EFFECTS OF SPINOSAD AND LAMBDA-CYHALOTHRIN ON THEIR TARGETS, CABBAGE LOOPER, *TRICHOPLUSIA NI*, AND DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA*, AND ON THEIR NON-TARGETS, SPIDERS, ON CABBAGE IN SOUTH TEXAS

A Thesis

by

ROSE WAMBUI IRUNGU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Entomology

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Approved by:

Co-Chairs of Committee,	Marvin K. Harris
	Tong-Xian Liu
Committee Members,	James M. Chandler
	Julio Bernal
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ABSTRACT

Effects of Spinosad and Lambda-Cyhalothrin on Their Targets, Cabbage Looper, *Trichoplusia ni* and Diamondback Moth, *Plutella xylostella*, and on Their Non-Targets, Spiders, on Cabbage in South Texas.

(December 2007)

Rose Wambui Irungu, B.S., University of Nairobi, Kenya

Co-Chairs of Advisory Committee: Dr. Tong-Xian Liu
Dr. Marvin K. Harris

A randomized block experiment was conducted in cabbage fields at Texas Agriculture Experiment Station at Weslaco in the spring and fall 2005 and spring 2006. There were four blocks and two pesticide treatments, spinosad (SpinTor®), λ-cyhalothrin (Warrior®), and an untreated control. The pesticide treatments were for the management of *Plutella xylostella* L. (Lepidoptera: Plutellidae) and *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae).

Pitfall traps captured eight families of spiders in fall 2005, and thirteen families in spring 2006. The most abundant family was Lycosidae with *Pardosa delicatula* (Gertsch and Wallace) followed by *Pardosa pauxilla* (Montgomery) and *Hogna helluo* (Walckenaer) in fall 2005, while in spring 2006 *Hogna helluo* was most abundant followed by *Pardosa delicatula* and *Pardosa pauxilla.*

The diversity of spiders in fall 2006 in the λ-cyhalothrin plots was lower than that of spiders found in the untreated control or the spinosad treated plots, which were up to

2.6 and 2.4 times, respectively, more diverse. In spring 2006, the spiders in untreated control and spinosad treated plots were 1.5 and 1.3 times respectively more diverse than spiders in the λ-cyhalothrin treated plots. In fall 2005, mean diversity of spiders in spinosad treated plots was 1.1 times more diverse than in the untreated control, although this difference was not statistically significant. In spring 2006, spinosad treated plots had 1.2 times greater diversity than untreated control and this difference was significant.

The effects of two insecticide treatments on height, width, and weight of cabbages were highly significant in all three seasons. Cabbage harvest in spinosad and λ-cyhalothrin plots showed greater height, width, and weight than in untreated control but were not different from each other. However, in the larval damage rating, spinosad treatment showed better management of diamondback moth and cabbage looper than λ-cyhalothrin.

DEDICATION

Kwa Mungu aliyeumba ulimwengu wote. Nashukuru kwa kunipa nafasi ya kuchunguza viumbe vyako. Mungu mweza yote, Mungu ambaye haonekani. Mungu mwaminifu, Mungu anayeishi milele, Mungu pekee wa kweli. *{To God, the creator of the universe, I thank you for allowing me to research your creatures. To the almighty god, invisible, faithful, immortal, the only true God.}*

Kwa mume wangu. Umenipa uhai mpya. Umenipa nguvu kwa mabawa yangu. Wewe ndiye nimpendae. Umekuwa nguzo yangu toka mwanzo hadi sasa. Umeyapanguza machozi yangu, umeniongoza, ukanituliza. Sasa wakati wangu umefika, nimemaliza masomo, nimerudi nyumbani na sitaondoka tena bila wewe. Sasa tunaanza maisha yetu pamoja. *{To my husband, you have given me a new life, you are the wind beneath my wings, you are the one I love. You have been my pillar of strength, you have wiped my tears, you have led me and you have comforted me. Now the time has come for me to return home, I will not leave again without you. Now we start our life together.}*

Kwa wazazi wangu na familia yangu, Mungu amewajalia kuwa watu wema. Mmenipenda bila kanuni zozote. Mmevumilia masomo yangu, mmenipa wasia. Sasa nimefikia nyota yangu. Nashukuru. *{To my parents and family, God has blessed you, you are good people. You have loved me unconditionally; you have endured my pursuit of education. You have given me advice. Now I have reached my star. I thank you}*

Kuna tai ndani yangu amabaye anataka kupepea ili apae angani. Lakini pia kuna kiboko amabaye anataka kuloweka kwa matope. Leo hii, tai amepaa. *{There is an eagle in me that wants to soar. And there is a hippo in me that wants to wallow in the mud. Today the eagle has soared.} Carl Sandburg*

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CHAPTER I

INTRODUCTION

The Cabbage

Cabbage, *Brassica oleracea* L. var. *capitata* (Brassicaceae), is an economically important vegetable crop in Texas, and is ranked second in national production of cabbage. It has a cash value of US$41,499,000 (USDA-NASS 2006) in Texas. Cabbage is a healthy food, providing vitamins K and C, dietary fiber, manganese, vitamin B6, folate, Omega 3 fatty acids, vitamin A, B1, and B2, calcium, and magnesium (Kurilich et al. 1999, USDA-ARS 2005). Numerous researchers have studied the effects of beneficial phytochemicals found in cabbage and other cole crops. Indole-3-carbinol (I3C), sulforaphane and indoles activate and stabilize the body's antioxidant and detoxification mechanisms. This, in turn, eliminates carcinogenic substances (Beecher 1994). Cabbage and other cole crops are known to help prevent breast and colon cancers (Pathak et al. 2006, Voorrips et al. 2000), and treat peptic ulcers (Shive et al. 1957), and may also protect against Alzheimer's disease (Commenges et al. 2000, Heo and Lee 2006).

This thesis follows the style of Journal of Economic Entomology.

Cabbage is consumed mainly as cole slaw salad, garnish for sandwiches, stuffed with meat as a main dish, and may be sautéed with onions. Sauerkraut is a traditional German dish made from fermented cabbage. Early German settlers introduced this recipe to the United States and, as a result people of German decent are sometimes referred to as 'krauts'. 'Kim Chee' is an aromatic Korean dish also made from fermented cabbage.

Approximately 3,000 hectares in Texas are under cabbage production (USDA-NASS 2006). Cabbage production regions include Lower Rio Grande Valley (LRGV), South Texas Winter Garden, High Plains and Trans Pecos (Fig. 1) (Appendix 1 describes the geographic regions of Texas; Appendix 2 describes various cole crops grown in Texas and production and acreage per region). In the LRGV, cabbage is planted from September to January. Prior to planting, the land is treated with herbicides and phosphate fertilizers. Cabbage is directly seeded in the field. Applications of nitrogen fertilizer are done through the irrigation system. Insecticides and fungicides are applied as needed. Most cabbage is harvested when the heads are about 15-20 cm (6-8 inches) in diameter and weigh over 1.5 kg (3 pounds). Most of the Texas cabbage crop is consumed fresh, while only about 10% is processed (USDA-NASS 2006).

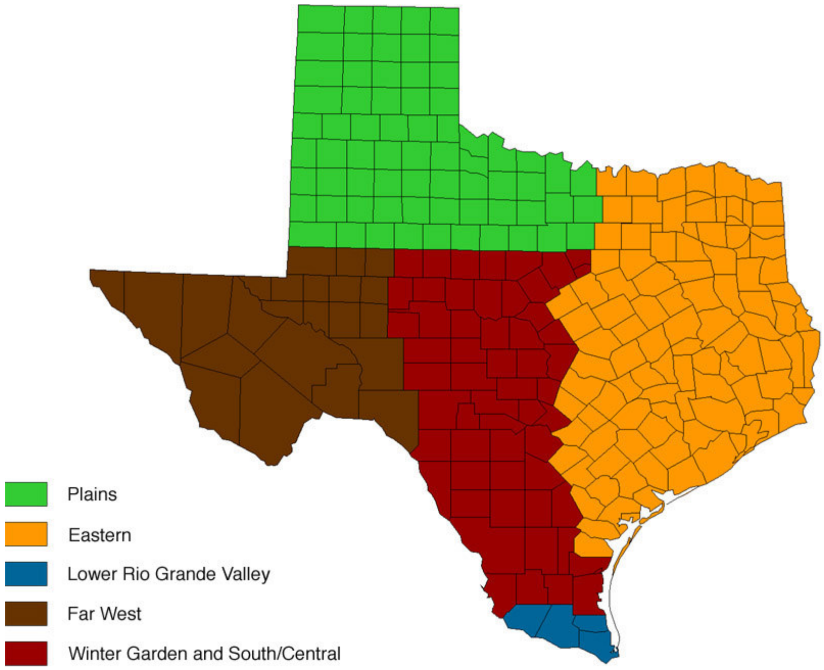

Fig. 1. Geographic regions of Texas. Cabbage is planted in the Plains, the LRGV, the Far West, and the Winter garden Areas. (Map by aggie horticulture)

Pests of Cabbage

Lepidopteran larvae are the most destructive pests of fresh market cabbage, and are often controlled with insecticides. Damage from these pests is caused by larval feeding. Although some Lepidoptera, such as diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae), are very small, the larvae can cause complete defoliation when densities are high. Other pests, such as cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae) chew large holes in leaves and deposit wet fecal material at the feeding sites. Both pests are able to bore into the head of the cabbage and render it unmarketable.

Trichoplusia ni is a key pest of cabbage in the LRGV (Cartwright et al. 1987, Edelson et al. 1993)**.** Different authors have studied the life history of *T. ni* (Shorey et al. 1962, Shorey 1963, Jackson et al. 1969, and Toba et al. 1973)**.** *T. ni* has four or more generations in a year, with each generation lasting four to six weeks. *T. ni* may overwinter as a pupa in the colder areas, and emerge as an adult in the spring to mate and find suitable host plants to lay eggs. Larvae eclose from the smooth, light green eggs in 3-4 d, and develop through various instars for about four weeks, as they feed aggressively. The caterpillars have three pairs of true legs and prolegs on the 3rd, 4th and 6th abdominal segments. They move by humping their backs, hence the name looper. They spin a silken cocoon in which they pupate, and adults emerge after 12-14 d.

Plutella xylostella is a key pest of cabbage since the early 1990s (Cartwright et al. 1992). In Texas, *P. xylostella* may have 8-12 generations in a year. The life cycle generally takes 25-30 d. Eggs are laid singly or in small groups. Larvae hatch from the pale green eggs in about 6 d; first instar larvae are leaf miners. After molting to the second instar, they emerge and continue to feed, chewing irregular holes on leaves. There are four larval instars. The larvae feed on the underside of leaves, leaving the upper surface and the leaf veins intact. The larvae wiggle violently when disturbed. Developmental time from first instar larva to pupation is approximately 18 d. Pupation occurs in a loose silken cocoon, and adults may take 5-15 d to emerge. The adult is small and grey, with a light colored band running down the back with constrictions, hence the name diamondback moth. Adults live for about 12-16 d, during which time they mate and the females begin to produce eggs. They are generally weak fliers, but are carried efficiently by wind (Marsh 1917, Harcourt 1955, 1957, 1963).

Management Practices of Cabbage Pests

Cultural practices have been and continue to be employed to control lepidopteran pests. In the management of *T. ni*, some cultivars have been found to be more resistant than others. However, this resistance is often overcome at high insect density. Resistant cabbage lines with glossy surfaces were studied in Honduras under extreme *P. xylostella* pressure and provided over 95% control (Eigenbrode et al. 1990). Glossiness genes were examined for their role in insect resistance (Stoner 1990, 1992). The results indicated high levels of resistance, and that the cause for resistance was leaf surface waxes (Eigenbrode et al. 1992). Especially relevant are results, from one study indicating high levels of resistance from glossy dominant genes (Stoner 1990).

Heavy rainfall is also a known mortality factor for *P. xylostella,* (Chang 1961, Harcourt 1963, Chin 1974), hence the adaptation of sprinkler irrigation by some farmers (Talekar and Lee 1985, Talekar et al. 1986). Water drops physically dislodge or drown larvae. This type of irrigation also reduces mating related flight activity, and oviposition if done at dusk (Asian Vegetable Research and Development Centre, 1988).

Intercropping has been used as a method of management of *P. xylostella*. Some intercrops act as physical barriers that prevent movement of *P. xylostella* into cabbage fields (Risch 1981), while others like Indian mustard, are more preferred hosts (Srinivasan and Krishna Moorthy 1992), and some intercrops reduce *P. xylostella* densities by hosting natural enemies (Root 1973), while some disrupt the visual or chemical communication between the insect and their hosts (Sheehan 1986).

Chemical control of lepidopteran pests is problematic due to insecticide resistance and is well documented in the literature. In the last few years, *P. xylostella* has been reported to have expressed resistance to conventional insecticides including organophosphates and pyrethrins (Tabashnik et al. 1987, Magaro and Edelson 1992, Leibee and Savage 1992, Plapp et al. 1992), as well as biorationals like *Bacillus thuringiensis* subspecies *kurstaki* (Shelton et al. 1993). There have been limited, measured successes in management of *P. xylostella* with *B. thuringiensis* subspecies *aizawai* (Shelton et al. 1993). *T. ni* control, like that of *P. xylostella*, has been heavily reliant on pyrethroids and other synthetic insecticides (Hines and Hutchison 2001), which are now less effective because of resistance development. Quality control regulations imposed by the Food Quality Protection Act of 1996 on fresh market vegetables, among other foods, dictate that there should be minimal or no insecticide residues on food. This has limited the number of acceptable insecticides. Indoxacarb, an environmentally friendly insecticide, was tested on *T. ni* (Liu et al. 2002) and *P. xylostella* (Liu et al. 2003a). Indoxacarb had little ovicidal effect on *T. ni* eggs, but had 100% mortality on first instar larvae after two days, and on third instar larvae after five days. On *P. xylostella,* indoxacarb caused very high mortalities (98 and 78%) in larvae fed cabbage leaves with 14 and 17 day old residues, respectively.

Biological control of *P. xylostella* has been studied over a long period of time. All stages of *P. xylostella* are attacked by parasitoids and predators. Egg parasitoids are from the genera *Trichogramma* and *Trichogrammatoidea,* while larval parasitoids are mostly from *Cotesia* and *Diadegma. Diadromus* spp. are usually pupal parasitoids. Adults are attacked by predators including spiders and birds. There have been cases of successful parasitoid introductions that have suppressed *P. xylostella* populations, e.g. introduction from England of *Diadegma semiclausum* Hellen and *Diadromus collaris* (Gravenhorst) to New Zealand (Hardy 1938) and Australia (Goodwin 1979).

In St. Helena, South Africa, percentage parasitism of *P. xylostella* by *Cotesia plutellae* (Kurdjumov) ranged from 28% in release sites to 80% in non-release sites, while percentage parasitism by the pupal parasitoid *D. collaris* was 55% in both sites (Kfir 2005). Biological control alone has not sufficiently controlled *P. xylostella* in Texas despite the abundant occurrence of *Diadegma, Cotesia,* and *Diadromus* spp. IPM practices have been necessary in order to conserve the parasitoids and other important natural enemies. These practices include scouting, pheromone disruption and reduced use of pesticides or use of environmentally friendly pesticides. In Texas, cabbage is also attacked by onion thrips and aphids. Control of these pests also must be compatible with the control of *P. xylostella* and *T. ni*.

Role of Predators in Cabbage Agro-Ecosystem

Predators often play important roles in the regulation of insect densities in an agro-ecosystem. Root (1973) explained in detail the organization of plants and arthropods in both simple and diverse habitats. His study showed that there was greater predator diversity and lower herbivore load in a complex habitat, in this case collards grown adjacent to meadow vegetation, compared to a simpler habitat. These results supported the hypothesis that natural enemies help control pests. Furlong et al. (2004) evaluated the impact of natural enemies on populations of *P. xylostella* in commercial *Brassica* farms, and found that predators were the most important cause of mortality, i.e. larval disappearance; other important causes of mortality were egg disappearance, larval parasitism and pupal parasitism. Insecticides interfere with these predators. The effect of various pesticides on spider densities is discussed in detail in chapter II.

Numerous papers have focused on the effect of insecticides on non-target organisms, such as lady beetles, minute pirate bugs, and others. Krishna Moorthy et al. (2004) showed that cypermethrin was acutely toxic to coccinellid predators causing 100% mortality in 1 h, while endosulfan caused 100% mortality in 3 h. Provost et al. (2003) demonstrated that exposure to a sublethal dose of λ-cyhalothrin resulted in lower consumption of *Hyaliodes vitripennis* (Say) by *Harmonia axyridis* Pallas. The study demonstrated this exposure affected predator mobility and behavior. Williams et al. (2003) reviewed the effect of spinosad on 52 species of natural enemies, including 27 species of predators and 25 species of parasitoids. They found that 79% of field type studies on predators gave a ‘not harmful’ result, while parasitoids showed a relatively greater susceptibility to spinosad. Berg et al. (1998) studied the effect of two insecticides on arthropods in soybeans. They concluded that monocrotophos, an organophosphate, suppressed predaceous ants, spiders and beetles, while λ-cyhalothrin had a greater impact on generalist predators, as well as suppressing phytophages. The recovery time was very short for predators, and long for lepidopteran larvae, indicating a potential for resurgence.

Spinosad (®, Dow Agro Sciences, Indianapolis, IN) and λ-cyhalothrin (Warrior®, Syngenta, Greensboro, NC) are products labeled and widely used for control of lepidopteran pests in cabbage and other fruiting and leafy vegetables. Spinosad is a biorational insecticide and is a secondary metabolite resulting from the aerobic fermentation of *Saccharopolyspora spinosa,* Mertz and Yao (1990), a soil actinomycete, on nutrient media, and is a mixture of spinosyn A and spinosyn D (Thompson et al. 1997). Spinosad has two modes of action: 1) disruption of the insect's nervous system at the nicotinic acetylcholine receptor, causing involuntary muscular contraction, leading to tremors and paralysis, and 2) activity at the GABA receptor (Salgado 1997). The mode of entry is either via contact or ingestion. Spinosad is highly toxic to honey bees exposed to direct sprays on blooming crops or other vegetation, and should not be applied when bees are actively foraging. Spinosad is also toxic to aquatic invertebrates. Direct application on a water surface, or contamination while cleaning equipment should be avoided. Spinosad is classified as an environmentally and toxicologically reduced-risk insecticide by the Environmental Protection Agency (EPA1997). Spinosad is dissipated in the environment by aquatic photolysis within one to two days of application. It may undergo biotic transformation in the absence of light (Cleveland et al. 2002).

Lambda-cyhalothrin is a synthetic pyrethroid, and a restricted use insecticide that acts on the nervous system as a sodium channel modulator (Ware and Whitacre 2004). It disrupts the sodium activation gate by keeping it in the "open" position, causing continuous transmission of impulses and excitation of nerve fibers, resulting in tremors, paralysis, and eventual death. λ-cyhalothrin also has repellant properties. This compound is extremely toxic to fish and other aquatic organisms, and is hazardous to humans and domestic animals. Although labeled for use on cabbage against *T. ni*, *P. xylostella,* and other lepidopteran pests, it is known to be toxic to honey bees. λ-cyhalothrin is photo degraded when exposed to sunlight. On plant surfaces, its half-life is five days, while on the soil the half-life is 30 days (Miller and Salgado, 1985).

