2=.90$; df= 1,18; $\underline{P}<.0001$; and $\underline{Y} = 0.29\pm.12 + 1.05\pm0.02\underline{x}$; $R^2=.86$; df=1,18; $\underline{P}<.0001$) for Perkins and Stillwater , respectively. Paired comparisons with Student's t-test ($\underline{P}=0.05$) showed that intercepts and slopes of these equations were not significantly different between the two sites. This indicated that by sampling for egg masses on abaxial surfaces, a reliable estimate of total egg mass numbers per plant could be made. In addition, sampling abaxial surfaces of leaves provided the greatest probability of encountering the highest egg mass numbers.

The mean number of leaves on plants on each sample date, and the average location and distribution of egg masses relative to numbers of leaves is shown in Table 4. Trends in frequency of egg masses on individual leaves during vegetative growth were similar at both Stillwater and Perkins. In the early stages of the infestation, egg masses were found primarily on the cotyledons and the first true leaf of the plant. When plants contained fewer than 10 leaves, an average of 92.6 % of the egg masses were found on leaves located on the lower one-half of the foliar canopy. The average weighted leaf position of egg masses through this period (2.0) indicated that egg masses had been deposited primarily near the bottom of the plant. As plants developed more leaves and approached the flowering stage, females deposited egg masses in a more even distribution among leaves in the lower and middle canopy. Egg masses were not found on the terminal growing points or small leaves at the tip of the plant on any sample occasion. Averaged over all sample dates, a significantly greater percentage (89.7%) of egg masses were located on the lower one-half of the plant.

In general, it appears that squash bugs oviposit preferentially on leaves in the lower plant canopy. Correlation analysis between average weighted leaf positions of egg masses on leaves and total numbers of leaves (Figure 1) shows that throughout vegetative growth of summer squash, the greatest frequency of egg mass numbers was consistently located closer to the base of the plant. This information on the location and distribution of egg masses through vegetative development of summer squash also provides useful information for developing management strategies for squash bugs.

Although distribution of squash bug nymphs within plants was not quantified in this study, it was consistently observed that first and second instar nymphs aggregated near recently eclosed egg masses. Beard (1935) and Gould (1943) noted similar behavior in aggregation of small nymphs on several cucurbit cultivars. Numbers of nymphs usually reach economic injury levels prior to fruit harvests (Chapter 4) and several applications of insecticide may be required for suppression. Analyses of egg mass distribution within plants reported in this study may partially explain why insecticidal control of squash bugs on fruiting summer squash is often ineffective (Criswell 1987). Because egg masses and small nymphs are located under leaves in the lower plant canopy, penetration of sprays is often inadequate with conventional insecticide application methods.

In conclusion, this study demonstrates that squash bugs preferentially disperse and oviposit within summer squash during vegetative growth. However, I suggest that sampling procedures for monitoring squash bugs be developed separately for adults and egg masses. Variation in adult distribution between the plant and soil surface indicates that examination of the soil surface beneath the plant is important for accurately estimating population densities early in the season. Distributional analyses of egg masses within the plant indicated that sampling procedures to locate egg masses should concentrate on the undersides of leaves in the lower one-half of the foliar canopy. This strategy will minimize the amount of plant material and sampling time needed to reliably evaluate egg mass density for management decisions.

References Cited

Beard, R. L. 1935. Further observations on the squash bug in Connecticut, pp 333-339. In Connecticut Agricultural Experiment Station Bulletin 383, New Haven.

1940. The biology of Anasa trisitisDeGeer, pp 31-51. In Connecticut Agricultural Experiment Station Bulletin 216, New Haven.

Bonjour, E. L., W.S. Fargo, & P.E. Rensner. 1990. Ovipositional preference of squash bugs (Heteroptera:Coreidae) among cucurbits in Oklahoma. J. Econ. Entomol. (In Press).

Cartwright, B., J.C. Palumbo, & W.S. Fargo. 1990. Influence of crop mulches and row covers on the occurrence of the squash bug (Heteroptera: Coreidae) on summer squash. J. Econ. Entomol. 83: (In Press).

