The Impact of Intercropping Squash with Non-Crop Vegetation Borders on the Above-Ground Arthropod Community

Authors: HansPetersen, Heidi N., McSorley, Robert, and Liburd, Oscar E.

Source: Florida Entomologist, 93(4) : 590-608

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.093.0418

THE IMPACT OF INTERCROPPING SQUASH WITH NON-CROP VEGETATION BORDERS ON THE ABOVE-GROUND ARTHROPOD COMMUNITY

HEIDI N. HANSPETERSEN, ROBERT MCSORLEY AND OSCAR E. LIBURD
Dept. Entomology and Nematology, University of Florida, Gainesville, FL 32611-0620

ABSTRACT

The influence of intercropping strips of non-crop vegetation on the above-ground arthropod community was assessed, including natural enemy populations and interference with pest colonization in an adjacent yellow squash crop (*Cucurbita pepo* L.). Four non-crop border treatments were evaluated including: sorghum × sudangrass hybrid (*Sorghum bicolor* (L.) Moench × *S. sudanense* (Piper) Stapf); pigeon pea, (*Cajanus cajan* (L.) (Millsp.); the native weed complex; and a bare ground control. Border treatments were established on both sides of experimental plots containing 'Early Crookneck' squash. Sticky cards, pitfall traps, pan traps, and *in situ* counts were used to assess differences in the arthropod community within each of the border treatments and the adjacent squash crop. Natural enemies were most abundant in the native weed complex and pigeon pea borders; however, the spill-over of natural enemies into the neighboring crop was only observed in 2008, when predatory Coleoptera were most abundant in both the sorghum-sudangrass treatment and adjacent squash. Border crops did not influence the movement of thrips and whiteflies; however, *in situ* aphid counts were lower on squash bordered by sorghum-sudangrass than in the control. Flea beetles (*Altica* spp.) were consistently most abundant in the bare ground border, but many arthropod groups were unaffected by the treatments. None of the border treatments could prevent a heavy infestation of melonworm (*Diaphania hyalinata* L.), which defoliated and killed many of the squash plants.

Key Words: field borders, habitat management, landscape ecology, natural enemies, polyculture, agroecosystem

RESUMEN

Se evaluó la influencia de mantener franjas de vegetación limpias del cultivo en las orillas del cultivo sobre la comunidad de los artrópodos que viven sobre la tierra, incluyendo poblaciones de enemigos naturales y la interferencia con la colonización de la plaga con un cultivo de ayote amarillo (*Cucurbita pepo* L.) sembrado a la par. Cuatro tratamientos de plantas diferentes al cultivo sembrados en la orilla del campo fueron evaluados incluyendo: un híbrido de sorgo × pasto de sudan (*Sorghum bicolor* (L.) Moench × *S. sudanense* (Piper) Stapf); gandulas, (*Cajanus cajan* (L.) (Millsp.); el complejo de malezas nativas; y terreno sin vegetación (el control). Los tratamientos de las orillas fueron establecidos en ambos lados de las parcelas experimentales de ayote de la variedad 'early crookneck'. Se usaron tarjetas pegajosas, trampas de caída, trampas bandejas y conteos *in situ* para evaluar las diferencias en la comunidad de los artrópodos entre cada tratamiento de orilla y el campo cercano de ayote. Los enemigos naturales fueron mas abundantes en las orillas con el complejo de maleza nativa y gandulas; sin embargo, el derrame de los enemigos naturales en las orillas al cultivo vecino solamente fue observado en 2008, cuando los depredadores del orden Coleóptera fueron mas abundantes en los tratamientos de sorgo-pasto de sudan y en el campo cercano de ayote. Los cultivos de la orilla no influenciaron el movimiento de los trips o de mosca blanca; sin embargo, los conteos de afidos hechos *in situ* fueron más bajos en campos de ayote con orillas de sorgo-pasto de sudan que en el control. Escarabajos pulgas (*Altica* spp.) fueron consistemente mas abundantes en la orillas sin vegetación, pero muchos grupos de artrópodos no fueron afectados por los tratamientos. Ninguno de los tratamientos de las orillas del campo pudo prevenir la infestación alta del gusano de melón, (*Diaphania hyalinata* L.), que deshojó y mató muchas de las plantas de ayote.

The establishment of favorable habitat within the agroecosystem can promote the survival, reproduction, dispersal and ultimately the regulatory activities of natural enemies (Landis et al. 2000; Flint & Gouveia 2001). Their success depends in part on the timely availability of food resources, adequate shelter, and alternative prey or hosts (Wilkinson & Landis 2005). The development and maintenance of an "ecological infrastructure" (Landis et al. 2000) that provides such requisites is the basis of habitat management, a form of conservation biological control that seeks to preserve and enhance existing natural enemy populations by altering the agricultural landscape (Gurr et al. 2000; Landis et al. 2000). Since many predators and parasitoids rely on plant-provided nutrition (Wilkinson & Landis 2005), habitat management often involves increasing vegetational diversity. Non-crop vegetation has enhanced populations of natural enemies in several agricultural ecosystems (Landis et al. 2005; Altieri & Nichols 2004a; Denys & Tscharntke 2002; Norris & Kogan 2000; Andow 1991; Van Emden 1965).

Diversification can occur spatially, temporally, and across multiple layers within the agroecosystem (Landis et al. 2000). On a landscape level this may involve the conservation of nearby non-crop habitats (Tscharnkte et al. 2007), while at the farm-level, hedgerows, adjacent fields, and boundaries can be managed to enhance diversity. Within a crop, diversification can be increased through various intercropping strategies or manipulating weed populations (Altieri & Letourneau 1982).

Conventional agricultural systems are typically characterized by uniform plantings of a single crop species. For specialist herbivores, monocropping provides a concentrated supply of food, shelter, oviposition sites, and potential mates (Root 1973; Altieri & Letourneau 1982) that together can create optimal conditions for a pest outbreak (Altieri & Nichols 2004a, 2004b; Altieri & Letourneau 1982). Diversified cropping systems, more common among subsistence farmers in developing countries, reduce the concentration of these requisites such that the agricultural landscape becomes less favorable to pest invasion (Root 1973; Altieri & Letourneau 1982). Such opportunities for diversification may be more limited in mechanized agricultural systems that require planting in rows. However, even in these systems, integration of non-crop vegetation into the agricultural landscape could be accomplished as long strips or rows. Rows of non-crop vegetation can provide several ecosystem services, impact arthropod population dynamics (Nentwig 1988), and may also be responsible for a reduction in pest outbreaks (Altieri & Nichols 2004b; Pimentel 1961). The potential mechanisms behind these phenomena have been extensively reviewed (Hooks & Johnson 2003; Smith & McSorley 2000; Andow 1991; Russell 1989; Sheehan 1986).

Intercropping provides vegetational camouflage that may confound insect visual orientation to a host-plant and provides a range of chemical volatiles that can interfere with olfactory-driven host-finding mechanisms (Smith & McSorley 2000). Additional plant architecture and surfaces may physically disrupt the dispersal of weak-flying arthropods by functioning as barrier (Compton 2002; Lewis 1969). The establishment of a border crop as a protective barrier around squash reduced aphid-vectored plant viruses (Murphy et al. 2008; Damicone et al. 2006; Fereres 2000).

Integrating rows of non-crop vegetation into the agricultural landscape may influence arthropod populations in adjacent crops (Landis et al. 2000; Showler & Greenberg 2003). When grassy corridors were interplanted within soybean fields, the distribution of colonizing potato leaf-hoppers, *Empoasca fabae* (Harris), was disrupted such that yields in intercropped plots were within 2% of those in insecticide-treated plots lacking corridors (Kemp & Barrett 1989). Weedy strips incorporated into cotton reduced pest pressure and increased natural enemy populations (Showler & Greenberg 2003). Similarly, augmenting vegetable production systems with insectary hedgerows consisting of a strip of flowering plants (Pascual-Villalobos et al. 2006) or weeds (Bugg et al. 1987) increased natural enemy activity in neighboring vegetable crops.

In the current study, we examine the influence of 4 different border treatments on the aboveground arthropod community in a diverse agricultural system. The borders consisted of plants or fallow treatments arranged in rows on either side of a vegetable crop. The objectives were to determine whether border crops function as barriers to or colonization sites for pests and natural enemies, to assess the arthropod groups associated with each border treatment, and to evaluate the effect of border crop composition on the arthropod populations in an adjacent squash (*Cucurbita pepo* L.) crop.