Spiders

> Grief stricken, Arachne strangled herself with a noose, but Athena took pity and transformed her into a spider; as such, she and her descendants practice the art of weaving forever
>
> Morford and Lenardon 2003. Classical Mythology

Spiders are a group of arthropods belonging to the class Arachnida and the family Araneae. The class Arachnida is also shared by scorpions, ticks, mites and pseudo-scorpions. Spiders are easily confused with insects. Spider body is divided into two main regions, cephalothorax and abdomen. The two body regions are connected by a narrow pedicel. The cephalothorax contains the eyes, mouthparts, and legs, while the abdomen contains the reproductive, respiratory and digestive systems, as well as the spinning apparatus.

Spiders have eyes called ocelli; there may be up to four pairs, depending on the spider family. Some families have fewer pairs of ocelli. Some families, such as Salticidae, have very advanced ocelli and acute eyesight. Salticids exhibit vision-guided behavior such as stalking, chasing down and accurately leaping on prey (Land 1974). Spiders in the genus *Portia* Karsch, 1878 (Salticidae) have complex behavior and acute vision highly correlated. Planning and executing detours is based primarily on seeing environmental features (Tarsitano and Andrew 1999).

Spider mouthparts consist of chelicerae with fangs at the tips on the front of the head. Next to the chelicerae are the pedipalps that appear to be small legs. The pedipalps are used to manipulate food, and in males are also used during mating. After the pedipalps are eight legs (four on each side of the cephalothorax). The legs are hairy and often covered with spines. At the posterior end of the abdomen, spiders have an anal opening. Below the anal opening are the spinnerets through which silk is secreted.

Eggs are laid within a silk cocoon. The silk cocoon may be fastened to a surface, or carried around by the mother attached to her spinnerets, held by her chelicerae or at the sternum. When spiderlings emerge, they molt a number of times to attain maturity. Generally, the smaller the spider species the fewer times it molts as compared to a larger spider species. When a male spider matures, elaborate courtship procedures begin. Depending on the species, this could be dancing by waving palpi or legs, or tweaking threads of the female’s snare. Perhaps a good courtship is a precursor for mating. In some species (e.g. European pisaurids), the male comes bearing gifts, in this case, an insect for the female to eat. It is only in a few species that the male is killed after mating. More frequently, male and female pairs may share the same retreat for a period of time, and then part without aggression.

Spiders are generally carnivorous in nature. They seize prey only. Most species prefer insects, but some may capture small frogs and fish as well. Some spiders wrap their prey in silk, while others manipulate the prey with the mouthparts. All digestion is external. Spiders with weak jaws puncture the insect body with fangs and inject digestive fluid. This digestive fluid liquefies the insect tissues, and the spider later sucks it in. Spiders with stronger jaws, like tarantulas and other wolf spiders, grind the insect into a pulp between jaws as digestive fluid is regurgitated over it.

Spiders are a group of arthropods that have been misunderstood over the years. This ignorance has led to misconceptions of their danger, and of their importance or the lack of it in agriculture. Spiders have been associated with myths and disease. The fear of spiders is commonly known as arachnophobia. An example of such misguided beliefs occurred in Europe about 500 years ago. The phenomenon was referred to as "tarantism", which was an alleged disease caused by tarantula spiders, *Lycosa tarantula* L. Tarantism was a collection of hysterical disorders caused by ignorance and superstition (Anonymous 1996). Although some of the symptoms were synonymous with those caused by the black widow spider *Latrodectus* spp., it is unlikely that tarantulas caused this disease. The cure however, involved energetic and violent dancing for about three to four days (Isbister 2004).

Although current misconceptions do not run as wild as those of Europeans 500 years ago, it is common knowledge that growers tend to eliminate any arthropod they see in their fields through spraying. This desire for a perfect agricultural product has led to regimental spraying, which in turn, is harmful to spiders, as well as other natural enemies.

The role of spiders in agro-ecosystems in less understood, although it is well agreed upon that they are important predators. They prey on living insects, and mites, eggs and larvae of various lepidopteran pests, scales, aphids, and many more. The reduction in density of a specific pest due to spiders may occur through actual spider predation, or abandonment of plant parts that are occupied by spiders (Sunderland 1999).

An individual spider species may not cause sufficient mortality to control a pest (Riechert 1992, Wise 1993). However, when assembled in groups of species, they significantly contribute to reducing pest densities, such as in scale insects in orchards (Mansour and Whitcomb 1986), leafhoppers in rice (Oraze and Grigarick 1989), and various pests in vegetables (Riechert and Bishop 1990), among others. Spider assemblages may segregate in their vertical location, diel cycle or foraging mode (Marc and Canard 1997). Thus, a spider assemblage may feed on all stages of a pest.

In nature, spiders do not need to act alone. They are part of the larger natural enemy complex that limits pest densities. For example, spiders are included in the natural enemy complexes of Colorado potato beetle (Cappaert et al. 1991), caterpillars in cotton (Gravena and Da Cuhna 1991), and corn (Clark et al 1994). Spiders are not dominant predators of *Helicoverpa* spp. (Bishop and Blood 1981), in Australian cotton, but are very important in Texas cotton where they account for 73% of the net value of arthropod, predators compared to 27% by insects (Sterling et al 1992)

Pest control by spiders also includes pest dislodgement, death of pests in webs not caused by predation, wasteful killing, partial consumption and wounding of pests (Sunderland 1999). During foraging, spiders may disturb pest aggregations and cause pests to leave plants. Mansour et al (1981) conducted manipulative experiments in which 33% of caterpillars were dislodged from plants. Once dislodged, pests may be more exposed to natural enemies or environmental factors. Dislodgement also causes loss of feeding time, which reduces plant damage and slows the rate of pest reproduction (Sunderland 1999).

Small pests, like mites, midges, and thrips usually die when caught in spider webs even though they were not targeted as prey. An example of this phenomenon was demonstrated by Alderweireldt (1994), who recovered 319 prey items in webs of linyphiid spiders in corn in Belgium. Spiders were only feeding on 184 of these. Samu et al. (1996) showed that nearly all female linyphiid spider webs contained a cereal aphid, *Sitobion avenae* (F), although none of the 60 observed spiders were feeding on the aphids.

In some cases, spiders may kill pests, but only partially ingest them. This is referred to as wasteful killing or partial consumption. This behavior is common when prey are plentiful. Wasteful killing has been observed in linyphiids killing aphids (Provencher and Coderre 1987), while partial killing (sic) has been reported by Samu (1993) on *Drosophila* prey by Thomisidae and Lycosidae. However, these experiments were lab based, and wasteful killing or partial consumption has not been quantified in the field. Some pests may be attacked wounded and released, but may die due to loss of haemolymph or infection by microorganisms.

Spiders are important components of various agro-ecosystems including the cotton agro-ecosystem. McDaniel and Sterling (1982), and Nuessly et al. (1994) studied predation of *Helicoverpa* spp. eggs on cotton by various predators, and showed that spiders preyed on *Helicoverpa* spp. eggs. Pfannenstiel (2005), showed that pest mortality due to nocturnal predation in cotton, was 50% greater than due to diurnal predation, and that cursorial spiders were responsible for 25% of nocturnal predation. A different study (Pfannestiel and Yeargan 2002) found that spiders were predators in corn and soybean but had not been previously reported.

Various studies in apple orchards have show the importance of spiders. In Israel, spider activity was responsible for 98% reduction in larval densities of *Spodoptera littoralis,* (Boisduval) a pest of apples (Mansour et al. 1981). In California, alongside carabid beetles, spiders were found to be important predators of codling moth, *Cydia pomonella* (L), a key pest of apples (Riddick and Mills 1994).

Spiders have also been used as bioindicatiors in various studies. Noss (1990) developed general attributes for their use as bioindicators, and summarized as follows: First, spiders are an abundant and diversified taxonomic group in most agro-ecosystems; secondly, some species found specifically in some habitats are “indicator species”. Pétillon et al. (2004) identified spider species that only resided in the salt marshes of France; thirdly, variations of populations or indicator groups should be detectable at microhabitat level, and fourthly, spiders can be easily sampled and usually identified.

Pétillon et al. (2005) sampled spiders in a salt marsh in France that was invaded by a new species of vegetation. They found that previously, non-coastal taxa of spiders were present, and abundances of some halophilic indicator species were reduced. This was of concern because competition for space and food between native, coastal and non-coastal species or further microhabitat change could lead to serious declines in native, coastal species.

Bonte et al. (2004) demonstrated the importance of habitat productivity and stability for spider species richness. They found that spider diversity and species richness were determined by the amount of nutrients available, as well as the size of the grey dunes patches in Belgium. The dunes have been shrinking in size due to urbanization, and losing their nutrient value due to leaching and mobilization of calcium carbonate.

Previous work showed that predators are an important part of the natural enemy complex that reduce the threat of damage by cabbage pests (Acheampong and Stark 2004, Eigenbrode et al. 1995, 1996). Predators also appear to be more tolerant of pesticide treatments in cabbage. Despite extensive studies of the role of natural enemies in cabbage, not much is currently known regarding the role of spiders in the cabbage agro-ecosystem. Spiders are exclusively predaceous, and often are a very abundant predator in the environment. This study was undertaken to improve our knowledge regarding the role of spiders in the cabbage agro-ecosystem and to assess the influence of two insecticides on cabbage yield and damage, and spider numbers and diversity.

Research Objectives

To study the effect of spinosad and λ-cyhalothrin on spiders found in the cabbage agro-ecosystem as well as identify the spiders to family and species level in south Texas.

To study the effect of spinosad and λ-cyhalothrin on *T. ni* and *P. xylostella* and the resulting yield and quality of the cabbage harvested.

CHAPTER II

EFFECT OF SPINOSAD AND LAMBDA-CYHALOTHRIN ON SPIDERS IN THE CABBAGE AGRO-ECOSYSTEM

> If you want to live and thrive, let the spider run alive.
>
> -American Quaker Saying

> Arthropod predators are the most abundant and consistently present insect natural enemies in most agro agro-ecosystems. Nevertheless, we know very little about their impact on pest populations.
>
> -M.H. Greenstone (1996)

Introduction

Spiders are an essential component in any IPM system. Several researchers have shown the susceptibility of spiders to different insecticides. Pekar and Haddad (2005) showed that some spider species, like *Clubiona* spp., *Philodromus* spp., *Xysticuss* spp., *Pardosa* spp., and *Theridion* spp., avoided paper surface with fresh residues of permethrin and phosalone, which helped them escape the detrimental effects of the insecticides. *Dictyna* spp. did not avoid the activity of the pesticides and high mortality resulted. The avoidance of insecticide residues was attributed to the web-building behavior of *Dictyna* spp. and *Theridion* spp.

Parathion and dimethoate had delayed effects on spiders causing ~30% and ~100% mortality after 1 d and 9 d exposure to insecticide residues, respectively (De Clercq et al. 1991). Pekar and Kocourek (2004) compared two management strategies, IPM and biological pest management (BPM), and found similar results in abundance in both plots. They attributed this to the use of products harmless to spiders, such as *Bacillus thuringiensis* ssp. *tenebrionis* (Bt), and viral products, i.e. codling moth granulosis virus, and IGRs (insect growth regulators). However, spider diversity was lower in IPM plots than BPM or control plots, which was attributed to the use of insecticides that might have had negative effects on the spiders.

While testing different insecticides at various concentrations, Mittal and Ujagir (2005) found that spinosad had no significant effect on spider densities or other natural enemies of pigeon peas in Pantnagar, India. Thomas and Mangan (2005) monitored populations of Mexican fruit fly *Anastrepha ludens* (Loew) in Texas. They found that although the number of beneficial arthropods was 10% lower in the fields treated with spinosad than those treated with other insecticides, this difference was not statistically significant. Moreover the total number of beneficial arthropods trapped in the treated fields was more than those collected in the controls.

Spinosad was detrimental to the survival, development and reproduction of the multicolored Asian lady beetle, *Harmonia axyridis* (Pallas) (Galvan et al. 2005). Their results showed that spinosad decreased the survival of first instar larvae, extended the time from first instar larvae to adult, slowed weight gain and reduced female fertility. Other studies have also shown that there may be some sublethal effects of spinosad on natural enemies. Ludwig and Oetting (2001) tested the compatibility of spinosad and *Orius insidiosus* (Say) against *Frankiliniella occidentalis* (Pergande) in potted chrysanthemums. They found that *O. insidious* failed to establish in the first trial when exposed to spinosad but was more compatible in the second trial. This difference between trials was attributed to lack of free movement of thrips and *O. insidious* between plants due to cage effects.

Tillman and Mulrooney (2000) studied the effect λ -cyhalothrin and spinosad in cotton. Lambda-cyhalothrin exhibited the greatest toxicity to the natural enemies and in topical toxicity tests, it adversely affected each natural enemy species studied. Residues of λ-cyhalothrin on cotton leaves were toxic to *Bracon mellitor* (Say 1836)*, Cardiochiles nigriceps* Viereck*, Coleomegilla maculata* (DeGeer)*,* and *Geocoris punctipes* (Say). In the field, *C. maculata,* and *G. punctipes* populations were lower while aphid populations increased in λ-cyhalothrin treated plots. Spinosad did not affect any of the natural enemies studied. Ohnesorg and O'Neal (2006) also found λ-cyhalothrin to be more toxic to natural enemies in soybean agro-ecosystems. Vanderkerkhove and De Clercq (2004) showed that although λ-cyhalothrin provided relatively good control of the rice pest *Nezara viridula* (L.), it greatly reduced one of its predators, *Podisus maculiventris* (Say).

In this study, the effects of spinosad, a microbial insecticide, and λ-cyhalothrin, a pyrethroid, on spider diversity and abundance were tested in cabbage agro-ecosystem. The purpose of this study was to establish which of the two insecticides is more compatible with conservation of spider densities in cabbage.

Materials and Methods

Study Site. The study was conducted on a 0.69 ha (1.7 acres) cabbage field located at the Texas A&M Agricultural Research and Extension Station (TAES) in Weslaco (26° 09’N, 97°57’W) in Hidalgo county, Texas (Fig 2). The fields were numbered 1026 stage 4 for fall 2005, and 1026 stage 5 for spring 2006. The previous crops on the fields were watermelon and cantaloupe respectively.

The surrounding vegetation consisted of other experimental plots of watermelon, cantaloupe, onion, tomato, and green pepper. Sorghum was commonly used as a windbreak and a separator in various fields. The soil type is Hidalgo sandy clay loam. The average precipitation in spring varies between 25.7 mm in February and 74.7 mm in June. The minimum temperature range is 14-23°C, and the maximum temperature range is 27-34°C. In fall, average precipitation varies between 119.6 mm in September and 34.3 mm in January. The minimum temperature range is 9°C in January to 23°C in August, and maximum temperature range is 21°C in January to 36°C in August (National Climatic Data Service, 2007).

Cabbage was seeded directly on raised beds. The variety used was Cabbage Golden Acres from Chriseed Company (Mount Vernon, WA.). Fertilizer was applied at 112.5 kg/ha (100 lb/ac) of N-32 at 4 weeks. Herbicide applications included bensulide (Prefar® 4E) at the rate of 14.19 l/ha (6qt/ac) at planting. Fungicide applications included Chlorothalonil (Bravo®720) 2.3 l/ha (1qt/ac) sprayed at 7-8 weeks after planting. Irrigation was done twice a week.

Fig. 2. Aerial view of Texas A&M Agricultural Research and Extension Station (TAES) in Weslaco. The arrows point to the experimental fields.

Experimental Design and Treatment Methods. Plots were arranged in a randomized block with three treatments and four replications. The treatment plots measured 6.1 m long by 18.2 m wide (20 ft by 60 ft), with 15 rows of cabbage, 0.30 m (≈1 ft) apart. Plots were separated by sorghum windbreaks and a 3.05 m (10 ft) alleyway. The treatments were λ-cyhalothrin, Warrior® applied at 0.032 kg ai/ha or 0.276 liters/ha (0.03 Ib ai/acre or3.8 fl oz/acre), spinosad, SpinTor® 2SC applied at 0.105 kg ai/ha or 0.4 liters/ha (0.094 Ib ai/acre or 6fl oz/acre) and untreated control.

The plants were scouted weekly, and insecticide applications were made when threshold levels exceeded 0.3 larvae of either *P. xylostella* or *T. ni* per plant. Foliar applications were made using a tractor drawn sprayer with 3 nozzles per 1.02 m (40 inch) beds (1 row) at 689.5 kPa (100 psi) at a delivery rate of 280 liters/ha (30 gal/acre). Scouting was initiated 4 weeks after planting with at least five plants per plot scouted and larval numbers recorded for both *P. xylostella* and *T. ni* in every plot. Table 1 shows the planting, scouting, spraying and harvesting dates from fall 2005 to spring 2006.

Sampling. Two kinds of sampling apparatus, pitfall traps and a blower, were used to determine the diversity and abundance of spiders in various treatments.

Pitfall traps. Pitfall traps (Carolina Biological Supply Company, Burlington, NC) were used to estimate relative abundance and species richness for ground dwelling predators. Two pitfall traps (590 ml plastic cups with a funnel and a 200 ml cup inside the larger cup) were placed in every plot. Holes were dug in the ground and the cups were sunk so that the mouth of the cup was level with the ground (Fig 3). These pitfall traps contained commercial antifreeze (ethylene glycol) (SuperTech® 50/50 prediluted, Bentonville, AR), which killed and preserved the arthropods. When a trap was sampled, the upper cup of the pitfall trap was removed from the ground and the contents were emptied into a quart glass container, labeled with the pitfall trap identification code (treatment and trap number) and the collection date. The top cup was replaced into the lower cup and the surface of the ground was leveled to the brim. The trap was then refilled with approximately 150 ml of propylene glycol. The pitfall traps were checked every seven days and the contents removed and stored in 70% alcohol for identification and analysis.

Table 1. Planting, scouting, spraying and harvesting dates

Season	**Planting/Harvest**	**Scouting**	**Spraying**
Fall 2005	7th September 2005	28th Sept. 2005	
		5th October 2005	6th October 2005
		19th October 2005	
		26th October 2005	27th October 2005
		2nd November 2005	
		15th November 2005	16th November 2005
		21st November 2005	
		1st December 2005	2nd December 2005
		13th December 2005	
	2nd January 2006		
Spring 2006	15th Feb 2006	9th March 2006	10th March 2006
		23rd March 2006	
		4th April 2006	5th April 2006
		11th April 2006	
		19th April 2006	20th April 2006
		11th May 2006	
		25th May 2006	26th May 2006
	9th June 2006		

The term spraying is used for the applications of spinosad and λ-cyhalothrin on the treated plots.

Fig. 3. Pitfall traps placed between cabbage plants were used to collect spiders in various treatment plots. These samples were identified weekly.