Criswell, J.T. 1987. Studies in the control of the squash bug, Anasa tristis DeGeer. Ph.D. dissertation, Oklahoma State Univ., Stillwater.

Davidson, R.H. & W.F. Lyon. 1979. Insect pests of farm, garden, and orchard. Wiley, New York.

Duncan, D. B. 1975. t Tests and intervals for comparisons suggested by the data. Bionomics 31: 339-359.

Eichmann, W. 1945. Squash bug depredations in Washington. J. Econ. Entomol. 32: 110-112.

Fargo, W.S., P.E. Rensner, E.L. Bonjour, & T.L. Wagner. 1988. Population dynamics in the squash bug (Heteroptera:Coreidae)-squash plant (Cucurbitales: Cucurbitaceae) system in Oklahoma. J. Econ. Entomol. 81: 1073-1079.

Fargo W.S. & E.L. Bonjour. 1988. Developmental rate of the squash bug, Anasa tristis (Heteroptera: Coreidae), at constant temperatures. Environ. Entomol. 17: 926-929.

Fielding D.J. & W.G. Ruesink. 1988. Prediction of egg and nymphal development times of the squash bug (Heteroptera: Coreidae) in the field. J. Econ. Entomol. 81: 1377-1382.

Gould, G.E. 1943. Insect pests of cucurbit crops in Indiana. Indiana Acad. Sci. Proc. 53: 165-171.

Hoffmann, M.P., L.T. Wilson, & F.G. Zalom. 1987. Control of stink bugs in tomatoes. Calif. Agric. 41: 4-6.

Nechols, J.R. 1987. Voltinism, seasonal reproduction, and diapause in the squash bug (Heteroptera: Coreidae) in Kansas. Environ. Entomol. 16:269-273.

Nechols, J.R. 1988. Photoperiodic responses of the squash bug (Heteroptera: Coreidae): diapause induction and maintenance. Environ. Entomol. 16:427-431.

SAS Institute. 1985. SAS user's guide: statistics, version 5 ed. SAS Institute, Cary, N.C.

Tweeten, L. 1982. Oklahoma agriculture 2000. Division of Agriculture, Oklahoma State University, Stillwater.

Table 1. Location of squash bug adults on plant and soil surfaces on several sample dates at Perkins and Stillwater, Oklahoma, 1988.

		% Adults (±SEM)				
Date	Mean no. leaves	Soil surface	Leaf surface	Cotyledon	Petiole	Stem
			Perkins			
24 May	2.1	56.0 ± 13.8	23.7 ± 10.5	20.3 ± 10.3	0.0 ± 0.0	0.0 ± 0.0
28 May	4.7	71.3 ± 9.9	14.4 ± 7.7	1.4 ± 1.0	5.6 ± 4.0	7.4 ± 5.8
2 June	7.3	76.5 ± 11.1	13.0 ± 4.6	5.9 ± 5.0	1.0 ± 0.5	3.6 ± 2.1
6 June	11.2	56.0 ± 6.9	39.0 ± 7.5	0.0 ± 0.0	1.7 ± 1.0	3.2 ± 2.2
10 June	13.9	47.0 ± 8.0	45.1 ± 6.8	0.0 ± 0.0	5.3 ± 3.0	2.5 ± 1.8
15 June	17.9	34.9 ± 7.3	38.5 ± 7.0	0.0 ± 0.0	16.8 ± 5.2	9.8 ± 3.5
21 June	22.5	29.3 ± 6.3	49.8 ± 5.3	0.0 ± 0.0	13.2 ± 3.9	7.7 ± 3.6

Table 1. Cont.