Materials and Methods

Field Management and Experimental Design

Field experiments were conducted during the fall growing seasons in 2007 and 2008 at the University of Florida Plant Science Research and Education Unit (PSREU) (29°24'N, 82°9'W) located in Citra, FL. The soil in the site is classified as Arredondo sand (95% sand, 2% silt, 3% clay) (Thomas et al. 1979) with 1.5% organic matter. Prior to establishing the experiment and between growing seasons, fields were maintained in weedy fallow. In May of 2007, Fusilade® (Syngenta Crop Protection, Inc., Greensboro, NC) was applied over the experimental area to control annual and perennial grasses and encourage the establishment of broadleaf weeds that may provide resources for insect herbivores and natural enemies.

Four treatments bordering a cultivated squash crop were assessed: pigeon pea (*Cajanus cajan* [L.] Millsp.), 'Vegetable'; Sorghum-sudangrass × sudangrass hybrid (*Sorghum bicolor* Moench × *S. sudanense* Piper Stapf), 'growers' choice,' the native weed complex, and a bare ground control. Border treatments were established during the summer (5 Jul 2007 and 9 Jun 2008) prior to planting squash to ensure that border plants would be taller than the crop at the time of transplanting. Pigeon pea was hand-seeded 0.3 m apart in four rows with 0.6 m spacing. The sorghum-sudangrass hybrid was drilled mechanically (Sukup Manufacturing Company, Sheffield, IA) at 27 kg/ha. The native weed complex was permitted to grow undisturbed during the growing season. The composition of weed treatment plot was evaluated by sampling weeds from two 0.5 m^2 quadrats one week prior to planting squash. Weeds were categorized as broadleaf weeds, grasses or sedges, and identified at the genus and species level when possible. The above-ground biomass was calculated by cutting weeds at the ground level, and drying it at 70°C for 5 days. Some weeds grew among the pigeon pea plants; therefore weed biomass was calculated for the pigeon pea treatment using the described procedure at the end of the season. The bare ground treatment was maintained manually using a push rototiller (Pro-line FRT Garden Tiller, Troy-Bilt Products, Cleveland, OH) and hand-weeding.

Plots were 8 m × 7.2 m with 3-m spacing between plots and arranged in a randomized complete block design with 4 replications. Experimental blocks were separated by a 3-m-wide strip of undisturbed perennial weed reservoir running the entire length of the block. These uncultivated strips comprised primarily (<80% by biomass) the following broadleaf weeds: Florida pusley (*Richardia scabra* L.), horseweed (*Conyza canadensis* (L.) (Cronquist), cutleaf evening primrose (*Oenothera laciniata* Hill), Mexican tea *(Chenopodium ambrosioides* L.*),* and *Sida* sp. All rows were orientated east to west to reduce the effects of shading on squash by border plants. Border treatments measuring 8 m × 1.8 m bordered both sides of the plot with a 4.3-m × 3.6-m squash planting centered in between. Three rows of the yellow squash cultivar 'Early Crookneck' with 0.9-m spacing were hand-transplanted (18 Sep 2007 and 14 Oct 2008) into the various plots. The 3-week-old transplants were placed 0.4 m apart, resulting in a density of 36 plants per plot. All weeding was done manually and squash plants were fertilized (16.8 kg N/ha) with drip tape. Space between plots was cultivated manually with a push rototiller. Height and plant stand (plants/m) of border crops were measured at the time of squash transplanting and approximately one month later. A section of the border (1 m) was selected on each side of the plot, the number of plants per meter were counted and averaged together as plant stand for pigeon pea and sorghum-sudangrass. The number of squash plants per plot was assessed and percent defoliation due to insect injury was calculated weekly based on the following scale, <25%, 25-50%, 51-99% defoliated, or missing.

Arthropod Sampling

Arthropod communities were sampled within both the border treatments and squash planting using 3 sampling techniques: sticky card traps, pitfall traps, and pan traps. Traps were set in the morning before noon and left in the field for 24 h; the day of collection was recorded as the sampling date. Taxa collected in traps were identified to family level or guild and counted.

A yellow, unbaited, Pherocon AM trap (Great Lakes IPM, Vestaburg, MI) was placed 5 cm above the ground between squash rows and within 1 border in each plot. Traps were set biweekly during both the 2007 and 2008 growing seasons beginning the week of transplanting. Collected sticky cards were wrapped in plastic food wrap (Stretch-tite®, Polyvinyl Films Inc., Sutton, MA) and stored at 4°C. Insects trapped within the grid (23 cm × 18 cm) on the sticky card were counted and recorded. A representative sample of the whiteflies and thrips on each card was counted with the aid of an exclusionary grid that allows one to systematically view roughly 25% of the total area of each card (Liburd et al. 2009).

Plastic sandwich containers (14 cm × 14 cm × 4 cm, 532 mL) were used as pitfall traps (Triplehorn & Johnson 2005) and buried so that the upper edge was flush with soil surface. The traps were filled three quarters (ca. 300 mL) with water, along with 3 to 4 drops of dish detergent (Ultra Joy®, Procter & Gamble, Cincinnati, OH) to break the surface tension and prevent the escape of insects. Two pitfall traps, 1in the border and 1 between rows of squash, were set in each plot every 3 weeks beginning the week of transplanting.

Clear polyethylene deli containers (11 cm in diameter × 4.5 cm deep; 236 mL) (Gainesville Paper Company, Gainesville, FL) were used as pan traps. Traps were placed at mid-plant height between squash rows and at the same height in one of the borders, and filled half way with water (ca. 175 mL) along with 2 to 3 drops of dish detergent (Southwood & Henderson 2000). Pan traps were set biweekly throughout the growing season beginning the first week after transplanting.

Whole plant visual (*in situ*) counts were performed weekly throughout the growing seasons by systematically selecting four plants from each plot. All of the leaves were examined and arthropods were identified to order or family in the field, and counted. Key pests were identified to genus and species, when present.

Statistical Analyses

Arthropods collected in traps were identified to order and at the family level. In many cases, orders represented by only a few individuals in several families were grouped together by order or feeding guild for statistical analysis. Commonly occurring arthropod groups and 1 particularly frequent genus were analyzed. Data for all members of the entire arthropod community were reported for each of the sampling methods. However, pitfall trapping targets organisms found at the soil surface, while pan trap and stickycards are typically used to sample flying insects (Southwood & Henderson 2000).

Data from arthropod counts were analyzed by repeated measures analysis of variance (ANOVA) by the GLM procedure (SAS Institute 2008). Means were separated with the least significant difference (LSD) test at $P \leq 0.10$ (SAS Institute 2008). Pitfall trap data for Formicidae were log transformed by $\log_{10}(x+1)$ prior to analysis to meet assumptions of ANOVA, but untransformed means are reported.

Results

Border Composition

At the time of transplanting, heights of plants in borders were measured and plant density was established. Height and plant stand of border treatments are shown in Table 1. The total rainfall at the Citra research station during the first 3 weeks of border treatment establishment was 3.3 cm (FAWN 2009). Some of the sorghum-sudangrass and pigeon peas succumbed to drought conditions resulting in a somewhat lower plant density than expected. During the 2008 growing season, the total rainfall during the 3-week period after planting was 17.9 cm (FAWN 2009) which led to more densely established pigeon pea and sorghum-sudangrass. An understory of low-growing weeds dominated by Florida pusley (*R. scabra)*, crowfootgrass (*Dactyloctenium aegyptium* (L.) (Willd.), Bermudagrass (*Cyndon dactylon* L.), crabgrass (*Digitaria* spp.), and sedges grew in the pigeon pea treatment during both seasons.

The native weed complex was composed of a mixture of broadleaf weeds, grasses, and sedges. During 2007, the native weed complex was nearly 60% (biomass) grasses, namely barnyardgrass (*Echinochloa crus-galli* (L.) (P. Beauv.) and crabgrass (*Digitaria* spp.). Broadleaf weeds, primarily Florida pusley (*R. scabra*) and hairy indigo (*Indigofera hirsuta* L.) comprised about 30% of the native weed complex, while the remainder were sedges (*Cyperus* spp.). Broadleaf weeds dominated more than 50% of the native weed complex during the 2008 growing season, while grasses comprised 33%, and sedges the remaining 16%.