Blower/Vacuum. Once every week, a blower/vacuum was used to sample the arthropods in two 1.5 m (5 ft) rows of cabbage. This was done by holding the blower/vacuum (Craftsman Blower/ Vac, 24cc 185 mph, Sears, Davenport, IA, a modified version), and walking a length of 1.5 m, along the cabbage rows (Fig. 4). The measurement of 1.5 m was done with a 1.5 m string. This procedure was repeated three times per row. The bag used to collect the samples was made of very fine mesh fabric. It had a diameter of 22 cm and a height of 30 cm. This bag containing the sample was removed and labeled according to the treatment for every row that was sampled. The arthropods collected were taken to the laboratory, placed in a -10°C freezer, and later identified and recorded.

Fig. 4. Using the blower/ vacuum in a row of cabbage. Collecting samples was done by walking the same length of 1.5 m three times.

Spider Identification. All spiders collected in pitfall traps were sorted and curated before being stored in vials containing 70% alcohol. The vials were labeled according to treatments and taken to Department of Entomology, Texas A&M University, College Station, TX, for identification. Most adult spiders were identified to family and species, by sex, and immatures to family (Ubick et al. 2005) and verified by Texas A&M spider taxonomist, Allen Dean.

Voucher Specimen. Three specimens of each species were deposited in the Texas A&M University Insect Collection (TAMUIC) of the Department of Entomology, Texas A&M University, College Station, TX. Specimens were labeled for locality, sampling technique, date, collector, and comments. Voucher number is 664.

Analysis of Data. ANOVA was used to compare mean spider captures in plots. Means were further separated by Student-Newman-Keuls. The diversity of spiders was compared among treatments using the Shannon (H') (Shannon 1948) and Brillouin $(\hat{H})$

(Magurran 1988) diversity indices. Indices were estimated per treatment and the 90% upper and lower confidence levels of the means were used to identify differences among means (SAS Institute, 2001).

Shannon-Wiener function is commonly used to characterize species diversity in a community. It expresses likelihood of the next individual to be drawn being the same as the last one drawn. The higher the value of *H'*, the greater the uncertainty or the probability that the next individual chosen at random, from a collection of species, containing N individuals, will not belong to the same species as the previous one. The same principle applies in reverse for a low value of *H'*. The proportion of species *i* relative to the total number of species (P_i) is calculated and then multiplied by the natural logarithm of this proportion ($\mathrm{Log}_2 P_i$). The resulting product is summed across species and multiplied by -1 and is expressed with the formula

$$H' = \sum (P_i)(\log_2 P_i).$$

The Brillouin's index =

$$H = \frac{1}{N} \log \left(\frac{N!}{n_1!n_2!n_3!.....} \right)$$

The Shannon-Wiener and the Brillouin indices were calculated for each treatment and each replication. They were used because they are more sensitive to the occurrence of rare species in a community.

Evenness is a heterogeneity measure that attempts to quantify the unequal representation of species against a hypothetical community in which all species are equally common (Krebs 1999). An ecosystem where all the species are represented by the same number of individuals has high species evenness, while an ecosystem with some species being represented by many individuals, and other species by very few individuals, has low species evenness.

Smith and Wilson (1996) index of evenness is based on the variance in species abundance and is measured by the log of abundance as opposed to absolute differences, ensuring that proportional differences are used. This index is:

$$E_{\mathrm{var}} = 1 - \left[\frac{2}{\pi \arctan \left\{ \sum_{i=1}^{s} \left(\log_e(n_i) - \sum_{j=1}^{s} \log_e(n_j)/s \right)^2 \Big/ s \right\}} \right]$$

E_{var} is Smith and Wilson's index of evenness, n_1 is number of individuals in species *i* in sample (i =1,2,3,4…..s), n_j is the number of individuals in species *j* in sample (j ==1,2,3,4…..s) and *s* is the number of species in the entire sample. This index is independent of species richness and is sensitive to both rare and common species.

Results

A total of 567 spiders were collected through pitfall traps in fall 2005 and spring 2006, belonging to 14 families. In fall 2005, 160 spiders were collected from eight families, of these 30 were immatures, while 407 spiders were collected in spring 2006 from 13 families, of which 70 were immatures. There were approximately 50 different species collected. The most abundant family was Lycosidae with *Pardosa delicatula* Gertsch & Wallace, *Pardosa pauxilla* (Montgomery 1904) and *Hogna helluo* Walkanaer 1837) as the most abundant species (Table 2).

The blower/ vacuum sampling method recovered 13 spiders in fall 2005 and 21 in spring 2006. Most of them belonged to the Lycosidae with a few salticids and one gnaphosid. Other arthropods found in the blower/vacuum bags included whiteflies, stink bugs, lady beetles, ants, aphids, flea beetles, *P. xylostella,* and *T. ni.*

In fall 2005, pitfall traps captured 42 individuals in the spinosad treated plots. These were representatives from 6 families (Fig. 5). The plots treated with λ-cyhalothrin had three families (Fig.6), Lycosidae, Salticidae and Gnaphosidae, represented by 46 individuals. In untreated control plots, 72 individuals from eight spider families were captured, which included all families captured in both spinosad and λ-cyhalothrin plots, plus Theridiidae and Philodromidae (Fig. 7). Fig. 8 shows the accumulation of species among treatments for fall 2005.

Table 2. A list of spider families and species collected in fall 2005 and spring 2006.
(x / – represent presence or absence of each family in each season.)

Family	Species	Presence / absence of family	
		Fall 05	Spring 06
Anyphaenidae	**unidentified anyphaenid**	-	X
Araneidae	**unidentified araneid**	-	X
Clubionidae	***Clubiona kagani* Gertsch**	-	X
Corrinidae	***Castianeira longipalpa* (Hentz)**	X	X
	***Falconina gracilis* (Keyserling)**		
	***Meriola decepta* Banks**		
	unidentified corinid		
Dictynidae	***Phantyna segregata* (Gertsch & Mulaik)**	X	X
	***Phantyna* sp. nr *pixi* (Chamberlin & Gertsch)**		
	unidentified dictynid		
Gnaphosidae	***Drassyllus lepidus* (Banks)**	X	X
	***Drassyllus notonus* Chamberlin**		
	***Gnaphosa altudona* Chamberlin**		
	***Gnaphosa sericata* (L. Koch)**		
	***Gnaphosa* sp. nr *maritima* Platnick & Shadab**		
	***Gnaphosa* sp. nr *sericata* (L. Koch)**		
	***Micaria deserticola* Bryant**		
	***Micaria gertschi* Barrows & Ivie**		
	***Micaria* sp.**		
	***Sergiolus* sp.**		
	***Trachyzelotes lyonneti* (Audouin)**		
	***Zelotes gertschi* Platnick & Shadab**		
	unidentified gnaphosid		
Hahniidae	***Neoantistea mulaiki* Gertsch**	-	X
	***Neoantistea* sp. nr *riparia* (Keyserling)**		

Table 2, continued

Family	Species	Presence / absence of family	
		Fall 05	Spring 06
Linyphiidae	***Eperigone eschatologica* (Crosby)**	X	X
	***Eperigone tridentat*a (Emerton)**		
	***Erigone* sp. nr *barrowsi* Crosby & Bishop**		
	***Meioneta* sp nr *unimaculat*a (Banks)**		
	***Tennesseellum formic*a (Emerton)**		
	***Walckenaeria puella* Millidge**		
	linyphiid sp 1		
	unidentified linyphiid		
Lycosidae	***Hogna helluo* (Walckenaer)**	X	X
	***Hogna* sp. nr *frondicola* (Emerton)**		
	***Hogna* sp. nr *hellu*o (Walckenaer)**		
	***Pardosa delicatula* Gertsch & Wallace**		
	***Pardosa pauxilla* Montgomery**		
	***Rabidosa rabida* (Walckenaer)**		
	nr *Geolycosa missouriensi*s (Banks)		
	unidentified lycosid		
Miturgidae	***Teminius affinis* Banks**	-	X
Salticidae	***Habronattus coecatus* (Hentz)**	X	X
	***Habronattus* sp. nr *cockerelli* (Banks)**		
	***Habronattus* sp. nr *conjunctus* (Banks)**		
	***Habronattus* sp. nr *pyrrithrix* (Chamberlin)**		
	***Habronattus* sp.**		
	Marpissa obtusa Barnes		
	unidentified salticid		
Theridiidae	***Euryopis* sp.**	X	X
	***Steatoda quadrimaculata* (O. P.-Cambridge)**		
	***Steatoda transversa* (Banks)**		
	nr *Dipoena* sp.		
Thomisidae	***Misumenops* sp.**	-	X
Philodromidae	***Tibellus duttoni* (Hentz)**	X	-

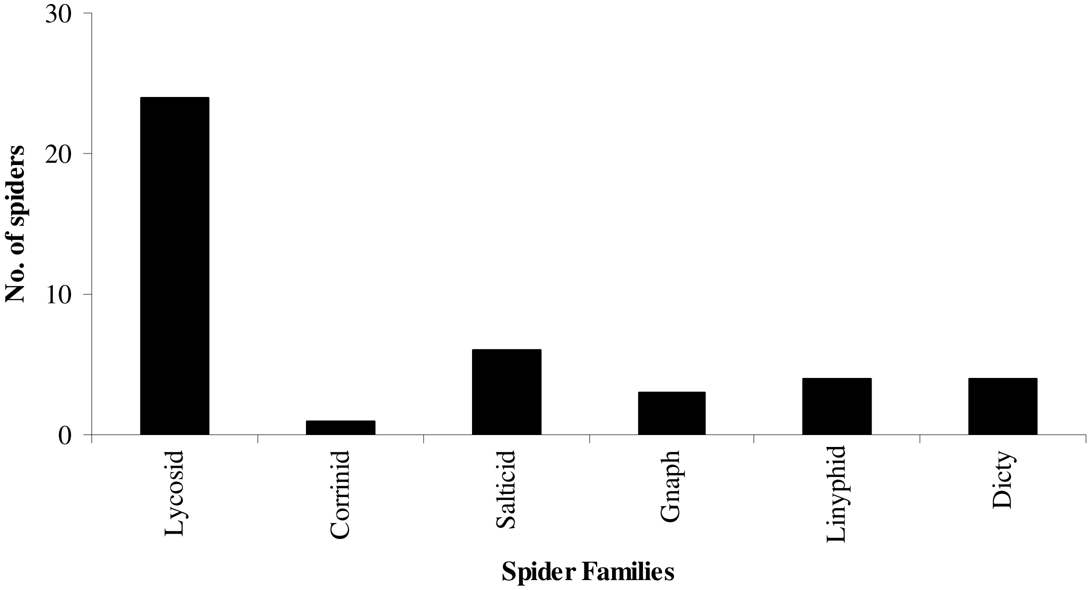

Fig. 5. Numbers of spiders in each spider family collected in spinosad treated plots in fall 2005. (Lycosid = Lycosidae, Corrinid = Corrinidae, Salticid = Salticidae, Gnaph = Gnaphosidae, Linyphid = Linyphidae, Dicty = Dictynidae)

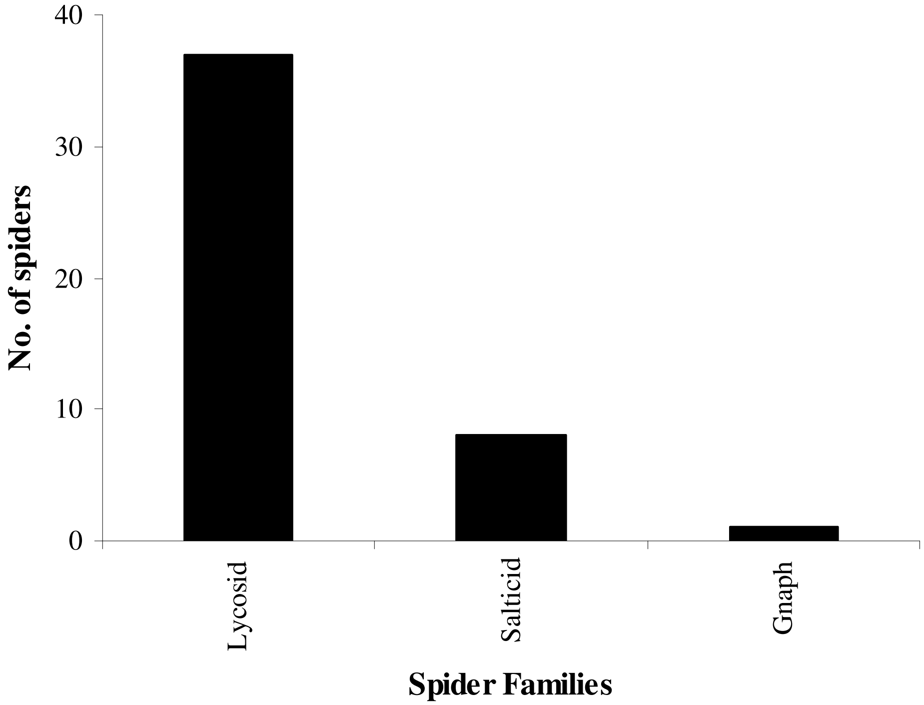

Fig. 6. Numbers of spiders in each spider family collected in λ-cyhalothrin treated plots in fall 2005. (Lycosid= Lycosidae, Salticid= Salticidae, Gnaph= Gnaphosidae)

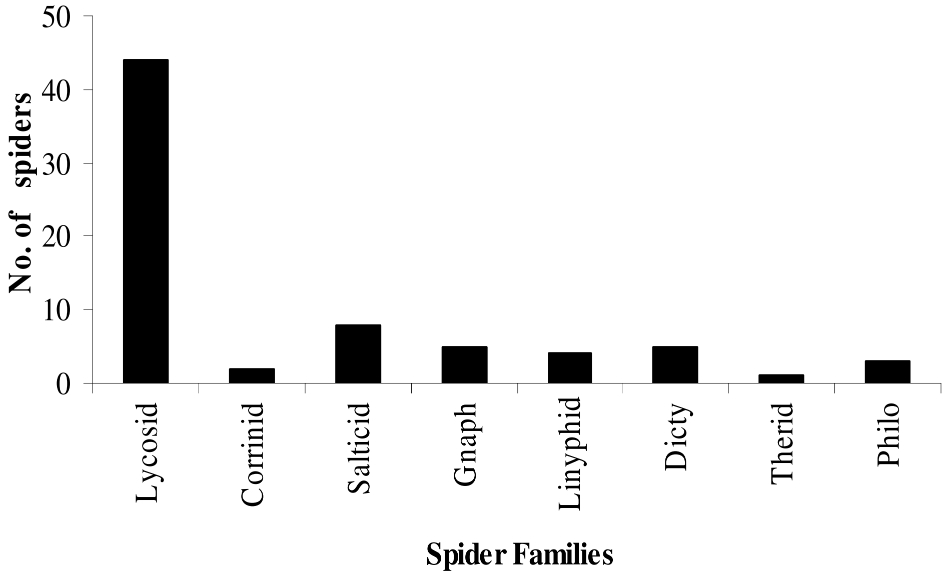

Fig. 7. Numbers of spiders in each spider family collected in untreated control plots in fall 2005. (Lycosid = Lycosidae, Corrinid = Corrinidae, Salticid = Salticidae, Gnaph = Gnaphosidae, Linyphid = Linyphidae, Dicty = Dictynidae, Therid = Theriididae, Philo = Philodromidae)

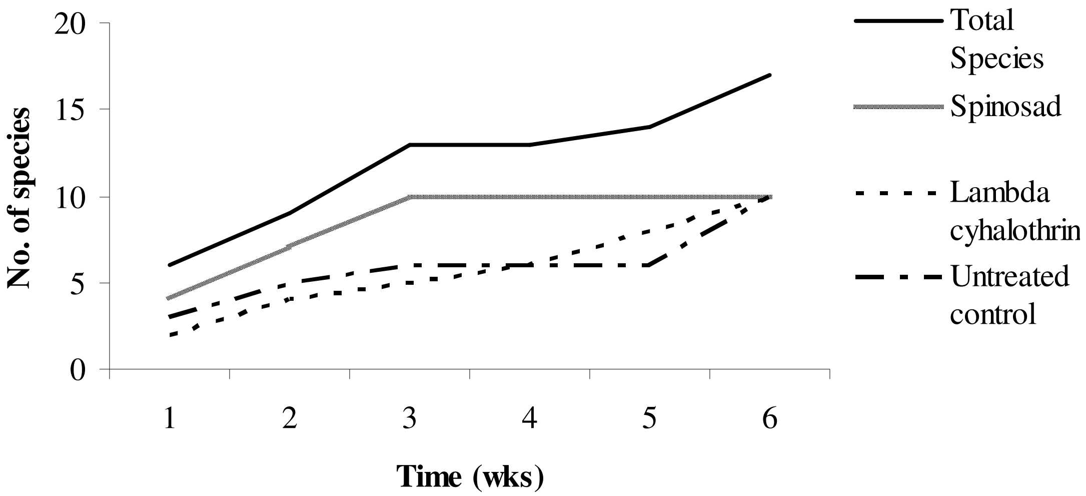

Fig. 8. Accumulation of species of spiders among treatments in fall 2005.

In spring 2006, 13 families were found in pitfall traps in which all treatments. In the spinosad treated plots, there were 11 families (Fig. 9), of which three were not found in the untreated control. The 11 families were represented by 177 individuals. In the plots treated with λ-cyhalothrin only six families were recovered, and were represented by 60 individuals (Fig. 10). In the untreated control plots, 10 families were represented by 160 individuals (Fig. 11). Generally there were more species that were recovered in the spring 2006 in all treatments (Table 2, Figs. 8 and 12). Fig. 12 shows accumulation of species in different treatments spring 2006.