Date	Mean no. leaves	% Adults (±SEM) Soil surface	Leaf surface	Cotyledon	Petiole	Stem
		Stillwater				
6 June	1.2	50.8 ± 13.8	37.1 ± 11.3	12.1 ± 6.4	0.0 ± 0.0	0.0 ± 0.0
10 June	3.6	82.4 ± 5.8	5.8 ± 2.7	10.2 ± 5.6	0.0 ± 0.0	2.6 ± 2.0
13 June	5.8	85.4 ± 5.7	12.4 ± 5.7	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 1.9
17 June	7.9	60.6 ± 7.7	17.8 ± 6.7	2.7 ± 1.9	7.8 ± 3.5	11.1 ± 6.0
21 June	12.1	52.5 ± 7.4	32.4 ± 6.5	1.1 ± 1.0	6.3 ± 3.9	7.7 ± 4.4
26 June	15.8	33.5 ± 7.2	57.9 ± 7.7	0.0 ± 0.0	7.6 ± 3.4	1.1 ± 0.6
1 July	18.4	27.7 ± 5.6	40.9 ± 5.4	0.0 ± 0.0	19.7 ± 5.2	11.7 ± 4.1
4 July	21.3	24.4 ± 5.0	48.5 ± 4.9	0.0 ± 0.0	22.3 ± 6.1	4.8 ± 2.1

Table 2. Mean percentage of adults located on plants and soil surfaces on several samples dates at Perkins and Stillwater, Oklahoma, 1988.

	Perkins				Stillwater		
Date	Soil surface	Plant surface	*t*	Date	Soil surface	Plant surface	*t*
24 May	56.0	44.0	0.4	6 June	50.8	49.2	0.1
28 May	71.3	28.7	2.2[a]	10 June	82.4	18.6	5.6[a]
2 June	76.5	23.5	2.8[a]	13 June	85.4	14.6	6.2[a]
6 June	56.0	44.0	0.9	17 June	60.6	39.4	0.3
10 June	47.0	53.0	0.7	21 June	52.5	47.5	0.3
15 June	34.9	65.1	2.2[a]	26 June	33.5	66.5	2.3[a]
21 June	29.3	71.7	3.1[a]	1 July	27.7	72.3	4.0[a]
				4 July	24.4	75.6	4.2[a]
Total	54.8	45.2	1.3	Total	54.5	45.5	1.4

[a] means are significantly different (Student's *t* test, df=19; *P*<0.05)

Table 3. Mean percentage (±SEM) of egg masses distributed among summer squash plant structures on several sample dates at Perkins and Stillwater, Oklahoma, 1988.

		Plant Structure				
		Leaf surface				
Date	Mean no. leaves	Abaxial	Adaxial	Cotyledon	Petiole	Stem
			Perkins			
24 May	2.1	77.0 ± 11.2	3.7 ± 2.5	19.3 ± 10.4	0.0 ± 0.0	0.0 ± 0.0
28 May	4.7	91.7 ± 4.6	5.2 ± 3.6	3.1 ± 1.8	0.0 ± 0.0	0.0 ± 0.0
2 June	7.3	89.6 ± 5.4	7.5 ± 4.1	1.7 ± 1.0	1.2 ± 0.8	0.0 ± 0.0
6 June	11.2	89.1 ± 4.9	8.6 ± 5.5	0.0 ± 0.0	2.3 ± 0.9	0.0 ± 0.0
10 June	13.9	94.8 ± 2.7	3.5 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 1.3
15 June	17.9	90.8 ± 2.8	5.9 ± 1.7	0.0 ± 0.0	1.8 ± 0.8	1.5 ± 1.0
21 June	22.5	84.4 ± 3.8	11.1 ± 2.4	0.0 ± 0.0	3.2 ± 1.6	1.3 ± 1.1

Table 3. Cont.