Arthropod Sampling

Border-2007

Most differences within the border treatments were detected with sticky cards (Tables 2 and 3). Total natural enemies including, predatory Diptera, Coleoptera, Hemiptera, Hymenoptera (parasitoids), and Aranae, were higher on sticky cards and in pitfall traps in the native weed complex and pigeon pea treatments when compared to sorghum-sudangrass (Table 2). Although the total natural enemies were lower ($P = 0.0351$) on sticky cards placed in sorghum-sudangrass, predatory Coleoptera, which included primarily the family Coccinellidae followed by Staphylinidae, Carabidae, Mordellidae, and Cantharidae were more abundant ($P = 0.0166$) in sorghum-sudangrass than in any other treatment. Dolichopodidae were found in lowest numbers in the sorghum-sudangrass treatment on sticky cards as well. Microhymenoptera were most abundant ($P = 0.0119$) in the pigeon pea and weeds on sticky cards and in weeds in pitfall traps. The most ($P = 0.0001$) spiders were trapped on sticky cards in the bare ground control.

Among insect pests captured on sticky cards, Orthoptera (grasshoppers and crickets) were

Table 1. Border treatment mean height and plant stand (±SE) 1 week prior to transplanting and one month after transplanting.

Treatment	Pre-transplant Height (cm)	Pre-transplant Stand (plants/m)	Post-transplant Height (cm)	Post-transplant Stand (plants/m)
2007				
Bare ground	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Pigeonpea	80.94 ± 7.87	4.81 ± 0.81	98.81 ± 7.82	4.88 ± 0.97
Sorghum	114.19 ± 10.32	48.25 ± 5.15	115.19 ± 5.06	50.75 ± 2.47
Weeds	44.81 ± 4.85		41.88 ± 5.11	
2008				
Bare ground	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Pigeonpea	87.38 ± 4.69	5.88 ± 0.62	79.75 ± 10.25	4.50 ± 0.35
Sorghum	116.06 ± 3.85	62.88 ± 3.62	91.31 ± 3.32	61.63 ± 5.22
Weeds	42.00 ± 2.83			30.63 ± 4.51

TABLE 2. SELECTED BENEFICIAL ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN BORDER TREATMENTS, 2007.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	*F*	*P*
Coleoptera Predatory[2]	Sticky	1.00 ± 0.33 b	0.67 ± 0.26 b	3.00 ± 1.06 a	0.50 ± 0.29 b	3.83	0.0166
	Pitfall	1.00 ± 0.30	1.33 ± 0.47	0.42 ± 0.19	1.83 ± 0.75	1.50	0.2290
Diptera Dolichopodidae	Sticky	5.58 ± 1.21 a	5.67 ± 0.97 a	0.83 ± 0.27 b	3.58 ± 0.91 a	6.21	0.0014
	Pan	0.33 ± 0.19	0.83 ± 0.42	0.00 ± 0.00	0.58 ± 0.26	1.71	0.1805
	Pitfall	2.42 ± 0.69	2.83 ± 1.02	0.58 ± 0.29	2.50 ± 0.92	1.60	0.2051
Hymenoptera Formicidae	Sticky	0.25 ± 0.13	0.50 ± 0.26	0.92 ± 0.43	0.42 ± 0.19	1.02	0.3943
	Pan	0.17 ± 0.11 b	0.75 ± 0.31 b	2.50 ± 0.93 a	0.25 ± 0.18 b	2.62	0.0303
	Pitfall	27.18 ± 1.23	25.92 ± 1.38	25.92 ± 1.29	20.88 ± 1.38	0.15	0.9273
Microhymenoptera	Sticky	16.92 ± 2.38 b	29.25 ± 2.38 a	16.33 ± 3.46 b	30.92 ± 6.35 a	4.13	0.0119
	Pan	0.42 ± 0.15	0.33 ± 0.14	0.33 ± 0.14	0.50 ± 0.20	0.27	0.8481
	Pitfall	1.75 ± 0.72 b	2.17 ± 0.68 b	1.25 ± 0.43 b	4.42 ± 0.97 a	3.74	0.0183
Araneae	Sticky	1.58 ± 0.37 a	0.58 ± 0.26 b	0.00 ± 0.00 b	0.17 ± 0.11 b	9.93	0.0001
	Pan	0.08 ± 0.08	0.08 ± 0.08	0.25 ± 0.13	0.08 ± 0.08	0.75	0.5312
	Pitfall	1.08 ± 0.31	1.08 ± 0.31	1.17 ± 0.34	2.08 ± 0.75	1.01	0.3981
Total natural enemies[3]	Sticky	25.75 ± 2.82 ab	37.42 ± 4.03 a	22.00 ± 3.70 b	36.08 ± 7.27 a	3.15	0.0351
	Pan	1.00 ± 0.28	2.25 ± 0.51	3.08 ± 1.04	1.58 ± 0.53	1.80	0.1615
	Pitfall	6.75 ± 1.04 bc	8.25 ± 1.36 ab	3.92 ± 0.58 c	11.67 ± 1.95 a	6.00	0.0017

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \le 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; *F* and *P* values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 41$); Pitfall traps ($df = 3, 41$).

[2]Coccinellidae, Staphylinidae, Carabidae, Cantharidae, and Mordellidae. Predatory Coleoptera were rarely observed in pan traps, and were included in Total natural enemies.

[3]Aranae, Formicidae, Mutillidae, microhymenoptera, macrohymenoptera, predatory Coleoptera, Diptera (Asilidae, Bombyliidae, Dolichopodidae and Syrphidae), and Hemiptera (*Geocoris* spp., Anthrocoridae, and Reduviidae).

TABLE 3. SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN BORDER TREATMENTS, 2007.

	Treatments					ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	*F*	*P*
Orthoptera	Sticky	0.08 ± 0.08 b	0.83 ± 0.27 a	0.00 ± 0.00 b	1.00 ± 0.35 a	5.00	0.0048
	Pan	0.17 ± 0.11	0.00 ± 0.00	0.25 ± 0.13	0.08 ± 0.08	1.24	0.3067
	Pitfall	1.33 ± 0.50	1.75 ± 0.37	3.00 ± 2.12	2.17 ± 0.60	0.39	0.7633
Hemiptera Aleyrodidae Aphididae							
	Sticky	8.33 ± 2.73 a	5.67 ± 1.97 ab	1.58 ± 1.23 b	3.33 ± 0.96 ab	2.51	0.0720
	Sticky	15.33 ± 3.82 ab	12.17 ± 2.74 bc	1.33 ± 0.41 c	25.75 ± 7.62 a	4.98	0.0049
	Pan	0.17 ± 0.11 b	0.42 ± 0.15 ab	0.92 ± 0.38 a	0.17 ± 0.11 b	2.49	0.0734
	Pitfall	0.17 ± 0.11	1.08 ± 0.43	0.83 ± 0.32	0.75 ± 0.35	1.32	0.2809
Auchenorrhyncha[2]	Sticky	9.03 ± 1.98 a	6.67 ± 1.39 ab	3.67 ± 0.50 b	8.25 ± 1.47 ab	3.22	0.0333
	Pan	0.25 ± 0.25 b	1.17 ± 0.49 ab	0.83 ± 0.24 b	4.08 ± 1.94 a	2.75	0.0551
	Pitfall	2.75 ± 0.63	3.75 ± 0.64	2.67 ± 0.91	4.58 ± 1.31	0.95	0.4270
Cicadellidae Membracidae Heteroptera[3]	Sticky	7.33 ± 1.48 a	3.83 ± 0.92 bc	3.58 ± 0.62 c	7.08 ± 0.14 ab	2.98	0.0425
	Sticky	1.00 ± 3.25 ab	1.67 ± 0.55 a	0.00 ± 0.00 b	0.75 ± 0.37 ab	3.50	0.0239
	Sticky	0.75 ± 0.43	0.33 ± 0.19	0.08 ± 0.08	0.25 ± 0.13	1.37	0.2649
	Pan	0.00 ± 0.00	0.08 ± 0.08	0.25 ± 0.18	0.25 ± 0.13	1.07	0.3725
	Pitfall	0.50 ± 0.23	0.50 ± 0.20	0.25 ± 0.18	0.92 ± 0.38	1.73	0.1763
Coleoptera *Altica* spp	Sticky	5.08 ± 2.06 a	0.08 ± 0.08 b	0.00 ± 0.00 b	0.00 ± 0.00 b	5.74	0.0022
	Pan	0.08 ± 0.08	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.00	0.4025
Non-predatory[4]	Sticky	1.08 ± 0.25	1.08 ± 0.29	0.75 ± 0.31	0.25 ± 0.13	1.96	0.1350
	Pan	0.17 ± 0.11	0.00 ± 0.00	0.17 ± 0.11	0.25 ± 0.13	1.08	0.3693
	Pitfall	083 ± 0.27	0.33 ± 0.19	0.17 ± 0.11	0.50 ± 36	1.35	0.2723
Lepidoptera	Sticky	0.33 ± 0.26	0.17 ± 0.11	0.50 ± 0.26	0.42 ± 0.26	0.41	0.7452
	Pan	0.25 ± 0.13	0.25 ± 0.18	0.17 ± 0.17	0.17 ± 0.11	0.10	0.9580

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; *F* and *P* values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 41$); Pitfall traps ($df = 3, 41$).