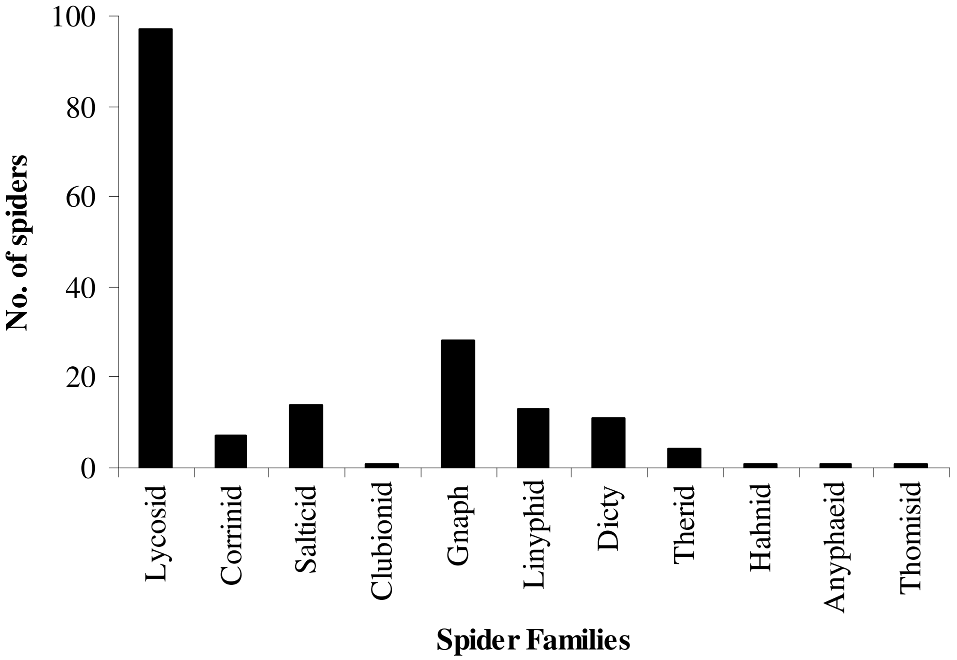

Fig. 9. Numbers of spiders in each spider family collected in spinosad treated plots in spring 2006. (Lycosid= Lycosidae, Corrinid= Corrinidae, Salticid= Salticidae, Clubionid= Clubionidae, Gnaph= Gnaphosidae, Linyphid= Linyphidae, Dicty= Dictynidae, Therid= Theriididae, Hahnid= Hahnidae, Anyphaeid= Anyphaeidae, Thomisid= Thomisidae)

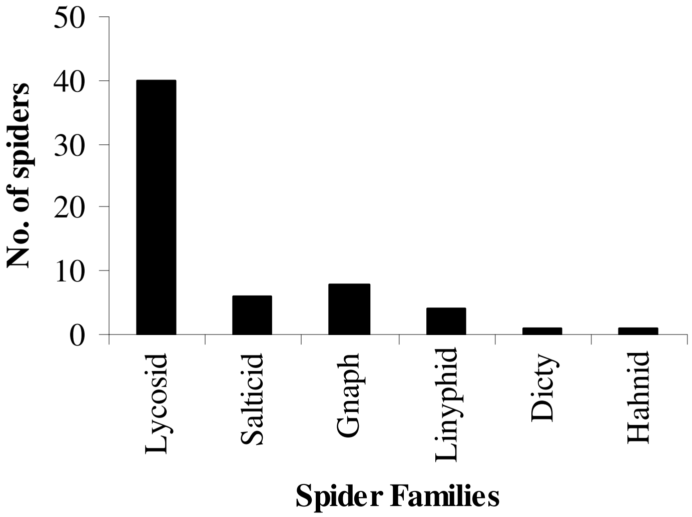

Fig. 10. Numbers of spiders in each spider family collected in λ-cyhalothrin treated plots in spring 2006. (Lycosid= Lycosidae, Salticid= Salticidae, Gnaph= Gnaphosidae, Linyphid= Linyphidae, Dicty= Dictynidae, Hahnid= Hahnidae.)

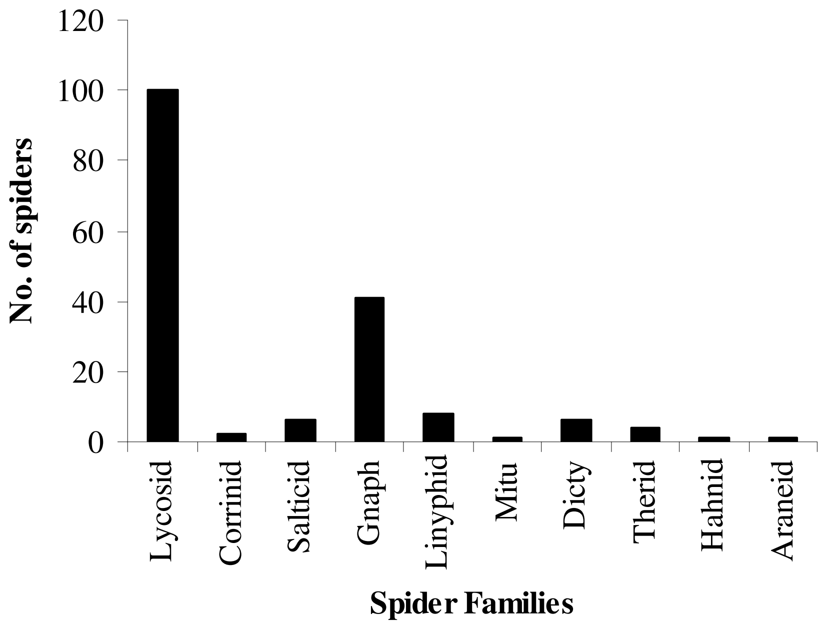

Fig. 11. Numbers of spiders in each spider family collected in untreated control plots in spring 2006. (Lycosid= Lycosidae, Corrinid= Corrinidae, Salticid= Salticidae, Gnaph= Gnaphosidae, Linyphid= Linyphidae, Mitu= Miturgidae, Dicty= Dictynidae, Therid= Theriididae, Hahnid= Hahnidae)

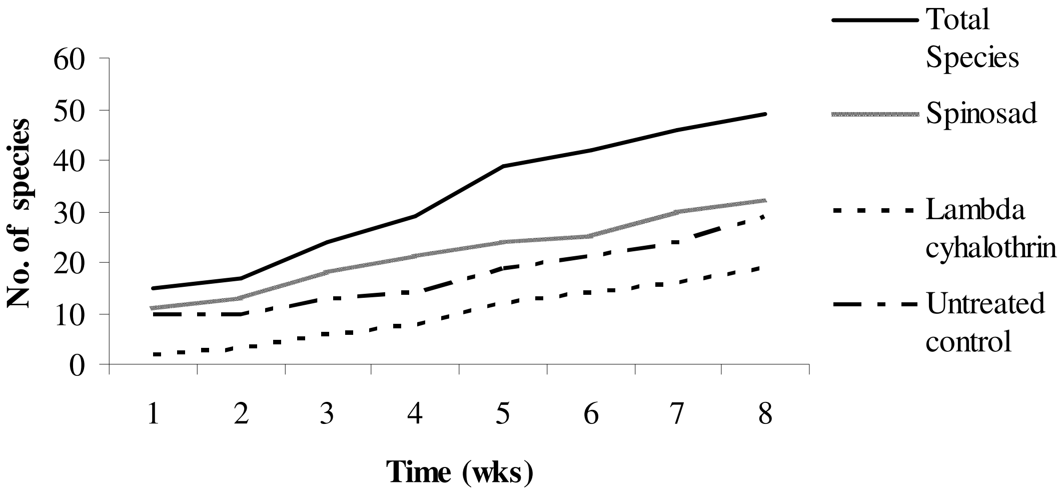

Fig. 12. Accumulation of species of spiders among treatments in spring 2006.

Abundance. In comparing the means of spider individuals among treatments in the two seasons, the three means were almost different in the fall 2005 (ANOVA: *F*=4.89; df = 2, 9; *P*=0.0549). On the contrary, in spring 2006, there was a significant difference among treatments (ANOVA: *F*=26.86; df =2, 9; *P*=0.001). The Student-Newman-Keuls (SNK) separation of means indicated that both untreated control and spinosad plot means were similar to each other while both were significantly higher than those of λ-cyhalothrin plot. Table 3 shows the SNK separation of means for fall 2005 and spring 2006.

Table 3. Student-Newman-Keuls separation of means for abundance of spider individuals in fall 2005 and spring 2006.

Season	Treatment	Means ± SE
Fall	Spinosad	10.5 ± 1.4433 **a**
	λ-cyhalothrin	11.5 ± 1.5545 **a**
	Untreated control	18.0 ± 1.6832 **a**
Spring	Spinosad	44.3 ± 5.4524 **a**
	λ-cyhalothrin	15.0 ± 2.0000 **b**
	Untreated control	40.0 ± 4.1028 **a**

Means with the same letter are not significantly different in each season

Diversity. Diversity was compared using Shannon-Wiener function and the Brillouin index. A comparison of the 90 percent confidence intervals of means was used to identify differences among treatments. A 90 percent confidence interval was used because there were many variables to consider in the cabbage ecosystem, and to accommodate all acceptable significant changes that may not necessarily be detectable at a higher confidence limit. The results indicate that in fall 2005, there were significant differences among treatments ($\alpha = 0.1$). Untreated control was significantly more diverse than λ–cyhalothrin. Spinosad was not different from either untreated control or λ–cyhalothrin (Table 4). In spring 2006, spinosad and untreated control were not significantly different from each other but were both more diverse thank λ-cyhalothrin. Table 4 shows the Shannon-Wiener and Brillouin indices of diversity for fall 2005 and spring 2006 as calculated. Table 5 shows lower and upper confidence limits of Shannon-Wiener indices of diversity ($\alpha = 0.1$) for fall 2005 and spring 2006.

Table 4. The Shannon-Wiener *(H')* and Brillouin *(Ĥ)* indices of diversity of species for fall 2005 and spring 2006

Season	Treatment	Replication	Shannon-Wiener Function	Brillouin's Index
Fall 2005	Spinosad	1	1.241	0.942
		2	2.236	1.471
		3	1.571	1.130
		4	1.627	1.205
	λ-cyhalothrin	1	0.863	0.627
		2	0.940	0.783
		3	0.986	0.686
		4	0.000	0.000
	Untreated control	1	1.808	1.400
		2	1.799	1.341
		3	1.736	1.351
		4	1.967	1.486
Spring 2006	Spinosad	1	1.857	1.663
		2	2.027	1.736
		3	2.318	1.975
		4	1.760	1.510
	Untreated control	1	1.829	1.575
		2	1.837	1.551
		3	1.559	1.329
		4	1.733	1.458
	λ-cyhalothrin	1	1.545	1.233
		2	1.322	1.030
		3	1.447	0.997
		4	1.277	0.995

Table 5. Confidence limits of Shannon-Wiener indices *(H')*

Season	Treatment	Means	Confidence Intervals
Fall 05	Spinosad	1.6686 **ab**	1.1804 - 2.1567
	λ-cyhalothrin	0.6974 **b**	0.1470 - 1.2476
	Untreated control	1.8275 **a**	1.7117 - 1.9432
Spring 06	Spinosad	2.0213 **a**	1.7724 - 2.2702
	λ-cyhalothrin	1.3976 **b**	1.2544 - 1.5408
	Untreated control	1.7396 **a**	1.5877 - 1.8916

Means with the same letter are not significantly different at $\alpha = 0.1$ in each season

Evenness. In both fall 2005 and spring 2006, there were no significant differences in Smith and Wilson evenness indices among all the treatments ($\alpha = 0.1$). Table 6 shows Smith and Wilson's index of evenness of spider species calculated for fall 2005 and spring 2006. Table 7 is the confidence interval comparisons for Smith and Wilson's index of evenness.

Table 6. Smith and Wilson's *(E_{var})* indices of evenness for fall 2005 and spring 2006 spiders

Treatment	Replication	Smith and Wilson's index	
		Fall 2005	Spring 2006
Spinosad	1	0.064	0.544
	2	0.927	0.569
	3	0.686	0.444
	4	0.600	0.507
λ-cyhalothrin	1	0.868	0.600
	2	0.945	0.553
	3	0.555	0.655
	4	0.000	0.487

Table 6, continued

Treatment	**Replication**	**Smith and Wilson's index**	
		Fall 2005	**Spring 2006**
Untreated control	1	0.554	0.412
	2	0.605	0.452
	3	0.600	0.425
	4	0.652	0.371

Table 7. Confidence limits for Smith and Wilson's *(E_{var})* indices of evenness.

Season	**Treatment**	**Means**	**Confidence Intervals**
Fall 05	Spinosad	0.7133 **a**	0.5405 – 0.8859
	λ-cyhalothrin	0.5920 **a**	0.0869 – 1.0970
	Untreated control	0.6028 **a**	0.5556 – 0.6499
Spring 06	Spinosad	0.5160 **a**	0.4521 – 0.5799
	λ-cyhalothrin	0.5738 **a**	0.4898 – 0.6576
	Untreated control	0.4150 **a**	0.3753 – 0.4546

Means with the same letter are not significantly different at α =0.1 in each season

Discussion

More than 50 species of spiders were collected in the two growing seasons sampled. These spiders belonged to fourteen families. Most of these spider species and their families have been collected in Texas and described before (Jackman 1997). In all agro-ecosystems, some species are more dominant than others. Wolf spiders (Araneae, Lycosidae) are one of the most abundant components of the spider community in agro-ecosystems (LeSar & Unzicker 1978; Luczak 1979; Young and Edwards 1990; Bishop and Riechert 1990). This information was consistent with this study. *P. delicatula* (Aranae: Lycosidae) was the most abundant species. Various reasons for specific species abundance in spiders have been suggested. For example, the method of sampling, length of the growing period and crop management practices.

The method of sampling used may affect which species are collected as well as how many individuals (Costello and Daane 1997, Amalin et al. 2001). Pitfall trapping captured more species and densities of spiders than blower/vacuum (D-vac) sampling. Wolf spiders were the most abundant taxon, and ground dwelling species not previously collected continued to appear as the sampling occurred (Figs. 8 and 12). The total number of species recovered in all plots is greater than that recovered in individual treatments. This indicates that by the end of sampling, not all spider species present in that agro-ecosystem were recovered.

The growing period of the cabbage sampled was between 10 – 14 weeks. Data were collected for only eight weeks. This length of the growing period may influence the abundance and diversity of the spiders. Several authors (Luczak 1979; Wissinger 1997; Marshall & Rypstra 1999 a, b) have suggested reasons for the genus *Pardosa*'s conspicuous success in the structurally-simple and seasonally-barren habitats provided by crop fields may lie in an evolved adaptation to life in riparian corridors and other periodically flooded habitats, which would pre-adapt them to the annual cycle of disturbance found in most row-crop systems. Cabbage agro-ecosystem in this study was seasonal and may not have been long enough to accumulate and retain resident spider species, except the genus *Pardosa*, hence the movement into the field plots of non-previously collected, dispersing species, when data were collected.

Crop management practices impact spider abundance and diversity (Bishop & Riechert 1990; Balfour and Rypstra 1998; Rypstra et al. 1999).The cabbage growing season is not only short, but also a high till environment. Thomas and Jepson (1997) showed that agricultural operations such as insecticide applications, cutting grass for silage and autumn cultivations caused large population depletions and reduced spider populations by 56% to 96%. Heavy grazing also caused virtual extinction in this study. Dispersal may be triggered by factors such as the avoidance of adverse conditions (Topping and Sunderland 1998). In the cabbage agro-ecosystem, there was constant use of machinery for plowing, weeding and for applying pesticides. These constant disturbances may have caused some species not to stay long enough to be captured. Others may have migrated in from neighboring reservoirs, or fields further away (Bishop and Riechert 1990), and as the cabbage grew older, there was more plant cover and fewer disturbances. The hypothesis that spiders may not stay long enough to be captured or migrate in from surrounding vegetation is further supported by the fact that at the beginning of sampling, there were fewer species in each treatment but the abundance and diversity became richer as sampling progressed (Figs. 8 and 12).

Green (1999) discusses the differences and effectiveness of different sampling techniques as well as time of sampling. He showed large discrepancies between pitfall and vacuum sampling as well as diurnal and nocturnal sampling. Topping and Sunderland (1992) noted that pitfall traps have limitations when used in some ecological studies, and their use in determining relative abundance was only partially successful in their study of spiders in winter wheat. Pitfall trapping was used to collect most of the spiders in this study. This passive “round-the-clock” method was efficient in collecting ground dwelling species but not species that dwell above ground. However, increasing the number of pitfall traps per plot from two to maybe four, or using pitfall traps with a larger opening, could have increased the chances of capturing more spiders (Work et al. 2002).

The difference in abundance between spring and fall can be attributed to several reasons. Firstly, spiders are more abundant in the spring than in the fall because they are more active in the spring than in the fall when the temperatures begin to decrease. The fact that there were more immatures collected in spring (70) than in fall (30) may support this hypothesis. *P. xylostella* and *T. ni* also overwinter (Theobald 1926, Miles 1924, Marsh 1917, Shorey et al. 1963 and Toba et al. 1973) in south Texas along with some species of wolf spiders which may overwinter as eggs or adults as well as other insects present in the cabbage agro-ecosystem. Secondly, in spring, as some spiders emerge from a less active state (Kaston 1981; Stratton and Lowrie 1984) there is an increased amount of food available as other insects end diapause or begin rapid reproduction. This increase in food resource may have encouraged more spider migration and residence in the cabbage agro-ecosystem in the spring as compared to fall season.

The results show the diversity of spiders with λ-cyhalothrin was lower than that of spiders in untreated control or with spinosad. In fall 2005, spiders in untreated control and spinosad treatments were up to 2.6 and 2.4 times more diverse than spiders in λ-cyhalothrin respectively. In spring 2006, untreated control and spinosad treatments were 1.5 and 1.3 times more diverse than spiders with λ-cyhalothrin. Hof et al. (1995) studying the effect of pesticides on wolf spiders found that λ-cyhalothrin resulted in a mortality of 50% among males and 19% among females raised in the laboratory. Further results comparing spiders collected in the field and those raised in the laboratory indicated that the reproduction, fecundity and aggression towards prey, of field spiders was not comparable to that of spiders raised in the laboratory. λ-cyhalothrin resulted in more damage to field spiders. Feeding rates of both field and laboratory raised spiders were reduced by λ-cyhalothrin. Although Hof et al. (1995) dealt with only one species of spiders, the effect of λ-cyhalothrin is clear on wolf spiders and maybe other species.

In fall 2005, when comparing the diversity of spiders between untreated control and spinosad treatments, this study found that there was no significant statistical difference between these two treatments. In spring 2006, spinosad treatments had 1.2 times greater diversity than untreated control and the difference was significant. This result may imply that spinosad treated plots were more hospitable to spiders in spring 2006.

There was no significant statistical difference in evenness in spider densities in the treatment plots in fall 2005 and spring 2006. The evenness measure was relatively low for all treatments because some species were represented by high number of individuals while others were represented by fewer individuals.

The difference in diversity among treatments (Table 5) indicates that λ–cyhalothrin reduces or limits the diversity of spiders. Spiders in plots treated with λ–cyhalothrin may either leave immediately, a phenomenon known as avoidance, or may move and hide under bigger cabbage leaves and debris, where they cannot be reached by the insecticide (Pekar and Haddad 2005) and hence are not easily captured.

Spinosad is a selective chemical and is primarily used for controlling lepidopteran pests. The selectivity for lepidopteran pests may have created a niche that was filled with other insects found in the cabbage agro-ecosystem like aphids, whiteflies, flea beetles, mirids, lygus bugs and others. Because spiders are generalist predators, availability of food in the newly occupied niche, in spinosad treated plots may have attracted more spiders, and may have ultimately resulted in their greater capture in pitfall traps.

CHAPTER III

EFFECT OF SPINOSAD AND LAMBDA-CYHALOTHRIN ON CABBAGE LOOPER DIAMONDBACK MOTH, AND ON CABBAGE YIELD

Introduction

Effective control of lepidopteran pests is important for the marketability of cabbage heads because cabbage heads attacked by lepidopteran pests are usually unsightly and unmarketable. Fresh market cabbage producers prefer nil to trace levels of insect damage or insect contaminants in the final product (Morisak et al. 1984). This preference results in strong measures to ensure marketability, which includes a reliance on calendar-based schedules for spraying insecticides against pests or conservative thresholds to reduce the risk of insect damage (Hutchinson and Burkness 1999). However, increased use of insecticides may result in resistance development in the targeted species and reduce profit margins.