		Plant Structure				
		Leaf surface				
Date	Mean no. leaves	Abaxial	Adaxial	Cotyledon	Petiole	Stem
			Stillwater			
6 June	1.2	62.9 ± 11.5	11.5 ± 8.3	25.6 ± 10.6	0.0 ± 0.0	0.0 ± 0.0
10 June	3.6	84.2 ± 5.7	5.7 ± 2.7	10.1 ± 5.5	0.0 ± 0.0	0.0 ± 0.0
13 June	5.8	92.5 ± 3.8	4.9 ± 2.3	2.6 ± 2.0	0.0 ± 0.0	0.0 ± 0.0
17 June	7.9	93.1 ± 3.2	5.1 ± 2.4	1.9 ± 1.3	0.0 ± 0.0	0.0 ± 0.0
21 June	12.1	90.0 ± 3.4	6.8 ± 3.3	1.0 ± 0.4	1.6 ± 1.2	0.0 ± 0.0
26 June	15.8	83.3 ± 4.8	11.3 ± 4.2	0.0 ± 0.0	3.0 ± 1.9	2.4 ± 1.8
1 July	18.4	87.5 ± 2.3	9.5 ± 1.9	0.0 ± 0.0	2.5 ± 1.4	0.5 ± 0.5
4 July	21.3	90.3 ± 2.9	6.2 ± 1.8	0.0 ± 0.0	3.5 ± 2.1	0.0 ± 0.0

Table 4. Location of squash bug egg masses on leaves of summer squash on several sample dates at Perkins and Stillwater, Oklahoma, 1988.

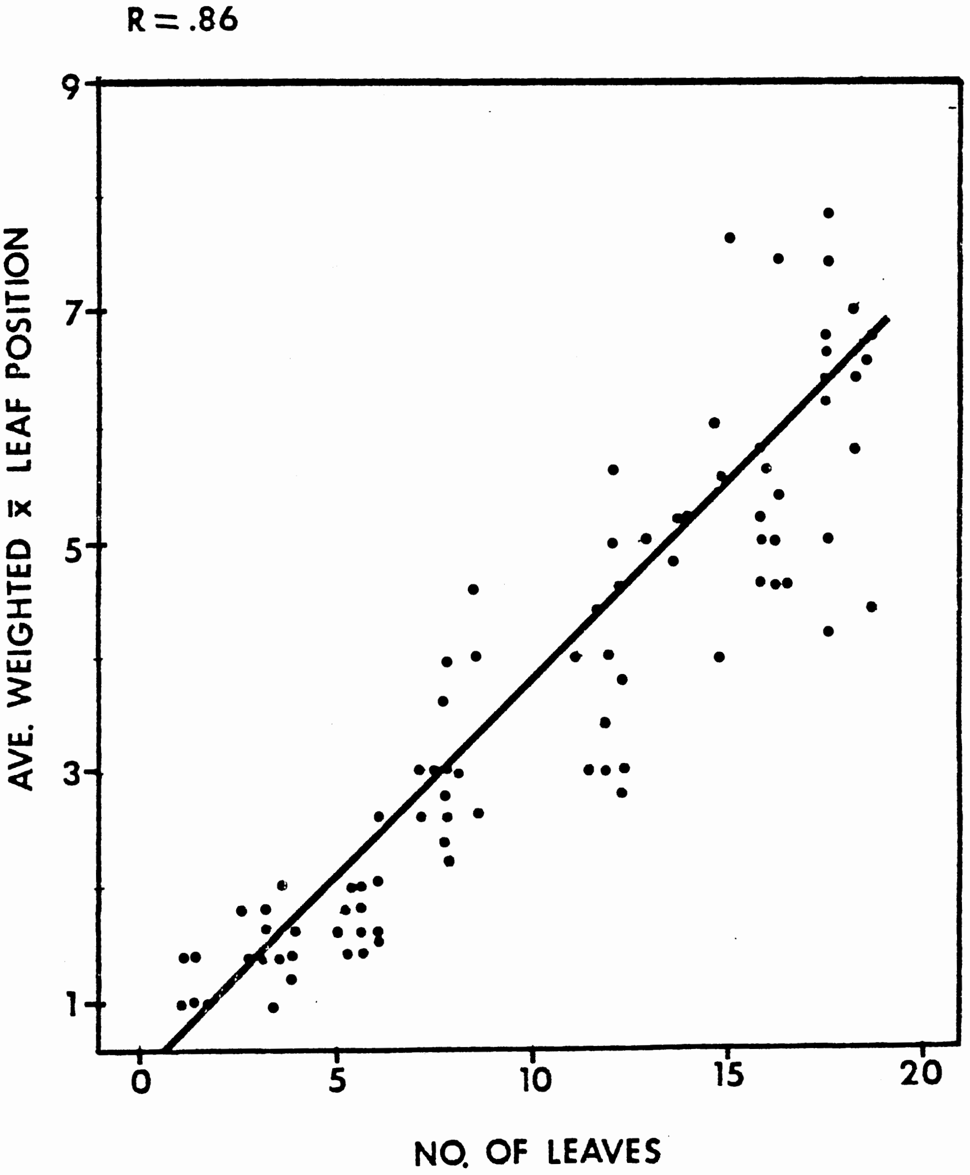
	Sample date							
Egg mass location	June 6	June 10	June 13	June 17	June 21	June 26	July 1	July 4
				Stillwater				
Ave. no. leaves	1.2	3.6	5.8	7.9	12.1	15.8	18.4	21.3
Ave. weighted leaf position	1	2	2	3	4	5	7	8
% egg masses on :								
lower ½ of plant	90.0	97.2	98.2	89.9	92.9	90.3	84.3	79.5
upper ½ of plant	10.0	2.8	1.8	10.1	7.1	9.7	15.7	20.5
t value[a]	6.0	24.8	62.0	10.8	13.6	10.2	7.5	7.0