[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.

[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.

[4]Chrysomelidae, Elateridae, Tenebrionidae

[5]Primarily Thripidae that were rarely observed in pitfall traps.

TABLE 3. (CONTINUED) SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN BORDER TREATMENTS,

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	*F*	*P*
	Pitfall	0.25 ± 0.13	0.75 ± 0.28	0.75 ± 0.22	0.25 ± 0.13	2.12	0.1124
Diptera Microdiptera	Sticky	14.58 ± 4.90	9.08 ± 1.27	11.33 ± 3.26	7.83 ± 1.62	0.89	0.4543
	Pan	1.33 ± 0.36 b	1.67 ± 0.53 ab	0.83 ± 0.51 b	3.08 ± 0.97 a	2.79	0.0526
	Pitfall	0.67 ± 0.36	2.00 ± 0.60	1.42 ± 0.57	2.17 ± 0.74	1.41	0.2536
Thysanoptera[5]	Sticky	9.83 ± 2.23 a	3.67 ± 0.86 b	0.33 ± 0.19 b	4.25 ± 1.66 b	7.07	0.0006
	Pan	0.00 ± 0.00	0.17 ± 0.17	0.00 ± 0.00	0.00 ± 0.00	1.00	0.4025

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; *F* and *P* values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 41$); Pitfall traps ($df = 3, 41$).

[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.

[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.

[4]Chrysomelidae, Elateridae, Tenebrionidae

[5]Primarily Thripidae that were rarely observed in pitfall traps.

most abundant (P = 0.0048) in the native weed complex and pigeon pea (Table 3). Thysanoptera, mainly *Frankliniella* spp. (P = 0.0006) and flea beetles, *Altica* spp., (P = 0.0022) were detected in highest numbers in the bare ground control. Significant differences were not observed for any Hemiptera groups between the native weed complex and the control on sticky cards. However, when those treatments were compared to sorghum-sudangrass, fewer Aphididae (primarily *Aphis gossypii*) (Glover) (P = 0.0049), Cicadellidae (P = 0.0425), and Aleyrodidae (*Bemesia tabaci*) (Gennadius) (P = 0.0720) were found than in bare ground. Membracidae were more abundant (P = 0.0239) in pigeon pea than sorghum-sudangrass as well.

When pan traps were used for sampling, auchenorrhynchan activity was higher in the native weed complex than in sorghum-sudangrass and the control (Table 3). Micro-Diptera and total Diptera were more numerous in the weeds than in the sorghum-sudangrass as well. Aphididae were more abundant in pan traps placed in sorghum-sudangrass than in the control, opposite from the results observed with sticky cards. In pitfall trap captures, more non-predatory Coleoptera (primarily *Altica* spp. and Elateridae) were trapped in the bare ground control than in pigeon pea or sorghum-sudangrass (Table 3). Although several arthropods groups were impacted by field border treatments, no differences were observed for Lepidoptera or herbivorous Heteroptera using any of the sampling methods (Table 3).

Border-2008

Several of the trends observed in 2007 were repeated during 2008. The groups micro-Hymenoptera (P = 0.0152), Dolichopodidae (P = 0.0011), and total natural enemies (P = 0.0157) were most common on sticky cards placed in pigeon pea; however, most (P = 0.0119) of the spiders were trapped in the control on sticky cards or pan traps (Table 4). In pan traps, micro-Hymenoptera numbers were higher (P = 0.0275) in the native weed complex and sorghum-sudangrass than in the control. More total natural enemies were collected in pitfall traps in the native weed complex than the bare ground control, but no differences were observed with the other sampling methods.

During 2008, significantly more (P = 0.0055) auchenorrhynchans were captured on sticky cards and pan traps in the native weed complex and pigeon pea than the control (Table 5). The native weed complex had the most (P = 0.0211) cicadellid activity, while membracids were most abundant (P = 0.0004) in pigeon pea.

Crop-2007

Fewer differences in arthropods counts were observed among treatments when traps were set within the crop, and no differences were measured in pitfall trap captures during 2007 (Tables 6 and 7). The most spiders were trapped in squash bordered by sorghum-sudangrass with sticky cards or pan traps (Table 6), however, no other beneficial arthropods collected within the crop were impacted by the border treatment.

Auchenorrhynchans were more abundant on sticky cards in squash bordered by the native weed complex than by sorghum-sudangrass (Table 7). Additionally, *Altica* spp. were least abundant when sorghum-sudangrass and weeds bordered the squash. When *in situ* counts were performed, ants were more numerous (F = 3.09; df = 3, 41; P = 0.0376) on squash bordered by the bare ground (10.08 ± 2.67) treatment than on squash bordered by sorghum-sudangrass (4.08 ± 1.85) and weeds (3.33 ± 1.19). *In situ* counts also revealed melonworm (*Diaphania hyalinata* L.) and saltmarsh (*Estigemene acrea*) (Drury) caterpillars present on many plants. Their numbers were not affected by the border treatments, but melonworms, which were more common than saltmarsh caterpillars, averaged 5.89 ± 1.37 caterpillars per plant over the season, reaching a high of 15.15 ± 3.87 caterpillars per plant on 30 Oct. 2007. These numbers resulted in heavy defoliation and plant mortality with 97.06 ± 4.33% of the plants in each plot more than 50% defoliated. Therefore, yield data could not be collected.

Regardless of sampling method, several other groups were unaffected by the presence of border treatments including Lepidoptera, herbivorous Heteroptera, Coleoptera, and beneficial insects from families within Coleoptera, Diptera, Hymenoptera, and Hemiptera.

Crop-2008

In 2008, more predatory Coleoptera, mainly coccinellids, were trapped on yellow sticky cards in squash bordered by sorghum-sudangrass, than by pigeon pea or the bare ground control (P = 0.0555; Table 8). Cicadellids were more abundant in squash bordered by weeds than by pigeon pea or the control (Table 9). Pigeon pea bordered squash had more membracids than squash bordered by sorghum-sudangrass or the native weed complex (Table 9). In pitfall traps, total auchenorrhynchans were more numerous in squash bordered by weeds than by sorghum-sudangrass or bare ground. During *in situ* counts, auchenorrhynchans were only (F = 4.53; df = 3, 73; P = 0.0057) observed on squash bordered by the native weed complex (0.45 ± 0.21).

During *in situ* counts, the most (F = 4.97; df = 3, 73; P = 0.0034) aphids were observed on squash plants bordered by the bare ground control (112.65 ± 22.49 aphids per plant) compared to sorghum-sudangrass (60.35 ± 12.91), pigeon pea (44.95 ± 11.45), and the native weed complex