Frequent applications of pyrethroid and other synthetic insecticides may accelerate the selection for resistance, and are detrimental to the management of beneficial arthropods (Ruberson and Tillman 1999). λ-cyhalothrin is often used to control *Plutella xylostella* and *Trichoplusia ni* on cabbage. Liu et al. (2003b) showed that *P. xylostella* from Minnesota and Texas were dying in response to λ-cyhalothrin over a 5-d period of observation, and that the two populations exhibited similar responses, such as rapid weight loss over time.

While conducting field trials in 1999 and 2000, Liu et al. (2002) found that cabbage treated with indoxacarb, spinosad or chlorfenapyr had less damage, with damage ratings of 0.6, 0.3 and 0.4, respectively, compared with that treated with emamectin benzoate, which had a damage rating of 3.0 in 1999. In 2000, cabbage treated with indoxacarb or spinosad had a damage rating of 0.2 and 0.4, respectively, which made them all marketable.

The purpose of this study was to test the efficacy of two pesticides, spinosad and λ-cyhalothrin, in management of two pests, *T. ni* and *P. xylostella*, and therefore determine whether they were still effective after several years of usage in the LRGV of Texas because *P. xylostella* has been reported to develop resistance to many insecticides when used for a long period of time (Tabashnik et al. 1987, Magaro and Edelson 1990, Leibee and Savage 1992, Plapp et al. 1992).

Materials and Methods

Experimental Design and Treatment Methods. The plots were arranged in a randomized block with three treatments and four replications. The treatment plots measured 6.1 m long by 18.2 m wide (20 ft by 60 ft), with fifteen rows of cabbage, 0.30 m (1 ft) apart. Plots were separated by sorghum windbreaks and a 3.05 m (10 ft) alleyway. The insecticides used were λ-cyhalothrin (Warrior®, Syngenta, Greensboro, NC), spinosad (SpinTor® 2SC, Dow Agro Sciences, Indianapolis, IN) and an untreated control. The treatments were λ-cyhalothrin, Warrior® applied at 0.032 kg ai/ha or 0.276 liters/ha (0.03 Ib ai/acre or3.8 fl oz/acre), spinosad, SpinTor® 2SC applied at 0.105 kg ai/ha or 0.4 liters/ha (0.094 Ib ai/acre or 6fl oz/acre) and untreated control. These two products are discussed in detail in Chapter I page 9-10. The plots were the same ones as those discussed in chapter II. Table 8 shows planting, scouting, spraying and harvesting dates.

Sampling. Two kinds of data were collected. Data from cabbage scouting and from cabbage harvest.

Scouting. Cabbage plants were scouted every week by examining 10 randomly selected plants from each plot. Scouting was done early in the morning and involved identifying and counting, from both upper and underside of leaves of all stages of the following arthropods: *T. ni*, *P. xylostella*, aphids (*Brevicoryne brassicae* L.), whiteflies (*Bemisia tabaci* Gennadius), thrips (*Thrips tabaci* Lindeman), leaf miners (*Phytomyza rufipes* Meigen), various species of flea beetles (Coleoptera: Chrysomelidae), spotted cucumber beetles (*Diabrotica undecimpunctata howardii* Barber), various species of lady bird beetles (Coleoptera: Coccinelliadae), various species of spiders and any other arthropod present on the cabbage plant. Only *P. xylostella* data is presented for the purpose of this study. The economic threshold established for cabbage in the LRGV IS 0.3 *T. ni* or *P. xylostella* per plant in a plot measuring 6.1 m long by 18.2 m wide (20 ft by 60 ft). (Cartwright et al. 1987). The insecticides were applied on the foliage using a tractor-mounted sprayer equipped with three ceramic hollow cone nozzles type TX6. These nozzles were arranged with one over the plant and one on each side of the row directed to the cabbage. The spray pressure was 689.5 kPa (100 psi) and a delivery rate of 280 liters/ha (30 gal/acre) at 3.2 km/h (2 mph).

Table 8. Planting, scouting, spraying and harvesting dates

Season	Planting/Harvest	Scouting	Spraying
Spring 2005	21st February 2005	23rd March 2005	
		30th March 2005	1st April 2005
		5th April 2005	
		11th April 2005	12th April 2005
		19th April 2005	
		2nd May 2005	3rd May 2005
		18th May 2005	
	13th June 2005	25th May 2005	26th May 2005
Fall 2005	7th September 2005	28th Sept. 2005	
		5th October 2005	6th October 2005
		19th October 2005	
		26th October 2005	27th October 2005
		2nd November 2005	
		15th November 2005	16th November 2005
		21st November 2005	
		1st December 2005	2nd December 2005
		13th December 2005	
	2nd January 2006		
Spring 2006	15th Feb 2006	9th March 2006	10th March 2006
		23rd March 2006	
		4th April 2006	5th April 2006
		11th April 2006	
		19th April 2006	20th April 2006
		11th May 2006	
		25th May 2006	26th May 2006
	9th June 2006		

Cabbage was seeded directly on raised beds. The variety used was Cabbage Golden Acres from Chriseed Company (Mount Vernon, WA.). Fertilizer was applied at 112.5 kg/ha (100 lb/ac) of N-32 at 4 weeks. Herbicide applications included bensulide (Prefar® 4E) at the rate of 14.19 l/ha (6qt/ac) at planting. Fungicide applications included Chlorothalonil (Bravo®720) 2.3 l/ha (1qt/ac) sprayed at 7-8 weeks after planting. Irrigation was done twice a week. Table 1 (page 23) outlines the planting, scouting, spraying and harvesting dates.

Harvest. Cabbage was harvested approximately four months after planting. The harvesting involved picking out twenty heads of cabbage per plot at random. For each head, a measurement of width (diameter across the head) and height (vertical measurement of diameter from the point of attachment to the ground; were recorded. Twenty heads of cabbage were weighed using a crane scale.

A damage score criterion, described in Greene et al. (1969), was used to approximate the degree of damage per cabbage head. This criterion involved inspecting the whole head of cabbage for damage caused by any lepidopteran pests. In this criterion, 0 = no feeding damage, 1 = minor damage (1% eaten), 2 = minor to moderate damage (2-5% eaten), 3 = moderate damage (6-10% eaten), 4 = moderate to heavy damage (11-30% eaten), 5 = heavy damage (>30% eaten).

Analysis of Data. Single factor one-way analysis of variance (ANOVA) (SAS Institute, 2001) procedure was employed to identify significant differences in treatment means, in the scouting data for damage ratings. The means were then separated and compared using the Student-Newman-Keuls multiple comparison test at $P<0.05$. The same procedure for data analysis was used to analyze harvest data. The variables in harvest data were width, height, weight and larval damage score on the head of cabbage.

Results

Scouting. The results of the scouting data indicate that there were significant differences in means of *P. xylostella* for all three seasons, spring 2005, fall 2005 and spring 2006 (ANOVA, *F*=8.34; df =2, 178; *P*=0. Fig. 13 shows the numbers of *P. xylostella* per plant in each treatment per season. Table 9 shows these mean differences for *P. xylostella* per10 plants. Spinosad had the lowest mean and was significantly different from the untreated control and λ-cyhalothrin.

In spring 2005, the means of *P. xylostella* were not significantly different from each other (ANOVA, *F*=2.36; df = 2, 47; *P*=0.1063). In the subsequent season, fall 2005, there was a significant difference due to treatment (ANOVA, *F*=3.88: df = 2, 57; *P*=0.0266). The untreated control mean was similar to that of λ-cyhalothrin but different from that of spinosad. The λ-cyhalothrin mean is similar to that of spinosad. In spring 2006, a similar trend to that found in fall 2005 was encountered. There is a significant difference among the means (ANOVA, *F*=3.46; df = 2, 68; *P*=0.0373). The mean of untreated controls is similar to that of λ-cyhalothrin, but different from that of spinosad. The mean of the spinosad is different from that of the untreated controls but similar to that of λ-cyhalothrin. Fig. 14 shows numbers of *P. xylostella* per plant per season. The means of *T. ni* were not significantly different in any season (ANOVA, *F*=0.17; df = 2, 127; *P*=0.8462.

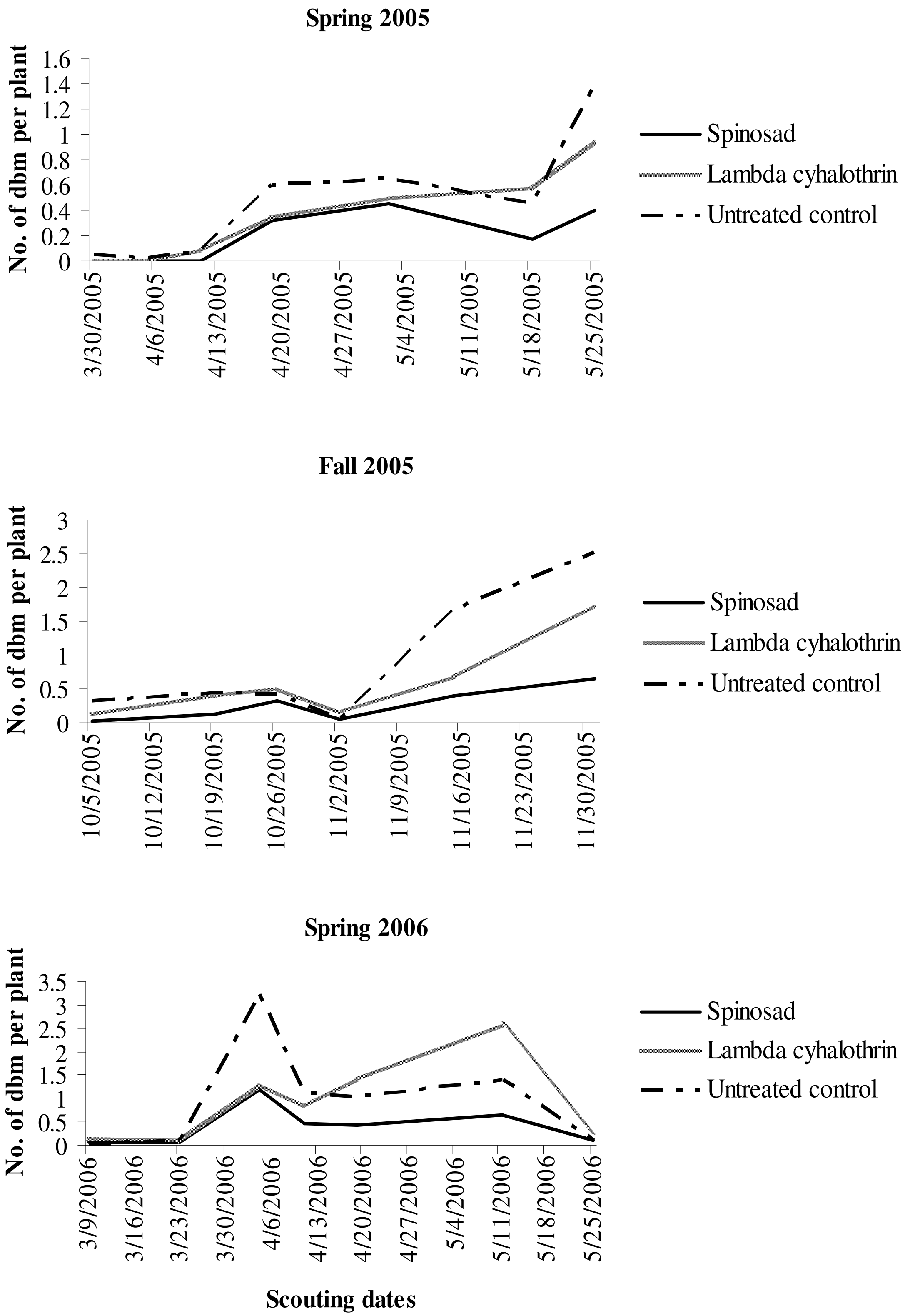

Fig. 13. Numbers of diamondback moth per plant in each treatment per season.

Table 9. Student-Newman-Keuls mean separation of *P. xylostella* per 10 plants for the sampling period.

Season	Treatment	Means ± SE
Spring 05	Spinosad	3.60 ± 0.48 **a**
	λ-cyhalothrin	6.13 ± 0.94 **a**
	Untreated control	6.84 ± 1.37 **a**
Fall 05	Spinosad	3.50 ± 0.71 **a**
	λ-cyhalothrin	6.81 ± 1.43 **ab**
	Untreated control	10.38 ± 2.28 **b**
Spring 06	Spinosad	5.26 ± 1.05 **b**
	λ-cyhalothrin	10.60 ± 2.10 **ab**
	Untreated control	12.35 ± 2.32 **a**

Means were grouped by SNK. Means with the same letter are not significantly different in each season.

Harvest. Cabbage head height, width, weight and larval damage for spring 2005 means are separated by SNK in Table 10.

Spring 2005. In spring 2005, different treatments had a significant effect on the height of cabbage heads (ANOVA, F=217.67; df = 2, 237; P<0.0001). According the SNK grouping, all treatments were significantly different from each other.

The effect of treatment on width of cabbage heads was also significant (ANOVA, F=473.18; df = 2, 237; P<0.0001). When grouped using SNK, the mean width of cabbages in spinosad treated plots was statistically similar to that of λ-cyhalothrin treated plots. However both of these means were statistically different from that of the untreated control.

The weight of the cabbage heads was significantly different among treatments (ANOVA, *F*=42.93; df = 2, 237; *P*<0.0003). The mean weight of cabbage heads treated with spinosad was statistically similar to that of cabbage treated with λ-cyhalothrin. However, both spinosad and λ-cyhalothrin treated heads statistically differ from those of the untreated controls

In the larval damage score, the effect of treatment remains significant throughout the season (ANOVA, *F*=85.84; df = 2, 237; *P*<0.0001). The means for λ-cyhalothrin and spinosad were statistically similar but both differed from untreated control.

Table 10. Student-Newman-Keuls mean separation of four variables for different treatments for spring 2005 yield.

Variable	Treatment	Means ± SE
Height	Spinosad	21.73 ± 0.21 **a**
	λ-cyhalothrin	21.03 ± 0.02 **b**
	Untreated control	15.96 ± 0.25 **c**
Width	Spinosad	17.46 ± 0.13 **a**
	λ-cyhalothrin	17.13 ± 0.13 **a**
	Untreated control	11.69 ± 0.19 **b**
Weight	Spinosad	21.50 ± 0.65 **a**
	λ-cyhalothrin	21.00 ± 0.41 **a**
	Untreated control	12.75 ± 0.75 **b**
Larval damage	Spinosad	1.93 ± 0.27 **a**
	λ-cyhalothrin	2.06 ± 0.41 **a**
	Untreated control	4.55 ± 0.06 **b**

Means separated by SNK. Means with the same letter are not significantly different in each variable.

Fall 2005. In fall 2005, some trends similar to those of spring 2005 were repeated. Table 11 presents means of the various variables in fall 2005. Considering the variable height, there was a treatment effect, i.e. means were statistically different (ANOVA, F=61.38; df = 2, 237; P<0.0001). When the means were grouped according to SNK, the average height of cabbage in λ-cyhalothrin was statistically similar to that of spinosad, however λ-cyhalothrin and spinosad differed significantly from the untreated control.

When considering the variable width, there was a difference in means due to treatment (ANOVA, F=25.84; df = 2, 237; P<0.0001), a trend similar to spring 2005. The SNK grouping classified spinosad and λ-cyhalothrin as being statistically similar while subsequently both differed from the untreated control.

The weight of the cabbage heads measured was statistically different among all the treatments (ANOVA, F=23.22; df = 2, 237; P<0.0001). The mean weight of spinosad treated cabbage heads was similar to that of cabbage treated with λ-cyhalothrin. Both of these means differed significantly from the untreated control.

The ANOVA-GLM procedure indicated that there were significant differences among larval damage means in different treatments (ANOVA, F=1007.96; df = 2, 237; P<0.0001). In the SNK separation of means, all the means are different from each other.

Table 11. Student-Newman-Keuls mean separation of four variables for different treatments for fall 2005 yield.

Variable	Treatment	Means ± SE
Height	Spinosad	17.43 ± 0.19 **a**
	λ-cyhalothrin	17.70 ± 0.17 **a**
	Untreated control	15.43 ± 0.11 **b**
Width	Spinosad	15.05 ± 0.21 **a**
	λ-cyhalothrin	15.25 ± 0.18 **a**
	Untreated control	13.71 ± 0.14 **b**
Weight	Spinosad	18.75 ± 0.49**a**
	λ-cyhalothrin	19.06 ±0.45 **a**
	Untreated control	13.88 ± 0.74 **b**
Larval damage	Spinosad	1.31 ± 0.06 **a**
	λ-cyhalothrin	1.68 ± 0.07 **b**
	Untreated control	4.63 ± 0.57 **c**

Means with the same letter are not significantly different in each variable

Spring 2006. Table 12 shows means grouped by SNK for the four variables for spring 2006. For the variable height of cabbage heads in spring 2006, the means of the treatments were significantly different from each other (ANOVA, F=97.82; df = 2, 237; P<0.0001). When the means were grouped by SNK, the results indicated that all treatment means were different from each other.

Considering the variable width, treatments had an effect on the means of the cabbage heads (ANOVA, F=79.93; df = 2, 237; P<0.0001). In this case also, like in the variable height above, all the means differ from each other when grouped by SNK.

The weight of the cabbage heads measured was statistically different among all the treatments (ANOVA, F=218.583; df = 2, 237; P=0.0035). All the treatment means are different from each other.

The means of the larval damage score for spring 2006 were significantly different from each other (ANOVA, *F*=115.887; df = 2, 237; *P*<0.0001). These means were all different from each other when grouped with SNK.

Table 12. Student-Newman-Keuls mean separation of four variables for different treatments for spring 2006 yield

Variable	Treatment	Means ± SE
Height	Spinosad	17.69 ± 0.18 **a**
	λ-cyhalothrin	16.71 ± 0.16 **b**
	Untreated control	14.55 ± 0.16 **c**
Width	Spinosad	14.04 ± 0.14 **a**
	λ-cyhalothrin	13.14 ± 0.16 **b**
	Untreated control	11.50 ± 0.13 **c**
Weight	Spinosad	31.75 ± 1.89 **a**
	λ-cyhalothrin	25.25 ± 1.93 **b**
	Untreated control	17.00 ± 1.06 **c**
Larval damage	Spinosad	2.38 ±0.07 **a**
	λ-cyhalothrin	4.27 ± 0.04 **b**
	Untreated control	4.62 ± 0.062 **c**

Means with the same letter are not significantly different in each variable.

In the figs. 14 – 17 below, different variables are compared among treatments. Means with the same letter are not significantly different for each season. When comparing the variables height, width and weight, cabbage treated with spinosad scored as well as that treated with λ-cyhalothrin. In spring 2006, spinosad perfomed better than λ-cyhalothrin in terms of larval damage control and yield harvested from spinosad treated plots.