Table 4. Cont.

	Sample date						
Egg mass location	May 24	May 28	June 2	June 6	June 10	June 15	June 20
				Perkins			
Ave. no. leaves	2.1	4.7	7.3	11.2	13.9	18.4	23.5
Ave. weighted leaf position	1	2	2	4	5	7	9
% egg masses on :							
lower ½ of plant	89.6	90.6	92.9	89.9	85.6	83.8	88.2
upper ½ of plant	10.4	9.4	7.1	10.1	14.4	16.2	11.8
t value[a]	5.6	5.9	11.0	7.3	9.6	7.1	5.2

[a] all means are significantly different (Student's _t_ test; df=19; _P_<0.05)

Figure 1. Correlations of average weighted mean leaf positions for squash bug egg masses with numbers of leaves per plant (see text) at Stillwater and Perkins, Oklahoma in 1988. Coefficients of correlation (R) are significant at ($P<0.0001$; n=120).


R = .86
AVE. WEIGHTED x̄ LEAF POSITION
9
7
5
3
1
0
5
10
15
20
NO. OF LEAVES

VITA

John Charles Palumbo

Candidate for the Degree of
Doctor of Philosophy

Thesis: DEVELOPMENT OF MANAGEMENT STRATEGIES FOR SQUASH BUG (HETEROPTERA: COREIDAE) POPULATIONS IN SUMMER SQUASH

Major Field: Entomology

Biographical:

Personal Data: Born in Phoenix, Arizona, February, 8 1959, the son of Joseph A. and Joan M. Palumbo

Education: Graduated from Buckeye Union High School, Buckeye, Arizona in May, 1977; received Bachelor of Science Degree in Entomology from the University of Arizona, Tucson, Arizona in May, 1982; received Master of Science Degree in Entomology from the University of Arizona in 1985; completed requirements for the Doctor of Philosophy Degree at Oklahoma State University in December, 1989.

Professional Experience: Student Assistant, Department of Agriculture, Arizona Western College, 1977 to 1978; Research Assistant, Albany International-Conrel, 1981-1982; Graduate Research Assistant, Department of Entomology, University of Arizona, 1983-1985; Graduate Teaching Assistant, Department of Entomology, Oklahoma State University, 1986-1987; Graduate Research Assistant, Department of Entomology, Oklahoma State University, 1987 to present.

Professional Societies: Entomological Society of America; Southwestern Entomological Society; American Society for Horticultural Science; Gamma Sigma Delta; Sigma Xi.