TABLE 4. SELECTED BENEFICIAL ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN BORDER TREATMENTS, 2008.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	*F*	*P*
Coleoptera Predatory[2]	Sticky	0.42 ± 0.19 b	0.25 ± 0.18 b	1.42 ± 0.48 a	0.42 ± 0.19 b	3.45	0.0251
	Pitfall	0.08 ± 0.08	0.42 ± 0.15	0.08 ± 0.08	0.17 ± 0.11	1.50	0.2290
Diptera Dolichopodidae	Sticky	1.25 ± 0.31 b	3.92 ± 0.50 a	0.92 ± 0.29 b	1.67 ± 0.80 b	6.49	0.0011
	Pan	0.25 ± 0.11	0.75 ± 0.31	0.38 ± 0.16	0.21 ± 0.10	2.04	0.1189
	Pitfall	0.33 ± 0.23 ab	0.17 ± 0.11 b	0.00 ± 0.00 b	0.83 ± 0.32 a	2.92	0.0453
Hymenoptera Formicidae	Sticky	0.25 ± 0.13 a	0.00 ± 0.00 b	0.00 ± 0.00 b	0.00 ± 0.00 b	3.80	0.0170
	Pan	0.19 ± 0.14	2.00 ± 0.70	0.25 ± 0.11	2.00 ± 1.74	1.16	0.3347
	Pitfall	11.91 ± 7.91 b	25.58 ± 5.30 ab	24.67 ± 8.07 ab	36.92 ± 9.64 a	2.25	0.0967
Microhymenoptera	Sticky	7.75 ± 1.01 b	14.00 ± 2.05 a	7.67 ± 1.29 b	9.42 ± 1.37 b	3.91	0.0152
	Pan	0.19 ± 0.10 b	0.56 ± 0.16 ab	1.31 ± 0.37 a	1.13 ± 0.39 a	3.27	0.0275
	Pitfall	1.00 ± 0.39	2.50 ± 0.44	2.08 ± 0.82	2.83 ± 0.60	1.75	0.1720
Araneae	Sticky	1.08 ± 0.38 a	0.17 ± 0.11 b	0.17 ± 0.11 b	0.25 ± 0.013 b	4.14	0.0119
	Pan	0.44 ± 0.16 a	0.19 ± 0.10 ab	0.06 ± 0.06 b	0.13 ± 0.09 b	2.26	0.0909
	Pitfall	0.33 ± 0.14	0.75 ± 0.21	1.08 ± 0.29	1.00 ± 0.30	1.81	0.1613
Total natural enemies[3]	Sticky	11.08 ± 1.48 b	18.58 ± 2.07 a	10.25 ± 1.63 b	12.08 ± 2.23 b	3.88	0.0157
	Pan	0.94 ± 0.23	1.75 ± 0.46	1.81 ± 0.42	1.60 ± 0.47	0.97	0.4154
	Pitfall	1.83 ± 0.65 b	4.25 ± 0.65 ab	3.42 ± 1.03 ab	5.17 ± 0.90 a	2.80	0.0520

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; F and P values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 57$); Pitfall traps ($df = 3, 41$).

[2]Coccinellidae, Staphylinidae, Carabidae, Cantharidae, and Mordellidae. Predatory Coleoptera were rarely observed in pan traps, and were included in Total natural enemies.

[3]Aranae, Formicidae, Mutillidae, microhymenoptera, macrohymenoptera, predatory Coleoptera, Diptera (Asilidae, Bombyliidae, Dolichopodidae and Syrphidae), and Hemiptera (*Geocoris* spp., Anthrocoridae, and Reduviidae).

TABLE 5. SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN BORDER TREATMENTS, 2008.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	*F*	*P*
Orthoptera	Sticky	0.17 ± 0.17	0.33 ± 0.26	0.00 ± 0.00	0.58 ± 0.26	1.46	0.2393
	Pan	0.06 ± 0.06	0.25 ± 0.11	0.19 ± 0.10	0.06 ± 0.06	1.12	0.3476
	Pitfall	1.08 ± 0.31	1.92 ± 0.63	1.00 ± 0.46	1.25 ± 0.39	0.91	0.4428
Hemiptera Aleyrodidae Aphididae	Sticky	5.00 ± 1.29 a	3.25 ± 0.93 ab	1.08 ± 0.68 b	2.41 ± 0.65 b	3.42	0.0258
	Sticky	11.58 ± 2.21	9.92 ± 2.97	6.25 ± 1.80	7.83 ± 2.65	0.87	0.4631
	Pan	0.44 ± 0.22 b	0.88 ± 0.29 ab	1.56 ± 0.34 a	0.77 ± 0.20 b	3.01	0.0374
	Pitfall	1.17 ± 0.60	2.08 ± 0.81	0.67 ± 0.36	3.50 ± 1.71	1.46	0.2402
Auchenorrhyncha[2]	Sticky	3.25 ± 0.91 b	7.92 ± 1.16 a	2.91 ± 0.83 b	7.83 ± 1.85 a	4.87	0.0055
	Pan	0.06 ± 0.06 b	1.06 ± 0.40 a	0.44 ± 0.22 ab	1.31 ± 0.47 a	2.89	0.0431
	Pitfall	1.50 ± 0.44	20.25 ± 16.32	1.00 ± 0.33	9.08 ± 4.61	1.12	0.3536
Cicadellidae Membracidae Heteroptera[3]	Sticky	1.75 ± 0.52 b	3.00 ± 0.82 b	2.92 ± 0.83 b	6.83 ± 1.95 a	3.61	0.0211
	Sticky	1.42 ± 0.81 b	4.50 ± 1.13 a	0.00 ± 0.00 b	0.67 ± 0.31 b	7.45	0.0004
	Sticky	0.17 ± 0.17	0.33 ± 0.26	0.00 ± 0.00	0.58 ± 0.26	1.46	0.2393
	Pan	0.13 ± 0.09	0.06 ± 0.06	0.06 ± 0.06	0.00 ± 0.00	0.73	0.5379
	Pitfall	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.17 ± 0.11	1.14	0.2455
Coleoptera *Altica* spp.	Sticky	0.67 ± 0.28 a	0.08 ± 0.08 b	0.00 ± 0.00 b	0.00 ± 0.00 b	4.62	0.0071
	Pan	0.06 ± 0.06	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.00	0.3995
Non-predatory[4]	Sticky	0.25 ± 0.13	0.08 ± 0.08	0.42 ± 0.19	0.08 ± 0.08	1.46	0.2397
	Pan	0.13 ± 0.09	0.00 ± 0.00	0.13 ± 0.09	0.06 ± 0.06	0.81	0.4918
	Pitfall	0.00 ± 0.00	0.25 ± 0.13	0.33 ± 0.26	0.25 ± 0.18	1.17	0.3390
Lepidoptera	Sticky	0.08 ± 0.08	0.17 ± 0.11	0.00 ± 0.00	0.42 ± 0.19	2.13	0.1117
	Pan	0.13 ± 0.09	0.13 ± 0.09	0.13 ± 0.09	0.29 ± 0.15	0.64	0.5949
	Pitfall	0.08 ± 0.08	0.17 ± 0.11	0.00 ± 0.00	0.00 ± 0.00	1.33	0.2776

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \le 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; F and P values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 57$); Pitfall traps ($df = 3, 41$).

[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.

[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.

[4]Chrysomelidae, Elateridae, Tenebrionidae

[5]Primarily Thripidae that were rarely observed in pitfall traps.

TABLE 5. (CONTINUED) SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN BORDER TREATMENTS, 2008.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	F	P
Diptera Microdiptera	Sticky	9.42 ± 1.31 b	14.92 ± 2.98 a	5.33 ± 1.26 b	9.75 ± 1.10 b	4.83	0.0057
	Pan	1.00 ± 0.35	1.94 ± 0.50	2.31 ± 0.62	2.90 ± 0.73	1.91	0.1381
	Pitfall	1.41 ± 0.26 b	4.92 ± 1.50 a	2.67 ± 0.64 ab	3.17 ± 0.92 ab	2.31	0.0900
Thysanoptera[5]	Sticky	2.08 ± 0.74 ab	1.75 ± 0.71 ab	0.25 ± 0.18 b	2.92 ± 0.87 a	2.56	0.0678
	Pan	0.25 ± 0.11	0.19 ± 0.10	0.00 ± 0.00	0.23 ± 0.14	1.36	0.2651

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.
[1]Analysis of variance; F and P values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 57$); Pitfall traps ($df = 3, 41$).
[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.
[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.
[4]Chrysomelidae, Elateridae, Tenebrionidae
[5]Primarily Thripidae that were rarely observed in pitfall traps.

(40.45 ± 8.28). However, aphid captures with sticky cards and pan traps did not differ. No differences were observed for any groups in pan trap captures during 2008. As in the previous season, melonworms and saltmarsh caterpillars were present, but did not differ among treatments. Melonworms were the dominant lepidopteran species averaging 2.56 ± 0.61 caterpillars per plant over the season. By 18 Nov, 45.13 ± 12.29% of the plants in each plot were more than 50% defoliated. The crop was further damaged by a freeze on 20 Nov when temperatures dropped to -1.81°C (FAWN 2009). This marked the end of the experiment and prevented yield data from being collected.

DISCUSSION

The border treatments in this study varied greatly in terms of the arthropods they hosted. The sorghum-sudangrass treatment was both the tallest and most densely planted border treatment. Based on height and planting density, sorghum-sudangrass had more green surface area to serve as habitat for arthropods. However, sorghum-sudangrass often had the lowest populations of pests and natural enemy species. Few differences were observed between the pigeon pea treatment and the native weed complex, which may have been due to the weedy understory that developed beneath the pigeon pea during both years. Some weed cover beneath pigeon pea is typical in this location where weeds emerge rapidly during the summer months.