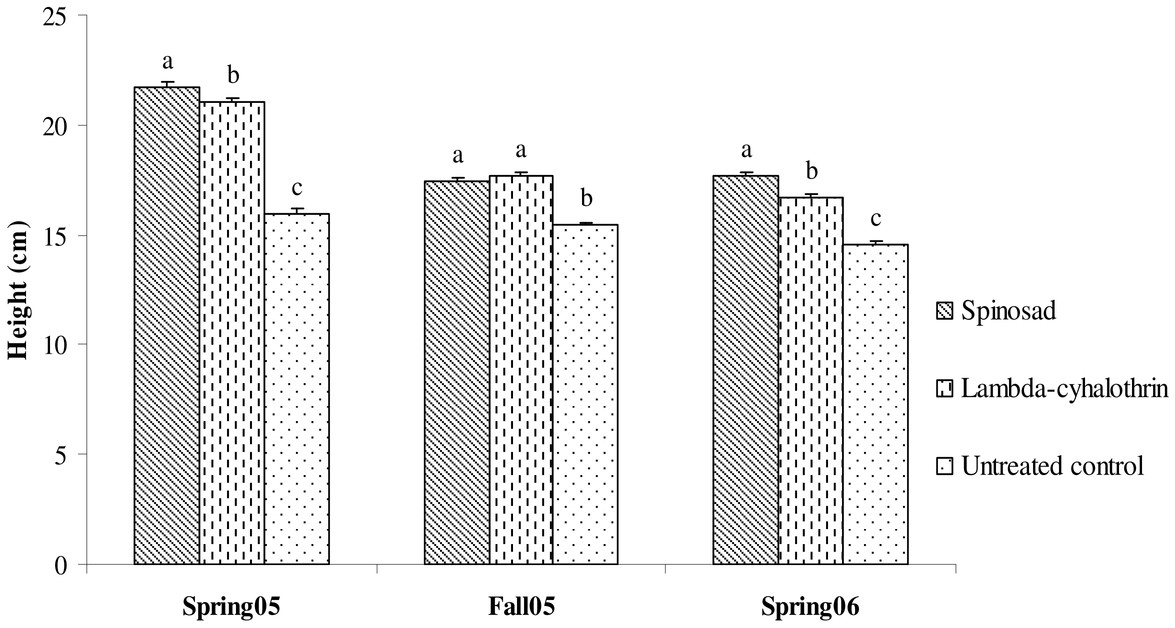

Fig. 14. The height of cabbage heads is compared among treatments.

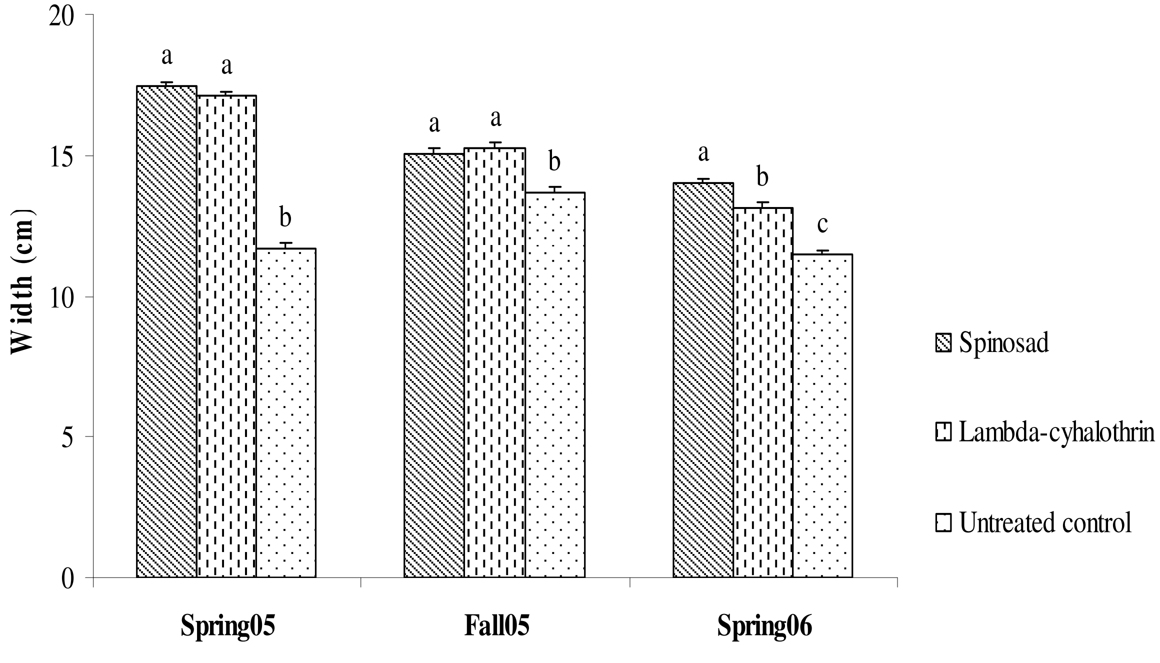

Fig. 15. The width of cabbage heads is compared among treatments.

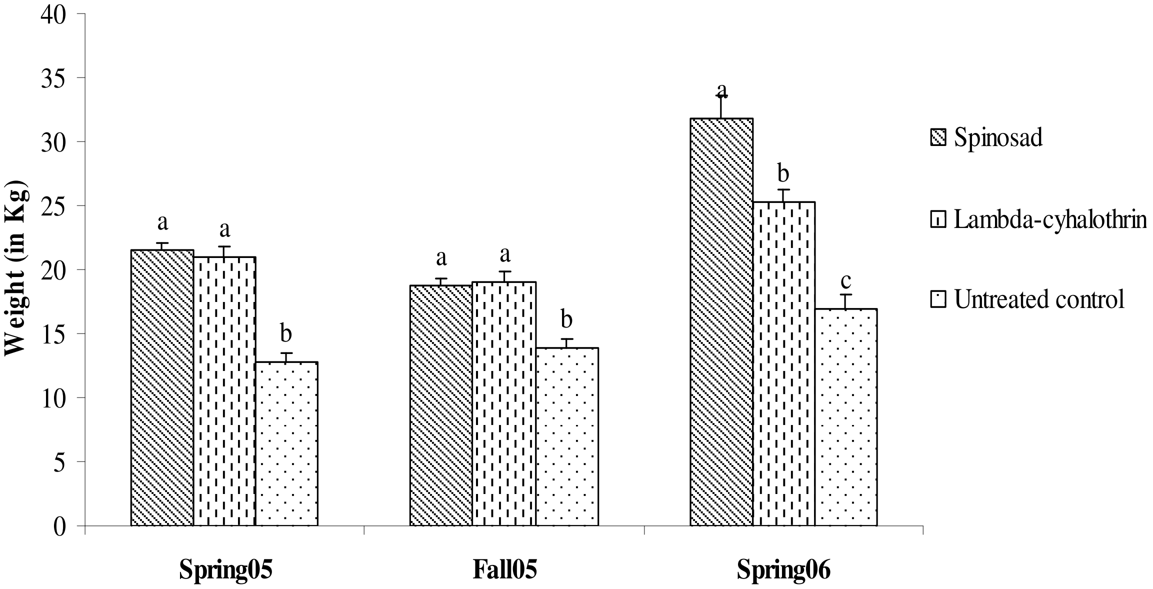

Fig. 16. The weight of cabbage heads is compared among treatments.

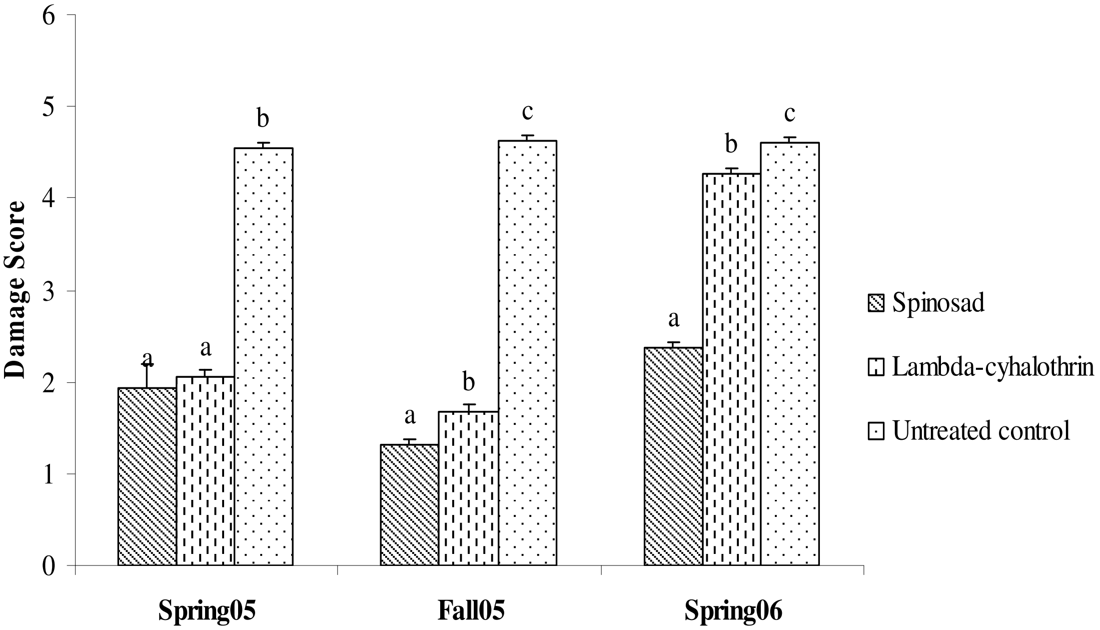

Fig. 17. Cabbage heads damaged by *T. ni* and *P xylostella* are compared among treatments.

Discussion

Scouting is an important aspect in integrated pest management. IPM scouting methods in cabbage can be divided into three categories (Cartwright et al. 1987): density counts of eggs and/or larvae, percent of plants infested, and damage counts. Sears et al. (1985) concluded that thresholds based on feeding damage evaluations, proportion of infested plants, or larval counts resulted in marketable cabbage yields similar to treatments that used a fortnightly schedule. Fields that were treated based on thresholds requiring fewer insecticide applications.

Scouting results from spring 2005 showed no significant differences among treatments. The scouting results of fall 2005 and spring 2006, showed significant differences among treatments. In both seasons, the untreated control was not different from λ-cyhalothrin and λ-cyhalothrin was not different from spinosad. Spinosad had comparatively lower means of *P. xylostella* compared to both untreated control and λ-cyhalothrin treatment.

Management of lepidopterous pests in the LRGV in cabbage has been based on regimental spraying prior to 1987, when expression of resistance to organophosphates and carbamates was first noted (Magaro and Edelson 1990). Thresholds for cabbage vary from region to region and according to the proportion of each larval species on the crop (Stewart and Sears 1988). As a result, various researchers have tested thresholds based on damage, insect density, or the proportion of plants infested with larvae. Greene (1972) concluded that a threshold of 0.10 *T. ni* per plant resulted in damage-free marketable cabbage. He used insect counts. Shelton et al. (1982), working with *P. xylostella*, *T. ni*, and *Pieris rapae* (Linnaeus) larvae, suggested that a threshold of 0.50 *T.*

ni equivalent per plant during head formation results in 95% marketable yields. Kirby and Slosser (1984) suggested a composite threshold of 0.30 larvae per plant produced 80% marketability. Cartwright et al. (1987) established an economic threshold of 0.30 larvae per plant and found it to be useful in commercial cabbage. This threshold is currently being used and was applied in this study. Other authors such as Chalfant et al. (1979) and Workman et al. (1980) have suggested thresholds based on visual ratings of leaf damage.

The means of *P. xylostella* for spinosad, λ-cyhalothrin and untreated control through out the whole experimental period were 0.41, 0.78, and 0.98, respectively. These means exceeded the thresholds suggested by various authors except for the spinosad treatement, which did not exceed the threshold suggested by Shelton et al. (1982) of 0.50 *T. ni* equivalent per plant during head formation.

In assessing the data collected during harvest, four variables were compared. These included height, width, weight and damage on the cabbage head. Consistently, spinosad treated plots yield the largest cabbage heads and the lowest larval damage in all three seasons. In most cases however, the differences between spinosad and λ-cyhalothrin were not statistically significant (Figs. 14 - 17).

Insecticides labeled for use in the same crops may generally be comparatively priced, i.e. the price of spinosad is $262.50 per pound of active ingredient while the price of λ-cyhalothrin is $260.72 per pound of active ingredient (Larson et al. 1999). Hutchinson et al. (2003) noted that percentage marketability of cabbage heads and net profit in IPM strategy which utilized biologically based insecticides (SpinTor$^{®}$ and Proclaim$^{®}$) was higher than the conventional strategy that utilized λ-cyhalothrin. In our study, a grower using spinosad only is more likely to get larger cabbage heads and more marketability than one using λ-cyhalothrin for the same cost of insecticide.

CHAPTER IV

CONCLUSIONS

Spiders are an important part of the natural enemy complex in any agro-ecosystem (Cappaert et al. 1991, Gravena and Da Cuhna 1991, Clark et al 1994). I found that spiders were continuously associated with cabbage in different treatments and increased in density and diversity as the season progressed (Fig. 8 and 12). This is consistent with a cropping cycle that is preceded by a fallow period where spider densities and diversity are low, followed by dispersal from surrounding areas into the field following planting. How can the cabbage agro-ecosystem be improved to increase its hospitability to spiders? Does the frequency and type of insecticides used influence spider diversity?

The data are consistent with the initial low diversity occurring because the field has been fallow, and thus the spiders begin dispersing into the field as cabbage and other plants become available (Fig 8 and 12). This suggests that the surrounding area may be a source of spiders, particularly in the early stages of cabbage production. Most species of spiders are univoltine. Spiders may exert their effects by aggregating where infestations of *P. xylostella* or *T. ni* are developing and this numerical response may prevent or delay economically important densities of these pests from occurring. The cabbage agro-ecosystem is a refuge for spiders and associated plants can affect the quality of that refuge. These plants should not be alternate hosts of *P. xylostella* or *T. ni*. The host range of *P. xylostella* is limited to crucifers that contain mustard oils and their glucosides (Gupta and Thorsteinson 1960a, b). Non-cruciferous plants, or trap crops such as glossy yellow rocket that is highly attractive for oviposition but on which DBM larvae cannot survive (Idris and Grafius, 1996; Badenes-Perez et al., 2004; Shelton and Nault, 2004). can be provided as a refuge for spiders.

Although further studies need to be conducted on susceptibility of spiders to various chemical pesticides, in different agro-ecosystems, this study found that plots treated with λ-cyhalothrin had lower diversity compared with those treated with spinosad or untreated controls. Rotation of different classes of insecticides, for example, use of λ-cyhalothrin in fall and spinosad in spring, may improve the quality of the habitat for spiders and also reduce selection on target species that may result in resistance. Fauna found in the spring included many spider immatures that were captured along with other natural enemies such as coccinelids, various parasitoids and *O. insidiosus.* Since spinosad has less adverse effects on spiders and other natural enemies (Sparks *et al.* 1998) compared to λ-cyhalothrin, it is the recommendation of this study that spinosad should be used in spring and, λ-cyhalothrin in fall when most of the arthropods are preparing to go into diapause.

Lambda-cyhalothrin and spinosad effectively controlled *P. xylostella* or *T. ni*. Gradual expression of resistance by *P. xylostella* or *T. ni* to various chemicals has been reported in the past (Tabashnik et al. 1987, Magaro and Edelson 1990, Leibee and Savage 1992, Plapp et al. 1992). In field trials in 1999 and 2000, Liu et al. (2002, 2003a) reported the damage caused by lepidopteran pests, on plants treated with spinosad, as 0.3 and 0.4 respectively. This study reported damage ratings for spring and fall 2005 and spring 2006 as 1.9, 1.3, and 2.3 respectively. These results may be an indicator that lepidopteran pests in the field may become resistant to spinosad.

An accepted technique for limiting the development of insecticide resistance is restricting the use of particular insecticide classes to part of the year. Rotating the use of insecticides classes over an entire area in a “window strategy” based on calendar periods has proven to be an effective resistance management tactic (Roush 1989, Forrester *et al.* 1993). The implementation of this approach requires regional and national support for an agreed strategy while success requires the participation of growers. This rotation of insecticides classes may benefit by delaying onset of resistance and by conserving spiders. The recommendation from this study is use of spinosad in spring and λ-cyhalothrin in fall.

Further studies need to be conducted on the impact of high tillage on spiders. Alternatives to use of machinery to control weeds include using polypropylene landscape fabric and compost mulch. These alternatives are less labor intensive and are important for water conservation. Compost mulch also enriches soil with nutrients while simultaneously suppressing weeds. Polypropylene landscape fabric is more durable than the common polyethylene fabric commonly used for one season in many vegetable agro-ecosystems. Feldman et al. (2000) found that compost provided the highest crop yields for both melons and cabbage with a moderate labor investment. They also found that surface-applied compost substantially increased underlying soil nutrient levels. Other authors (Tiwari et al. 2003, Brandsaeter et al. 1998) have also discussed the costs and benefits of mulching cabbage agro-ecosystems. However it is not clear how use of compost mulch or polyethylene fabric would impact the spider density and diversity.

This study shows that spiders are a consistent part of the arthropod complex in cabbage and increase in density and diversity as the growth of each crop progresses in the field. There are more spiders active in the spring than in the fall. The class of insecticide chosen for use in pest control also affects spider abundance and diversity. The primary recommendation from this study is to rotate insecticide use between fall and spring to enhance biocontrol opportunities and minimize risk of resistance in target pests.

REFERENCES CITED

Acheampong, S. and J. D. Stark. 2004. Can reduced rates of pymetrizone and natural enemies control the cabbage aphid, *Brevicoryne brassicae* (Homoptera: Aphididae) on broccoli? International Journal of Pest Management 50: 275-279.

Alderweireldt, M. 1994. Prey selection and prey capture strategies of Linyphiid spiders in high input agricultural fields. Bulletin of British Arachnological Society 9: 300-308.

Amalin, D. M., J. E. Pena, R. Mcsorley, H. W. Browning, and J. H. Crane. 2001. Comparison of different sampling methods and effect of pesticide application on spider populations in lime orchards in South Florida. Environmental Entomology 30: 1021-1027.

Anonymous. 1996. The tarantula-poison spider or a case of mistaken identity? Adverse Drug Reaction Toxicology Review 15: 199-202.

Asian Vegetable Research and Development Centre. 1988. 1986 Progress Report, pp 540. Shanhua, Taiwan. Asian Vegetable Research and Development Centre.

Badenes-Perez, F. R., A. M. Shelton, and B. A. Nault. 2004. Evaluating trap crops for diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). Journal of Economic Entomology 97: 1365–1372.

Balfour, R. and A. Rypstra. 1998. The influence of habitat structure on spider density in a no-till soybean agro-ecosystem. Journal of Arachnology 26:221–226.

Beecher, C. 1994. Cancer preventive properties of varieties of *Brassica oleracea*: a review. American Journal of Clinical Nutrition 59: 1166S-70S.

Berg, H. van den, K. Hassan, and M. Marzuki. 1998. Evaluation of pesticide effects on arthropod predator populations in soy bean in farmers' fields. Biocontrol Science and Technology 8: 125-137.