This research provided data for several objectives. The first question we hoped to address was the impact of border treatments on the migration of ambient flying pests into the squash crop. The bare ground control provided an unobstructed highway between the perennial weed refugia and squash crops. Notably, more weak flying insects, including whiteflies (Basu 1995) and thrips (Lewis 1997), as well as spiders that rely on aerial drift for dispersal (Bonte et al. 2008) were trapped on sticky cards in the bare ground control than in the sorghum-sudangrass treatment. However, the border treatments ultimately had no impact on the movement of whiteflies, a key pest of squash in north Florida (Nyoike et al. 2008), or thrips into the squash crop. In experiments, conducted in Oklahoma, squash plants intercropped with sorghum (*Sorghum bicolor* (L.) Moench) had reduced incidence of aphid-borne viruses (Damicone et al. 2006), even though alate captures in modified pan traps were not different. No treatment differences in aphid captures by sticky cards and pan traps placed within the squash crop were observed in the current study. Fewer aphids were recorded on sticky cards in sorghum-sudangrass compared to the control and weedy fallow in 2007. In addition, fewer aphids

TABLE 6. SELECTED BENEFICIAL ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN SQUASH CROP, 2007.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Weeds	*F*	*P*
Coleoptera Predatory[2]	Sticky	1.33 ± 0.44	0.75 ± 0.33	1.17 ± 0.35	0.75 ± 0.22	0.84	0.4782
	Pitfall	1.17 ± 0.46	1.00 ± 0.30	1.75 ± 0.71	0.42 ± 0.29	0.59	0.6272
Diptera Dolichopodidae	Sticky	4.33 ± 0.92	3.50 ± 0.75	3.00 ± 0.83	3.25 ± 0.61	0.56	0.6413
	Pan	0.25 ± 0.18	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.91	0.1427
	Pitfall	3.25 ± 1.05	2.67 ± 0.48	1.83 ± 0.71	2.17 ± 0.59	0.74	0.5332
Hymenoptera Formicidae	Sticky	0.33 ± 0.14	0.33 ± 0.19	0.00 ± 0.00	0.33 ± 0.19	1.26	0.3002
	Pan	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.08	0.00 ± 0.00	1.00	0.4402
	Pitfall	3.37 ± 1.55	5.92 ± 1.26	4.50 ± 1.48	5.31 ± 1.35	0.31	0.8161
Microhymenoptera	Sticky	23.33 ± 4.47	17.50 ± 2.70	15.58 ± 2.64	17.50 ± 2.64	1.12	0.3522
	Pan	0.08 ± 0.08	0.33 ± 0.19	0.42 ± 0.19	0.17 ± 0.11	1.00	0.4004
	Pitfall	2.25 ± 0.64	2.08 ± 0.68	1.08 ± 0.29	3.58 ± 1.00	2.17	0.1066
Araneae	Sticky	0.83 ± 0.27 b	1.00 ± 0.41 b	2.08 ± 0.45 a	1.00 ± 0.30 b	2.34	0.0873
	Pan	0.25 ± 0.13 ab	0.08 ± 0.08 b	0.42 ± 0.15 a	0.00 ± 0.00 b	2.79	0.0525
	Pitfall	0.83 ± 0.27	1.00 ± 0.44	0.67 ± 0.19	0.67 ± 0.23	0.32	0.8085
Total natural enemies[3]	Sticky	31.17 ± 4.73	24.00 ± 3.51	22.42 ± 3.47	23.42 ± 3.09	1.17	0.3326
	Pan	0.67 ± 0.23	0.42 ± 0.26	0.92 ± 0.26	0.17 ± 0.11	2.03	0.1247
	Pitfall	8.25 ± 1.46	7.67 ± 0.98	6.75 ± 1.01	7.33 ± 1.19	0.31	0.8177

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; *F* and *P* values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 41$); Pitfall traps ($df = 3, 41$).

[2]Coccinellidae, Staphylinidae, Carabidae, Cantharidae, and Mordellidae. Predatory Coleoptera were rarely observed in pan traps, and were included in Total natural enemies.

[3]Aranae, Formicidae, Mutillidae, microhymenoptera, macrohymenoptera, predatory Coleoptera, Diptera (Asilidae, Bombyliidae, Dolichopodidae and Syrphidae), and Hemiptera (*Geocoris* spp., Anthrocoridae, and Reduviidae).

TABLE 7. SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS RECOVERED IN ADJACENT SQUASH CROP, 2007.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Native Weeds	*F*	*P*
Orthoptera	Sticky	0.42 ± 0.19	0.83 ± 0.44	0.08 ± 0.08	0.42 ± 0.19	1.30	0.2872
	Pan	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.08	1.00	0.4025
	Pitfall	1.08 ± 0.34	1.17 ± 0.51	1.42 ± 0.31	1.83 ± 0.41	0.72	0.5471
Hemiptera Aleyrodidae Aphididae	Sticky	14.75 ± 3.39	12.08 ± 3.16	8.33 ± 1.75	9.92 ± 1.60	1.07	0.3712
	Sticky	21.25 ± 5.11	21.25 ± 5.54	18.75 ± 4.42	14.83 ± 4.12	0.41	0.7490
	Pan	0.17 ± 0.11	0.25 ± 0.18	1.08 ± 0.66	0.25 ± 0.13	1.61	0.2011
Auchenorrhyncha[2]	Sticky	6.50 ± 0.77 ab	7.42 ± 1.28 ab	4.17 ± 0.76 b	8.25 ± 1.57 a	2.39	0.0828
	Pan	0.42 ± 0.26	0.25 ± 0.13	0.75 ± 0.18	0.67 ± 0.28	1.08	0.3688
	Pitfall	1.58 ± 0.48	1.50 ± 0.58	1.58 ± 0.36	1.83 ± 0.63	0.06	0.9818
Cicadellidae Membracidae Heteroptera[3]	Sticky	5.58 ± 0.69	6.17 ± 1.13	3.83 ± 0.74	6.92 ± 1.50	1.50	0.2291
	Sticky	0.75 ± 0.22	1.08 ± 0.29	0.25 ± 0.13	0.75 ± 0.33	1.97	0.1328
	Sticky	0.42 ± 0.15	0.50 ± 0.26	0.25 ± 0.13	0.17 ± 0.11	0.79	0.5040
	Pan	0.17 ± 0.11	0.05 ± 0.26	0.17 ± 0.11	0.00 ± 0.00	1.82	0.1594
	Pitfall	2.58 ± 0.76	1.67 ± 0.63	1.17 ± 0.37	1.92 ± 0.69	0.82	0.4907
Coleoptera *Altica* spp.	Sticky	3.00 ± 1.27	2.83 ± 0.43	4.33 ± 1.81	3.08 ± 1.29	0.23	0.8716
	Pan	0.08 ± 0.08 ab	0.25 ± 0.13 a	0.00 ± 0.00 b	0.00 ± 0.00 b	2.41	0.0863
Non-predatory[4]	Sticky	0.75 ± 0.37	1.08 ± 0.44	1.00 ± 0.30	0.50 ± 0.20	0.58	0.6289
	Pan	0.25 ± 0.13	0.25 ± 0.13	0.00 ± 0.00	0.25 ± 0.18	0.92	0.4396
	Pitfall	1.00 ± 0.46	0.67 ± 0.28	1.08 ± 0.50	0.42 ± 0.29	0.59	0.6272
Lepidoptera	Sticky	0.08 ± 0.08	0.42 ± 0.23	0.67 ± 41	0.50 ± 0.15	0.94	0.4301
	Pan	0.42 ± 0.19	0.33 ± 0.17	0.17 ± 0.11	0.08 ± 0.08	0.98	0.4133
	Pitfall	0.08 ± 0.08	0.42 ± 0.23	0.25 ± 0.18	0.17 ± 0.11	0.80	0.5033

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; *F* and *P* values; Sticky cards (df = 3, 41); Pan traps (df = 3, 41); Pitfall traps (df = 3, 41).

[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.

[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.

[4]Chrysomelidae, Elateridae, Tenebrionidae

[5]Primarily Thripidae that were rarely observed in pitfall traps.

TABLE 7. (CONTINUED) SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS RECOVERED IN ADJACENT SQUASH CROP, 2007.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Native Weeds	*F*	*P*
Diptera Microdiptera	Sticky	15.08 ± 4.82	8.42 ± 2.04	15.08 ± 3.40	11.92 ± 2.77	0.84	0.4819
	Pan	1.42 ± 0.56 ab	0.42 ± 0.26 b	1.17 ± 0.34 ab	2.17 ± 0.61 a	2.07	0.0734
	Pitfall	2.08 ± 1.47	1.92 ± 0.63	1.17 ± 0.34	1.25 ± 0.41	0.30	0.8264
Thysanoptera[5]	Sticky	10.08 ± 1.92	5.42 ± 1.56	4.75 ± 1.26	15.67 ± 7.62	1.50	0.2280
	Pan	0.08 ± 0.08	0.08 ± 0.08	0.17 ± 0.17	0.00 ± 0.00	0.44	0.7250

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; *F* and *P* values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 41$); Pitfall traps ($df = 3, 41$).

[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.

[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.

[4]Chrysomelidae, Elateridae, Tenebrionidae

[5]Primarily Thripidae that were rarely observed in pitfall traps.

were found on squash plants bordered by sorghum-sudangrass during *in situ* counts in 2008. This suggests that during the 2008 season, sorghum-sudangrass may have functioned as a barrier to aphid dispersal and colonization. Two possible explanations may account for the reduced colonization or dispersal of aphids in squash bordered by a sorghum-sudangrass treatment. First, sorghum-sudangrass may act as a direct physical barrier preventing aphids from entering the field, or it may alter the background of host crop/vegetation and subsequently reduce the potential for aphid alightment. Thus, aphids maybe investing more time and energy probing a diversionary intercrop, rather than attacking the main crop (Smith & McSorley 2000). Trenbath (1977) describes this phenomenon as the "fly-paper effect" because herbivores are "lost" to plant surfaces other than the main crop, which may delay colonization and increase their exposure to mortality factors (Smith & McSorley 2000; Trenbath 1977, 1993). Secondly, the high population of coccinellids may have increased the potential for enhanced natural control, which will ultimately reduce aphid numbers. It should be noted that yellow sticky cards serve as an attractant for aphids (Southwood & Henderson 2000); therefore, further testing with clear plexiglass sticky boards, or other passive sampling methods may offer a better understanding of natural patterns of dispersal and movement of aphids in this system (Powell et al.1996).

Our second objective was to observe and document the components of the above-ground arthropod community within each of the border crop treatments. Each treatment provided a unique habitat that was attractive to particular arthropods while most other groups remained unaffected by the border composition. Natural enemies were generally highest in the pigeon pea and native weed complex borders, which were the most vegetationally diverse treatments. However, sorghum-sudangrass had the highest number of predatory Coleoptera (sticky cards) during both seasons. Spiders were most abundant in the bare ground on sticky cards and sometimes pan traps rather than in pitfall traps, which measure activity at the level of the soil surface. Since uncultivated strips in the agricultural landscape have been demonstrated as an important source of spiders (Nentwig 1988), it is possible that aerial dispersal of spiders from the adjacent weed refugia blew through plots unobstructed by border treatments more readily than when any of the other treatments were there.

Non-predatory Coleoptera were unaffected by the composition of the border treatment with the exception of the herbivorous flea beetle, *Altica* spp. (Chrysomelidae). Flea beetles were most often captured on sticky cards in the bare ground control, while they were rarely recovered in pan

TABLE 8. SELECTED BENEFICIAL ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS WITHIN SQUASH CROP, 2008.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Native Weeds	F	P
Coleoptera Predatory[2]	Sticky	0.25 ± 0.13 b	0.17 ± 0.11 b	1.25 ± 0.55 a	0.42 ± 0.19 ab	2.74	0.0555
	Pitfall	0.08 ± 0.08	0.00 ± 0.00	0.17 ± 0.11	0.33 ± 0.142	2.05	0.1214
Diptera Dolichopodidae	Sticky	1.25 ± 0.46	1.25 ± 0.55	0.92 ± 0.26	2.33 ± 0.61	1.53	0.2202
	Pan	0.06 ± 0.06	0.06 ± 0.06	0.00 ± 0.00	0.00 ± 0.00	0.66	0.5830
	Pitfall	0.17 ± 0.11	0.42 ± 0.19	0.25 ± 0.13	0.42 ± 0.19	0.59	0.6248
Hymenoptera Formicidae	Sticky	0.17 ± 0.11 ab	0.00 ± 0.00 b	0.42 ± 0.19 a	0.08 ± 0.08 ab	2.22	0.0997
	Pan	0.13 ± 0.09	0.13 ± 0.09	0.15 ± 0.09	0.00 ± 0.00	0.81	0.4942
	Pitfall	12.75 ± 2.88	6.08 ± 1.37	7.75 ± 1.56	10.08 ± 2.78	1.66	0.1915
Microhymenoptera	Sticky	9.33 ± 1.61	8.25 ± 1.11	10.42 ± 2.36	7.08 ± 1.18	0.73	0.5423
	Pan	0.44 ± 0.18	0.75 ± 0.25	0.54 ± 0.20	0.56 ± 0.22	0.36	0.7822
	Pitfall	2.00 ± 0.49	2.08 ± 0.58	1.80 ± 0.52	2.92 ± 0.62	0.73	0.5387
Araneae	Sticky	1.08 ± 0.29	0.67 ± 0.28	0.50 ± 0.23	0.33 ± 0.14	1.69	0.1845
	Pan	0.31 ± 0.15	0.25 ± 0.14	0.35 ± 0.12	0.19 ± 0.10	0.31	0.8186
	Pitfall	0.25 ± 0.13	0.33 ± 0.14	0.17 ± 0.11	0.17 ± 0.11	0.41	0.7485
Total natural enemies[3]	Sticky	12.08 ± 2.06	10.50 ± 1.47	13.83 ± 2.44	10.25 ± 1.42	0.74	0.5331
	Pan	0.94 ± 0.21	1.31 ± 0.30	0.98 ± 0.25	0.81 ± 0.25	0.68	0.5689
	Pitfall	2.58 ± 0.54	3.17 ± 0.81	2.50 ± 0.68	4.08 ± 0.88	0.96	0.4193

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; F and P values; Sticky cards (df = 3, 41); Pan traps (df = 3, 57); Pitfall traps (df = 3, 41).

[2]Coccinellidae, Staphylinidae, Carabidae, Cantharidae, and Mordellidae. Predatory Coleoptera were rarely observed in pan traps, and were included in Total natural enemies.

[3]Aranae, Formicidae, Mutillidae, microhymenoptera, macrohymenoptera, predatory Coleoptera, Diptera (Asilidae, Bombyliidae, Dolichopodidae and Syrphidae), and Hemiptera (*Geocoris* spp., Anthrocoridae, and Reduviidae).

TABLE 9. EFFECT OF TREATMENTS ON SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS RECOVERED IN ADJACENT SQUASH CROP, 2008.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Native Weeds	*F*	*P*
Orthoptera	Sticky	0.08 ± 0.08	0.08 ± 0.08	0.25 ± 0.18	0.00 ± 0.00	0.92	0.4377
	Pan	0.00 ± 0.00	0.06 ± 0.06	0.08 ± 0.07	0.13 ± 0.09	0.70	0.5586
	Pitfall	0.17 ± 0.11	0.58 ± 0.29	0.92 ± 0.34	0.58 ± 0.19	1.71	0.1805
Hemiptera Aleyrodidae Aphididae	Sticky	13.00 ± 3.17	15.50 ± 4.53	13.92 ± 4.17	8.83 ± 2.56	0.61	0.6147
	Sticky	8.67 ± 2.21	8.83 ± 1.36	10.67 ± 1.74	8.25 ± 1.39	0.39	0.7595
	Pan	0.38 ± 0.15	0.69 ± 0.24	0.92 ± 0.28	0.94 ± 0.21	1.31	0.2790
Auchenorrhyncha[2]	Sticky	2.33 ± 0.63	3.08 ± 0.60	2.33 ± 0.88	4.42 ± 0.91	1.84	0.1558
	Pan	0.13 ± 0.09	0.25 ± 0.11	0.00 ± 0.00	0.19 ± 0.10	1.51	0.2222
	Pitfall	1.42 ± 0.66 b	5.08 ± 2.51 ab	0.75 ± 0.22 b	9.58 ± 0.42 a	2.68	0.0595
Cicadellidae Membracidae Heteroptera[3]	Sticky	1.50 ± 0.40 b	1.17 ± 0.35 b	1.92 ± 0.82 ab	3.42 ± 0.83 a	2.58	0.0665
	Sticky	0.83 ± 0.35 ab	1.58 ± 0.50 a	0.25 ± 0.13 b	0.58 ± 0.29 b	2.72	0.0571
	Sticky	0.17 ± 0.11	0.25 ± 0.13	0.08 ± 0.08	0.08 ± 0.08	0.62	0.6037
	Pan	0.06 ± 0.06	0.00 ± 0.00	0.06 ± 0.06	0.00 ± 0.00	0.70	0.5537
	Pitfall	2.58 ± 0.76	1.67 ± 0.63	1.17 ± 0.37	1.92 ± 0.69	0.82	0.4907
Coleoptera *Altica* spp.	Sticky	0.83 ± 0.42	0.33 ± 0.19	0.83 ± 0.37	0.67 ± 0.22	0.54	0.6603
	Pan	0.06 ± 0.06	0.00 ± 0.00	0.06 ± 0.06	0.13 ± 0.09	0.70	0.5537
Non-predatory[4]	Sticky	0.33 ± 0.22	0.00 ± 0.00	0.17 ± 0.11	0.08 ± 0.08	1.15	0.3416
	Pan	0.06 ± 0.06	0.13 ± 0.09	0.06 ± 0.06	0.13 ± 0.09	0.23	0.8719
	Pitfall	1.75 ± 0.79	1.58 ± 0.61	0.58 ± 0.34	2.08 ± 0.98	0.76	0.5221
Lepidoptera	Sticky	0.08 ± 0.08	0.08 ± 0.08	0.08 ± 0.08	0.00 ± 0.00	0.39	0.7605
	Pan	0.13 ± 0.09	0.06 ± 0.06	0.06 ± 0.06	0.00 ± 0.00	1.46	0.2078
	Pitfall	0.00 ± 0.00	0.00 ± 0.00	0.08 ± 0.08	0.17 ± 0.11	1.33	0.2776