Bishop, L., and S. Riechert. 1990. Spider colonization of agro-ecosystems: mode and source. Environmental Entomology. 19:1738–1745.

Bishop, A. L. and P. R. B. Blood. 1981. Interactions between natural populations of spiders and pests in cotton and their importance to cotton production in southern Queensland. General Applied Entomology 13: 98-104.

Bonte, D., P. Criel, L. Vanhoutte, I. Van Thournout and J, P. Maelfait. 2004. The importance of habitat productivity, stability and heterogeneity for spider species richness in coastal grey dunes along the North Sea and its implications for conservation. Biodiversity and Conservation 13: 2119-2134.

Brandsaeter, L. O., J. Netland, and R. Meadow. 1998. Yields, weeds, pests and soil nitrogen in a white cabbage-living mulch system. Biological Agriculture and Horticulture 16: 291-309.

Cappaert, D. L., F. A. Drummond and P. A. Logan. 1991. Populations dynamics of Colorado potato beetle (Coleoptera: Chrysomelidae) on a native host in Mexico. Environmental Entomology 20: 1549-1555.

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

Cartwright, B., R. J. Schatzer, W. P. Morrison, and C. Chambers. 1990. Economics of managing lepidopterous cabbage pests in the southwestern United States. In

Proceedings of the Second International Workshop on Management of Diamondback Moth and Other Crucifer Pests, Tainan, Taiwan, 10-14 December 1990.

Chalfant, R. B., W. H. Denton, D. J. Schuster, and R. B. Workman. 1979. Management of cabbage caterpillars in Florida and Georgia by using visual damage thresholds. Journal of Economic Entomology 72: 411-413.

Chang, L. C. 1961. The dynamics and insecticidal control of cruciferous insects. Plant Protection Bulletin (Taiwan) 3: 22-26.

Chin, T. 1974. Studies on the seasonal appearance of diamondback moth in relation to environmental factors. Taiwan Agriculture Quarterly 10: 81-84.

Clark, M. S., J. S. Luna, N. D. Stone and R. R. Youngman. 1994. Generalist predator consumption of armyworm (Lepidoptera: Noctuidae) and effect of predator removal on damage in no-till corn. Environmental Entomology 23: 617-622.

Cleveland, C. B., G. A. Bormett, D. G. Saunders, F. L. Powers, A. S. McGibbon, G. L. Reeves, L. Rutherford, and J. L. Balcer. 2002. Environmental fate of spinosad. 1. dissipation and degradation in aqueous systems. Journal of Agriculture and Food Chemistry 50: 3244 -3256.

Commenges, D., V. Scotet, S. Renaud, H. Jacqmin-Gadda, P. Barberger-Gateau and J. F. Dartigues. 2000. Intake of flavonoids and risk of demential. European Journal of Epidemiology 16: 357-363.

Costello, M. J., and K. M. Daane. 1997. Comparison of sampling methods used to estimate spider (Araneae) species abundance and composition in grape vineyards. Environmental entomology 26: 142-149.

De Clercq, R., H. Casteels, and J. Janssen. 1991. Influence of pesticides on epigeal arthropod fauna in laboratory tests. State Nematology and Entomology Research Station (C.L.O-Gent) Merelbeke, Belgium.

Edelson, J.V., J. J. Magaro and H. Browning. 1993. Control of insect pests on broccoli in southern Texas: a comparison between synthetic organic and biorational treatments. Journal of Entomological Science 28: 191-196.

Eigenbrode, S. D., A. M. Shelton, M. H. Dickson. 1990. Two types of resistance to the diamondback moth (Lepidoptera: Plutellidae) in cabbage. Environmental Entomology 19: 1086-90.

Eigenbrode, S. D., K. A. Stoner, A. M. Shelton and W. C. Kain. 1992. Characteristics of glossy leaf waxes associated with resistance to diamondback moth in *Brassica oleracea*. Journal of Economic Entomology 84: 1609-1618.

Eigenbrode, S. D., T. Castagnola and S. Moodie. 1995. Predators influence host plant resistance to a phytophagous pest in glossy leaf cabbage. Entomologia Experimentalis et Applicata 77: 335-342.

Eigenbrode, S. D., T. Castagnola, M-B. Roux and L. Steljes. 1996. Mobility of three generalist predators is greater on cabbage with glossy leaf wax than on cabbage with a wax bloom. Entomologia Experimentalis et Applicata 81: 335-343.

Environmental Protection Agency. 1997. Spinosad pesticide fact sheet No. 501C. Environmental Protection Agency, Office of Pesticides and Toxic Substances. Available from: <www.epa.gov>.

Feldman, R. S., C. E. Holmes, and T. A. Blomgren. 2000. Use of fabric and compost mulches for vegetable production in a low tillage, permanent bed system: effects on crop yield and labor. American Journal of Alternative Agriculture 15: 146-153.

Food Quality Protection Act. 1996. Data collection activities to assure the health of infants and children and other measures. US Public Law 104-170, Title III Section 301-305. 104th Congress, August 1996. Available from: <www.fda.gov>.

Forrester, N. W., M. Cahill, L. J. Bird, and J. K Layland. 1993. Management of pyrethroid and endosulfan resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Australia. Bulletin of Entomological Research, Supplement 1. CAB International, Wallingford, UK.

Furlong, M. J., Z. H. Shi, S. S. Liu, and M. P. Zalucki. 2004. Evaluation of the impact of natural enemies on *Plutella xylostella* L. (Lepidoptera: Yponomeutidae) populations on commercial *Brassica* farms. Agriculture and Forest Entomology 6: 311-322.

Galvan, T. L., R. L. Koch, and W. D. Hutchison. 2005. Effects of spinosad and indoxacarb on survival, development and reproduction of the multicolored Asian lady beetle (Coleoptera: Coccinellidae). Biological Control 34: 108-114.

Gravena, S. and H. F. DaCuhna. 1991. Predation of cotton leafworm first instar larvae *Alabama aragillacea* (Lepidoptera: Noctuidae). Entomophaga 36: 481-491.

Green, J. 1999. Sampling method and time determines composition of spider collections. Journal of Arachnology 27: 176–182.

Greene, G. L. 1972. Economic damage threshold and spray interval for cabbage looper control on cabbage. Journal of Economic Entomology 65: 205-208.

Greene, G. L., W. G. Genung, R. B. Workman, and E. G. Kelshimer. 1969. Cabbage looper control in Florida – a comparative program. Journal of Economic Entomology 62: 798-800.

Goodwin, S. 1979. Changes in the number of parasitoid complex associated with diamondback moth, *Plutella xylostella* (L.) (Lepidoptera) in Victoria, Australian. Journal of Zoology 27: 981-89.

Gupta, P. D and A. J. Thorsteinson. 1960 (a). Food plant relationship of diamondback moth (*Plutella maculipennis* (Curt.)). I. gustation and olfaction in relation to botanical specificity of larva. Entomologia Experimentalis et Applicata 3: 241-250.

Gupta, P. D, and A. J. Thorsteinson. 1960 (b). Food plant relationships of the diamond-back moth (*Plutella maculipennis* (Curt.)): II. sensory regulation of oviposition of the adult female. Entomologia Experimentalis et Applicata 3**:** 305–314.

Harcourt, D. G. 1955. Biology of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae), in eastern Ontario. Quebec Society of Plant Protection 37: 155-160.

Harcourt, D. G. 1957. Biology of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae), in Eastern Ontario. II. life-history, behaviour, and host relationships. Canadian Entomologist 89: 554-564.

Harcourt D. G. 1963. Major mortality factors in the population dynamics of the diamondback moth, *Plutella maculipennis* (Curt.) (Lepidoptera: Plutellidae). Memoirs of the Entomological Society of Canada 32: 55-66.

Hardy, J. E. 1938. *Plutella Maculipennis* Curt., its natural and biological control in England. Bulletin of Entomological Research 29: 343-72.

Heo, H. J. and C.Y. Lee. 2006. Phenolic phytochemicals in cabbage that inhibit amyloid βprotein-induced neurotoxicity. Food Science and Technology 39:330-336.

Hines, R. L., and W. D. Hutchison. 2001. Evaluation of action thresholds and spinosad for lepidopteran pest management in Minnesota cabbage. Journal of Economic Entomology 94: 190-196.

Hof, A., D. Heimann, and J. Rombke. 1995. Further development for testing the effects of pesticides on wolf spiders. Ecotoxicology and Environmental Safety 31: 264-270.

Hutchison, W. D., and E. C. Burkness. 1999. On-farm experience using action thresholds and SpinTor for the management of Lepidoptera in cabbage steps to implementation, pp 35-39. *In* Proceedings of the International Workshop on Integrated Pest Management of Cole Crops, 20-21 May 1999. Universidad de Celaya, Mexico.

Hutchison, W. D., and E. C. Burkness, G. Pahl and, T. Hurley. 2003. Integrating novel technologies for cabbage IPM in the USA: value of on-farm, research. *In* Proceedings of the 4th International Workshop on the Management of Diamondback Moth and other Crucifer Pests, University of Melbourne, Australia, 26-29 Nov 2001.

Idris, A. B., and E. Grafius. 1996. Effects of wild and cultivated host plants on oviposition, survival, and development of diamondback moth (Lepidoptera:

Plutellidae) and its parasitoid *Diadegma insulare* (Hymenoptera: Ichneumonidae), Environmental Entomology 25: 825–833.

Isbister, G. K. 2004. Necrotic arachnidism: the mythology of a modern plague. Lancet 364: 549-553.

Jackman, J. A. 1997. A field guide to spiders and scorpions of Texas. Texas Monthly Field Guide Series, Gulf Publishing Company, Houston, Texas.

Jackson, C. G, G. D Butler Jr., and D. E. Bryan. 1969. Time required for development of *Voria ruralis* and its host, the cabbage looper, at different temperatures. Journal of Economic Entomology 62: 69-70.

Kaston, B. 1981. Spiders of Connecticut. Bulletin 70. Connecticut Geological and Natural History Survey, Hartford, Connecticut.

Kfir, R. 2005. Impact of parasitoids on *Plutella xylostella* populations in South Africa, and the successful biological control of the pest on the island of St. Helena, pp 132-141. In Proceedings of the Second International Symposium on Biological Control of Arthropods. Davos, Switzerland, September 12- 16, 2005.

Khan, S. A, Y. Zafar, R. W. Briddon, K. A. Malik, and Z. Mukhtar. 2006. Spider venom toxin protects plants from insect attack. Transgenic Research 15: 249-357.

Kirby, R. D., and J. E. Slosser. 1984. Composite economic threshold for three lepidopterous pests on cabbage. Journal of Economic Entomology 77: 725-733.

Krebs, C. J. 1999. Ecological Methodology, 2nd ed. Addison-Welsey, Menlo Park, CA.

Krishnamoorthy, A., N. Rana, and M. Mani. 2004. Toxicity of pesticides to coccinellid predator *Cheilomenes sexmaculata*. Insect Environment 10: 183-185.

Kurilich, A. C., G. J. Tsau, A. Brown, L. Howard, B. P. Klein, E. H. Jeffery, M. Kushad, M. A. Walllig and J. A. Juvic. 1999. Carotene, tocopherol and ascorbate contents in subspecies of *Brassica oleracea*. Journal of Agricultural and Food Chemistry 47: 1576-1581.

Land, M. F. 1974. A comparison of the visual behavior of a predatory arthropod with that of a mammal, pp 341–431. *In* C. A. G. Wiersma (ed). Invertabrate neurons and behavior. MIT press, Cambridge, MA.

Larson, B. C., A. M. Mossler, and O. N. Nesheim. 1999. CIR 1233, Pesticide Information Office, Food Science and Human Nutrition Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Available at: <http://edis.ifas.ufl.edu>.

Leibee, G. L., and K. Savage. 1992. Insecticide resistance in diamondback moth in Florida. *In* Proceedings of the Second International Workshop on Management of Diamondback Moth and Other Crucifer Pests, Tainan, Taiwan, 10-14 December 1990.

LeSar, C., and J. Unzicker. 1978. Soybean spiders: species composition, population densities, and vertical distribution. Illinois Natural History Survey Biological Notes 107:1–14.

Liu, T. X., A. N. Sparks Jr., W. Chen, G. M Liang, and C. Brister. 2002. Toxicity, persistence and efficacy of indoxacarb on cabbage looper (Lepidoptera: Noctuidae) on cabbage. Journal of Economic Entomology 92: 360-367.

Liu, T. X., A. N. Sparks Jr., and W. Chen. 2003 (a). Toxicity, persistence and efficacy of indoxacarb and two other insecticides on *Plutella xylostella* (Lepidoptera: Plutellidae) immatures on cabbage. International Journal of Pest Management 49: 235-241.

Liu, T. X., W. D. Hutchison, W. Chen, and E. C. Burkness. 2003 (b). Comparative susceptibilities of diamondback moth (Lepidoptera: Plutellidae) and cabbage looper (Lepidoptera: Noctuidae) from Minnesota to south Texas to λ- cyhalothrin and indoxacarb. Journal of Economic Entomology 96: 1230-1236.

Luczak, J. 1979. Spiders in agrocoenoses. Polish Ecological Studies 5:151–200.

Ludwig, S., and R. D. Oetting. 2001. Effect of spinosad on *Orius insidiosus* (Hemiptera: Anthocoridae) when used for *Frankliniella occidentalis* (Thysanoptera: Thripidae) control on greenhouse pot chrysanthemums. Florida Entomologist 84: 311-313.

Magaro, J. J., and J. V. Endelson. 1990. Diamondback moth (Lepidoptera: Plutellidae) in south Texas: a technique for resistance monitoring in the field. Journal of Economic Entomology 83: 1201-06.

Magurran, A. E. 1988. Ecological diversity and its measurement. Chapman and Hall, Croom Helm, London.

Mansour, F., D. Rosen, and A. Shulov. 1981. Disturbing effect of a spider on larval aggregations of *Spodoptera littoralis.* Entomologia Experimentalis et Applicata 29: 234-37.

Mansour, F., and W. H. Whitcomb. 1986. The spiders of a citrus grove in Israel and their roles as biological control agents of *Ceroplastes floridensis* (Homoptera: Coccidae). Entomophaga 31: 269-276.

Marc, P., and A. Canard. 1997. Maintaining the spider biodiversity in agro-ecosystems as a tool in pest control. Agriculture, Ecosystems and Environment 62: 229-235.

Marsh, H. O. 1917. Life history of *Plutella maculipennis*, the diamond-back moth. Journal of Apicultural Research 10: 1-10.

Marshall, S., and A. Rypstra. 1999 (a.) Spider competition in structurally-simple ecosystems. Journal of Arachnology 27:343–351.

Marshall, S., and A. Rypstra. 1999 (b.) Habitat selection determines the colonization of two soybean agroecosytems by two wolf spiders (Araneae: Lycosidae). Environmental Entomology 28:1052–1059.

McDaniel, S. G., and W. L. Sterling. 1982. Predation of *Heliothis virescens* (F.) eggs on cotton in east Texas. Environmental Entomology 11: 60-66.

Miles, H. W. 1924. The diamondback moth, *Plutella maculipennis* Curt. Kirton Agricultural Institute, Worcester, England Annual Report 1923, pp. 45-48.

Miller, T. A., and V. L. Salgado. 1985. The mode of action of pyrethroids on insects pp. 151–262. In J.P. Leahey, (ed.) The pyrethroid insecticides. Taylor & Francis, London.

Mittal, V., and R. Ujagir. 2005. Toxicity of Spinosad 45SC to natural enemies associated with insect pests of pigeon pea at Pantnagar. Journal of Biological Control 19: 73-76.

Morford, M. P. O., and R. J. Lenardon. 2003. Philosophy, Classical mythology. 7th ed. Longman Press, New York.

Morisak, D. J., D. E. Simonet, and R. K. Lindquist. 1984. Use of action thresholds for management of lepidopterous larval pests of fresh-market cabbage. Journal of Economic Entomology 77: 476-482.

National Climatic Data Service. 2007. National climatic data, 2007. Available from: <www.ncds.noaa.gov>.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4: 355–364.

Nuessly, G. S., and W. L. Sterling. 1994. Mortality of *Helicoverpa zea* (Lepidoptera: Noctuidae) eggs in cotton as a function of oviposition sites, predator species, and desiccation. Environmental Entomology 23: 1189–1202.

Ohnesorg, W. J., and O'Neal, M. E. 2006. Effects of reduced risk-insecticides on the soybean (*Glycine max*) natural enemy community. *In* 2005 ESA Annual Meeting and Exhibition, December 15-18, 2005, Ft. Lauderdale, FL.

Oraze, M. J., and A. A. Grigarick. 1989. Biological control of aster fleahopper (Homoptera: Cicadelidae) and midges (Diptera: Chrinomomidae) by *Pardosa ramulosa* (Araneae: Lycosidae) in California rice fields. Journal of Economic Entomology 82: 745-749.

Pathak, D. R., M. Tseng, and A. H. Wu. 2006. Migrant studies aid the search for factors linked to breast cancer risk. Journal of National Cancer Institute 98: 436-438.

Pekar, S., and C. R. Haddad. 2005. Can agrobiont spiders (Aranae) avoid a surface with pesticide residues? Pest Management Science 61: 1179-1185.

Pekar, S., and F. Kocourek. 2004. Spiders (Aranae) in the biological and integrated pest management of apple in the Czech Republic. Journal of Applied Entomology 128: 561-566.

Pétillon, J., F. Ysnel, S. Le Gleut, J. C. Lefeuvre, and A. Canard. 2004. Responses of spider communities to salinity and flooding in tidal salt marsh (Mont. St- Michel Bay, France). Athropoda Selecta special issue 1: 235-248.

Pétillon, J., F. Ysnel, A. Canard, and J. C. Lefeuvre. 2005. Impact of an invasive plant *(Elymus athericus*) on the conservation value of tidal salt marshes in western France and implications for management: responses of spider populations. Biological Conservation 126: 103-117.

Pfannenstiel, R. S. 2005. Nocturnal predators and their impact on lepidopteran eggs in annual crops: what we don't see does help us! *In* Second International Symposium on Biological Control of Arthropods. Davos, Switzerland, 12–16 September 2005.

Pfannenstiel, R. S., and K. V. Yeargan. 2002. Identification and diel activity patterns of predators attacking *Helicoverpa zea* (Lepidoptera: Noctuidae) eggs in soybean and sweet corn. Environmental Entomology 31: 232-241.

Plapp, F. W., J. J. Magaro, and J. V. Endelson. 1992. Diamondback moth in south Texas: a technique for resistance monitoring in the field. *In* Proceedings of Second International Workshop on Management of Diamondback Moth and Other Crucifer Pests, Tainan, Taiwan, 10-14 December 1990.

Provencher, L. and D. Coderre. 1987. Functional responses and switching of *Tetragnatha laboriosa* Hentz (Araneae: Tetragnathidae) and *Clubiona pikei* Gertsch (Araneae: Clubionidae) for the aphids *Rhopalosiphum maidis* (Fitch) and *Rhopalosiphum padi* (L.) (Homoptera: Aphididae). Environmental Entomology 16: 1305-1309.

Provost, C., D. Coderre, E. Lucas, G. Chouinard, and N. J. Bostanian. 2003. Impacts of a sublethal dose of lambda-cyhalothrin on phytophagous mite intraguild predators in apple orchards. Phytoprotection. Quebec Society for the Protection of Plants, Sainte-Foy, Canada 84: 105-113.

Riddick, E.W. and N.J. Mills. 1994. Potential of adult carabids (Coleoptera: Carabidae) as predators of fifth-instar codling moth (Lepidoptera: Tortricidae) in apple orchards in California. Environmental Entomology 23: 1338-1345.

Riechert, S. E. 1992. Spiders are representatives of "sit-and-wait" predators, pp. 313-328. *In* M. J. Crawley, ed. Natural enemies: the population biology of predators, parasites and diseases. Blackwell Scientific Publications, Oxford.

Riechert, S. E., and L. Bishop. 1990. Prey control by an assemblage of generalist predators: spiders in garden test systems. Ecology 71:1441-1450.

Risch, S. J. 1981. Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. Ecology 62: 1325-1340.

Root, R. B. 1973. Organisation of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). Ecological Monographs 43: 95-124.

Roush, R. T. 1989. Designing resistance management programs; how can you choose? Pesticide Science 26: 423-441.

Ruberson, J. R. and P. G. Tillman. 1999. Effect of selected insecticides on natural enemies in cotton: laboratory studies, pp1210-1213. *In* P. Dugger and D. Ritcher (eds). Proceedings of Beltwide Cotton Conference, Orlando, FL. 3-7 January 1999. National Cotton Council, Memphis, TN.

Rypstra, A., P. Carter, R. Balfour, and S. Marshall. 1999. Architectural features of agricultural habitats and their impact on the spider inhabitants. Journal of Arachnology 27:371–377.

Salgado, V. L. 1997. The modes of action of spinosad and other insect control products. Down to Earth 52: 35-43.

Samu, F. 1993. Wolf spider feeding strategies: optimality of prey consumption in *Pardosa hortensis*. Oecologia 94:139-145.

Samu, F., K. D. Sunderland, C. J. Topping, and J. S. Fenlon. 1996. A spider population in flux. Selection and abandonment of artificial web-sites and the importance of intraspecific interactions in *Lepthyphantes tenui*s (Araneae: Linyphiidae) in wheat. Oecologia 106: 228-239.

Statistical Analysis Software Institute. 2001. The SAS system for Windows, release 8.12. Cary, N.C.

Sears, M. K., A. M. Shelton, T. C. Quick, J. A. Wyman, and S. E. Webb. 1985. Evaluation of partial plant sampling procedures and corresponding actionthresholds for management of Lepidoptera on cabbage. Journal of Economic Entomology 78: 913-916.

Shannon, C. E. 1948. The mathematical theory of communication. Bell System Technical Journal 27: 379-423 and 623-656.

Sheehan, W. 1986. Response of specialist and generalist natural enemies to agro-ecosystem diversification: a selective review. Environmental Entomology 15: 456-461.

Shelton, A. M., and B. A. Nault. 2004. Dead-end trap cropping: a technique to improve management of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). Crop Protection 23: 497–503.

Shelton, A. M., J. L. Robertson, J. D. Tang, C. Perez, S. D. Eigenbrode, H. K. Preisler, W. T. Wilsey, and R. J. Cooley. 1993. Resistance of diamondback moth (Lepidoptera: Plutellidae) to Bacillus thuringiensis subspecies in the field. Journal of Economic Entomology 86: 697-705.

Shelton, A. M., J. T. Andaloro, and J. Barnard. 1982. Effects of cabbage looper, imported cabbageworm, and diamondback moth on fresh market cabbage and processing cabbage. Journal of Economic Entomology 75: 742-745.

Shive, W, R. N. Snider, B. Dubilier, J. C. Rude, G. E. Clark Jr., and J. O Ravel. 1957. Glutamine in treatment of peptic ulcer: preliminary report. Texas State Journal of Medicine 53: 840-842.

Shorey, H. H, L. A. Andres, and R. L. Hale. 1962. The biology of *Trichoplusia ni* (Lepidoptera: Noctuidae). I. life history and behavior. Annals of the Entomological Society of America 55: 591-597.

Shorey, H. H. 1963. The biology of *Trichoplusia ni* (Lepidoptera: Noctuidae). II. factors affecting adult fecundity and longevity. Annals of the Entomological Society of America 56: 476-480.

Smith, B. and J. B. Wilson. 1996. A consumer's guide to evenness indices. Oikos 76: 70-82.

Sparks, T. C., G. D. Thompson, H. A. Kirst, M. B. Hertlein, L. L. Larson, T. V. Worden, and S. T. Thibault. 1998. Biological activity of the spinosyns, new fermentation derived insect control agents, on tobacco budworm (Lepidoptera: Noctuidae) larvae. Journal of Economic Entomology 91: 1277-1283.

Srinivasan, K., and P. N. Krishna Moorthy. 1992. Development and adaptation of integrated pest management of major pests of cabbage using Indian mustard as a trap crop. *In* Proceedings of the Second International Workshop on Management of Diamondback Moth and Other Crucifer Pests, Tainan, Taiwan, 10-14 December 1990.

Sterling, W. L., A. Dean, and N. M. Abd El-Salam. 1992. Economic benefits of spider (Araneae) and insect (Hemiptera: Miridae) predators of cotton fleahoppers. Journal of Economic Entomology 82: 52-57.

Stoner, K. A. 1990. Glossy leaf wax and plant resistance to insect in *Brassica oleracea* under natural infestation. Environmental Entomology 19: 730-39.

Stoner, K. A. 1992. Resistance and susceptibility to glossy genetic lines of *Brassica oleracea* in Connecticut. *In* N.T. Talekar, (ed.). 1992. Management of diamondback moth and other crucifer pests: Proceedings of the Second

International Workshop, pp 57-63. Asian Vegetable Research and Development Center, Shanhua, Taiwan. 10-14 December 1990.

Stratton, G. E. and D. C. Lowrie. 1984. Courtship behavior and life cycle of the wolf spider *Schizocosa mccooki* (Araneae, Lycosidae). Journal of Arachnology 12: 223-228

Stewart, J. G., and M. K. Sears. 1988. Economic threshold for three species of lepidoptera larvae attacking cauliflower grown in southern Ontario. Journal Economic Entomology 81: 1726-1731.

Sunderland, K. D. 1999. Mechanisms underlying the effects of spiders on pest populations. Journal of Arachnology 27: 308-316.

Tabashnik, B. E., N. L. Cushing, and M. W. Johnson. 1987. Diamondback moth (Lepidoptera: Plutellidae) resistance to insecticides in Hawaii: intra island variation and cross-resistance. Journal of Economic Entomology 80: 1091-99.

Talekar, N. S., and S. T. Lee. 1985. Seasonality of insect pests of Chinese cabbage and common cabbage in Taiwan. Plant Protection Bulletin 27: 47-52.

Talekar, N. S., S. T. Lee and S. W. Huang. 1986. Intercropping and modification of irrigation method for the control of diamondback moth. *In* Proceedings of the 1st International Workshop on Management of Diamondback Moth, pp 145-151. Asian Vegetable Research and Development Center. Shanhua, Taiwan.

Tarsitano, M. S., and R. Andrew. 1999. Scanning and route selection of the jumping spider *Portia labiata*. Animal Behavior 58: 255-265.

Theobald, F. V. 1926. The diamondback moth *(Plutella maculipennis)*. Journal of Kent Farmers Union 20: 1-7

Thomas, C. F. G., and P. C. Jepson. 1997. Field-scale effects of farming practices on linyphiid spider populations in grass and cereals. Entomologia Experimentalis et Applicata 84:59–69.

Thomas, D. B., and R. L. Mangan. 2005. Nontarget impact of spinosad GF-120 bait sprays for control of the Mexican fruit fly (Diptera: Tephritidae) in Texas citrus. Journal of Economic Entomology 98: 1950-1956

Thompson, G. D., H. H. Michel, R. C. Yao, J. S. Mynderse, C. T. Mosburg, T. V. Wordsen, E. H. Chio, T. C. Sparks, and S. H. Hutchins. 1997. The discovery of *Saccharopolyspora spinosa* and a new class of insect control products. Down to Earth 52: 1-5.

Tillman, P. G., and J. E. Mulrooney. 2000. Effect of selected insecticides on the natural enemies *Coleomegilla maculata* and *Hippodamia convergens* (Coleoptera: Coccinellidae), *Geocoris punctipes* (Hemiptera: Lygaeidae), *Bracon mellitor*, *Cardiochiles nigriceps,* and *Cotesia marginiventris* (Hymenoptera: Braconidae) in cotton. Journal of Economic Entomology 93: 1638-1643.

Tiwari, K. N., Singh A., and P. K. Mal. 2003. Effect of drip irrigation on yield of cabbage (*Brassica oleracea* L. var. *capitata*) under mulch and non-mulch conditions. Agricultural Water Management 58: 19-28.

Toba, H. H, A. N. Kishaba, R. Pangaldan, and P. V Vail. 1973. Temperature and the development of the cabbage looper. Annals of the Entomological Society of America 66: 965-974.

Topping, C. J., and K. D. Sunderland. 1992. Limitations to the use of pitfall traps in ecological studies exemplified by a study of spiders in a field of winter wheat. Journal of Applied Ecology 29:485–491.

Topping, C. J., and K. D. Sunderland. 1998. Population dynamics and dispersal of *Lepthyphantes tenuis* in an ephemeral habitat. Entomologia Experimentalis et Applicata 87:29–41.

Ubick, D., P. Pierre Paquin, P. E. Cushing, and V. Roth (eds.). 2005. Spiders of North America: an identification manual. American Arachnological Society 377 pp.

U. S. Department of Agriculture. 2006. USDA-NASS**.** Vegetables 2005 Summary. Available at <www.nass.usda.gov>.

U. S. Department of Agriculture, Agricultural Research Service. 2005. USDA National Nutrient Database for Standard Reference, Release 18. Nutrient Data Laboratory Home Page, <http://www.nal.usda.gov/fnic/foodcomp>.

Vanderkerkhove, B. and P. De Clercq. 2004. Effects of an encapsulated formulation of lambda-cyhalothrin on *Nezera viridula* and its predator *Podisus maculiventris* (Heteroptera: Pentatomidae). Florida Entomologist 87: 112-118.

Voorrips, L. E., R. A. Goldbohm, G. van Poppel, F. Sturmans, R. J. Hermus, and P. A. van den Brandt. 2000. Vegetable and fruit consumption and risks of colon and rectal cancer in a prospective cohort study. American Journal of Epidemiology 152: 1081-92.

Ware, G. W., and D. M. Whitacre. 2004. An Introduction to Insecticides, 4th Ed. MeisterPro Information Resources, Willoughby, OH.

Williams, T., J. Valle, and E. Vinuela. 2003. Is the naturally derived insecticide spinosad compatible with insect natural enemies? Biocontrol Science and Technology 13: 459-475.

Wise, D. H. 1993. Spiders in Ecological Webs. Cambridge Univ. Press, London.

Wissinger, S. 1997. Cyclic colonization in predictably ephemeral habitats: a template for biological control in annual crop systems. Biological Control 10:4–15.

Work, T. T., C. M. Buddle, L. M. Korinus, and J. R. Spence. 2002. Pitfall trap size and capture of three taxa of litter-dwelling arthropods: implications for biodiversity studies. Community and Ecosystem Ecology 31:438–448.

Workman, R. B., R. B. Chalfant, and D. J. Schuster. 1980. Management of the cabbage looper and diamondback moth on cabbage by using two damage thresholds and five insecticide treatments. Journal of Economic Entomology 73: 757-758.

Young, O., and G. Edwards. 1990. Spiders in United States field crops and their potential effect on crop pests. Journal of Arachnology 18:1–27.

APPENDIX A

Descriptions of geographic regions in Texas

The Lower Rio Grande Valley. Major vegetable region in the state; includes the four southern most counties. Alluvial soils along the Rio Grande River, subtropical environment with 340 frost-free days, irrigation water from canals or wells along the river. A wide diversity of crops for fresh and processing markets, including citrus and early season vegetables for early market windows and agronomic crops of cotton and grains.

Winter Garden and South/Central. Includes the Winter Garden and Uvalde area, an intensive irrigated region west and south of San Antonio and the Hill Country. Extends northward to Abilene and southward to the Lower Rio Grande Valley. Diversified dryland and irrigated crop production (Edwards Aquifer) inter-dispersed in the vast rangeland and beef production areas.

Plains Region. Includes northern Panhandle (Amarillo, north to Oklahoma) and South Plains (Lubbock, south to Big Spring), with vast dryland and center pivot irrigation production (Ogallala Aquifer). Clay soils to the north and generally sandy soils to south and east. Includes eastward Rolling Plains along the Red River to I-35 and south to I-20 and Abilene, with dryland production and with some pockets of irrigation. Region varies from 2,000 to 4,600 feet elevation; 26 inches of rain on the east to 16 inches on west at the NM border and growing seasons from 160 to 240 days. Grains, cotton, and oil seed crops predominate but major acreages of horticultural crops.

Eastern Areas. Includes East Texas; typified by sandy soils, small farms and family operations with intensive crop production and numerous cow-calf/pasture operations. Bordered by I-35 on west and OK and LA on north and east and extends southward to Beaumont and Upper Gulf Coast, south to Houston, Corpus Christi, and Coastal Bend region. Good seasonal rains but irrigation is common. Humid summers, long growing season, and close proximity to rural roadside and major metro markets.

Far West Texas. Includes Trans Pecos region (Del Rio, north on US 277) and west to El Paso, with arid lands in the upper Chihuahuan Desert and Desert Grasslands; sparse rainfall (10 inches or less) but intensive crop production where irrigation water is available from the Rio Grande and Pecos Rivers. Crops include cotton, grains, and intensive vegetable and other horticultural crops on alluvial soils in a high desert environment. Production systems are similar to those in NM and AZ.

APPENDIX B

Brassica/Cole Crops

Brassica/cole crops (Crop Group 5) includes cabbage, crucifer greens, collards, kale and mustard greens. Asterisks indicate representative crops for the Group.

Descriptions of cole crops

Bok Choy. A specialized loose-leaf Chinese mustard, seeded or transplanted; produces thick stalk-like leaves. Produced as a fresh market crop in small family-managed plots around metro areas and Texas Gulf Coast areas for ethnic markets. Pest problems similar to those of cabbage.

Broccoli. Transplanted and direct-seeded production. Broccoli is grown in the LRGV and WG for fresh market sales and local metro use. Once a major crop in Texas, acreage peaked in the 1980's due to imports from earlier cheaper production in Mexico. Contains powerful antioxidants that are helpful in dietary health. Insect pests include aphids, cabbage looper, beet armyworm, cutworm, diamondback moth, and mites. Weeds include winter annual broadleaf species. Diseases include Alternaria leaf spot, anthracnose, blackleg leaf spot, damping off, downy and powdery mildews, black rot. Broccoli flower is grown on 60 to 80 acres.

Cabbage. An important crop in Texas, cabbage is easy to grow, yields well (commonly 25,000 lbs/acre) and marketed in 50 pound bags.

Some growers direct-seed plant 2 to 10 acres every two weeks to hit some market window; some plantings are abandoned if prices are low. LRGV plants from September to February, WG plants fall and spring, and East Texas plants for roadside markets. 95% are green cabbage and 5% red and savoy types. Insect pests include Harlequin bug, thrips, mites, white flies, loopers, aphids, diamondback moth, flea beetles, and imported cabbageworm. Weeds include nutsedge, mustards and other winter annual weeds. Diseases include *Alternaria panax* (Alternaria leaf spot), *Sclerotinia borealis* (Sclerotinia), *Xanthomonas campestris campestris* (black rot), *Leptosphaeria maculans* (blackleg), *Fusarium*, *Pythium* spp., *Rhizoctonia* spp., *Peronospora parasitica* and *Sphaerotheca pannosa* (downy and powdery mildews), and *Meloidogyne incognita* (root knot nematode).

Chinese cabbage. A tight head-cabbage, produced mostly for Asian markets in Gulf Coast area. Production and markets similar to bok choy. Pests are similar to those of cabbage.

Cauliflower. Production is mostly in the LRGV and some production around metro areas for local fresh market sales. Also, common backyard or roadside market crop in East Texas. Pests similar to those of broccoli and cabbage.

Collards. Commonly produced on four acres or less. Some 20-acre blocks are grown for frozen food processors. Grows like a non-heading cabbage. A high tonnage crop with repeated harvests from September to June from one planting. Commercial production in the LRGV and WG; small plots in East Texas for roadside and local markets. Insect pests include white flies, Harlequin bug, cabbage looper, diamondback moth, leaf hoppers, leaf miners, mites, and armyworms. Weeds include winter annual broadleaf weeds. Diseases include *Alternaria* leaf spot, *Cercospora*, damping off, downy and powdery mildew, *Sclerotinia*, and white rust.

Kale. Commercially produced in LRGV and WG for processing (some estimates are less than 200 acres). Planted in fall; whole plants are harvested through winter and early spring. Also grown in small plots (<2 acres) in East Texas for fresh market, potherb, salad, and home use. Insect pests include aphids, armyworms, cabbage loopers, diamondback moth, and white fly. Winter annual weeds include mustard and diseases like damping off, downy and powdery mildews, Sclerotinia and white rust.

Kohlrabi. Seeded in fall in small plots for roadside sales. Grown for turnip-like root; has a turnip flavor. A cabbage relative with both green and purple types. Leaves are used in salads or steamed before eating. Pests include cabbage loopers and others similar to those in turnip and cabbage. Diseases include leaf spot, blackleg, downy mildew, and white rust.

Mustard greens. Production from the Lower Valley and Winter Garden is processed, with nominal amount for fresh markets. East Texas production is in small plots for fresh roadside markets and truck farms. Numerous foliar insect pests include cabbage loopers, Harlequin bug, and cabbageworm. Condiment “mustard” is the ground seed of another species. Weeds are mostly winter annuals such as London rocket, and others. Diseases include *Alternaria* leaf spot and *Cercospora* leaf spot.

Table 13. Statewide production of Cole crops.

Statewide Production				Acreage by Production Region				
Crop	**Acres**	**$ Value/ Acre**	**Total Value ($x1000)**	**Lower Valley**	**Winter Garden**	**Plains Region**	**Far West Texas**	**Eastern Areas**
Bok choy	280	$2,300	$644	50	50	0	0	180
Broccoli*	670	$3,800	$2,546	100	200	100	0	270
Cabbage*	8,330	$4,100	$34,153	3,800	1,700	1,500	600	730
Cauliflower*	350	$2,800	$980	100	100	0	0	150
Chinese cabbage	630	$3,500	$2,205	150	80	0	0	400
Collards	1,200	$1,000	$1,200	500	300	100	0	300
Kale	1,100	$3,200	$3,520	500	300	100	0	200
Kohlrabi	400	$3,200	$1,280	300	100	0	0	0
Mustard greens*	2,700	$1,200	$3,420	1,800	300	0	0	600
Totals	**15,660**	**$3,190**	**$49,948**	**7,300**	**3,130**	**1,800**	**600**	**2,830**

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