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \leq 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.

[1]Analysis of variance; F and P values; Sticky cards (df = 3, 41); Pan traps (df = 3, 57); Pitfall traps (df = 3, 41).

[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.

[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.

[4]Chrysomelidae, Elateridae, Tenebrionidae

[5]Primarily Thripidae that were rarely observed in pitfall traps.

TABLE 9. (CONTINUED) EFFECT OF TREATMENTS ON SELECTED ARTHROPOD GROUPS (NUMBER PER TRAP) RECOVERED ON STICKY CARDS, PAN TRAPS AND PITFALL TRAPS RECOVERED IN ADJACENT SQUASH CROP, 2008.

		Treatments				ANOVA[1]	
Arthropod group	Trap	Bare ground	Pigeon pea	Sorghum	Native Weeds	*F*	*P*
Diptera Microdiptera	Sticky	8.50 ± 1.04	9.00 ± 0.65	9.33 ± 0.69	7.83 ± 1.10	0.52	0.6692
	Pan	0.56 ± 0.20	0.75 ± 0.27	0.85 ± 0.22	1.13 ± 0.29	0.89	0.4538
	Pitfall	0.83 ± 0.30	1.08 ± 0.31	1.33 ± 0.40	2.00 ± 1.13	0.63	0.5990
Thysanoptera[5]	Sticky	0.14 ± 0.16	1.58 ± 0.47	1.25 ± 0.49	1.42 ± 0.71	0.10	0.9605
	Pan	0.63 ± 0.20	0.31 ± 0.15	0.44 ± 0.16	0.19 ± 0.10	1.40	0.3804

Data are means ± standard errors of 4 replications. Means in rows followed by the same letter do not differ ($P \le 0.10$) according to LSD test. No letters in rows indicate means are not significantly different.
[1]Analysis of variance; *F* and *P* values; Sticky cards ($df = 3, 41$); Pan traps ($df = 3, 57$); Pitfall traps ($df = 3, 41$).
[2]Cercopidae, Cicadellidae, Delphacidae, and Membracidae.
[3]Herbivorous Aleyidae, Lygaeidae, Miridae, Pentatomidae, Pyrrochoridae, and Rhopalidae.
[4]Chrysomelidae, Elateridae, Tenebrionidae
[5]Primarily Thripidae that were rarely observed in pitfall traps.

traps and pitfall traps. Tahvanainen & Root (1972) demonstrated that intercropping interfered with host-finding and feeding behavior of the flea beetle, *Phyllotreta cruciferae* (Goeze). The habitat simplicity that results from cultivation and the absence of a diverse background may signal favorable conditions to colonizing insects like flea beetles (Root 1973; Cromartie 1975; Dosdall et al. 1999), whose host-finding behavior appears to be adapted to be adapted to hosts that stand out against bare soil (Cromartie 1975).

The third objective of this study was to evaluate whether planting borders impacted arthropod populations in the adjacent crop, providing a spill-over effect. Although total natural enemies were most abundant in the native weed complex, no corresponding increase in total natural enemy captures was detected in the adjacent squash. This may be the result of lag time or attributed to the type of border crops employed. However, in 2008 greater numbers of predatory Coleoptera trapped on sticky cards in sorghum-sudangrass corresponded to the higher populations trapped within the squash crop. In 2007, severe squash defoliation by melonworm may have prevented significant numbers of predatory Coleoptera from moving into the squash crop. The spill-over effect was also observed to a limited extent for auchenorrhyncans, although the trends were not consistent between seasons. Since leafhoppers are not a major pest of squash, the impact of high leafhopper populations in squash was negligible.

Because this was a community study, multiple methods were employed to assess arthropod populations. Not every method was best suited for every group, thus discrepancies between results for the same arthropod group using different sampling tools are to be expected. The use of yellow sticky cards is a standard sampling method to determine relative abundance (Southwood & Henderson 2000). However, colored traps do not provide information regarding the natural movement patterns of insects (Powell et al. 1996). Passive traps including clear pan traps and pitfall traps likely provide more information regarding natural patterns of locomotion (Powell et al. 1996; Southwood & Henderson 2000). However in these experiments pan traps captured fewer arthropods per trap than pitfall and sticky card traps left in the field for the same period of time. Although some differences were detected using pan traps, increasing the time that they are placed in the field may provide more data.

Crop diversity is thought to have a stabilizing effect on arthropod populations and reduce pest outbreaks (Pimentel 1961). However, the intercropped refuge strips in this study were not sufficient to prevent pest outbreak. This was most evident from *in situ* counts. Melonworm, a specialist herbivore was not hindered by border crops, and was responsible for nearly 100% crop loss by the end of the 2007 and nearly 50% crop loss 2008. Generalist defoliators like the saltmarsh caterpillar appeared unencumbered by the border treatments as well.

Although crop diversity impacts a wide range of pests and beneficial species (Landis et al. 2000; Andow 1991), many of the studies examined in these reviews included only a few key pests or natural enemies rather than the full arthropod community. In the current study, the impact of vegetational diversity on the arthropod community was evaluated, and while a number of members responded, most groups were unaffected by treatments. These results occurred even with a fairly liberal criterion ($P \leq 0.10$) selected to detect differences among treatments. These results are interesting in that they are consistent with the possibility that a large number of arthropod groups may be unaffected by vegetational diversity, at least under the current conditions.

Uncultivated weed refugia were established between each of the experimental blocks to provide a source of arthropods that could migrate into the border treatment areas and the squash crop (van Emden 1965). The presence of weed refugia mimics the reality of low resource and organic farmers who are typically forced to tolerate some level of weeds because of limited weed control options or labor constraints (Bàrberi 2002). Since plant diversity in the habitat surrounding a crop may have stronger effects on the abundance of certain species than the host-plant patch size (Bach 1984), plot dimensions and the proximity of weed refugia may be responsible for attenuated treatment affects, especially in the bare ground treatment. The results of the current experiment suggests that incorporating strips of pigeon pea, sorghum, or weeds may not make a significant contribution to the activity of natural enemies in neighboring crops in a site that already has a considerable amount of crop or non-crop diversity in the adjacent landscape. Results cannot be generalized to conventional vegetable production systems that operate against a less diverse background because these systems may lack reservoirs from which resident arthropods could move to colonize intercropping strips or crops.

Acknowledgments

We thank H. K. 'Rosie' Gill, Romy Krueger, and Namgay Om for assistance with sample processing and field work as well as the University of Florida Plant Science Research Unit staff for maintaining our experimental fields. We are grateful to Lyle Buss and Craig Roubus for assistance with insect identification. Special thanks to E. C. H. O., the Educational Concerns for Hunger Organization, North Fort Myers, FL, for providing pigeon pea seeds. We appreciate the assistance of Dr. Carlene Chase in the review of this paper.

References Cited

ALTIERI, M. A. 1994. Biodiversity and Pest Management in Agroecosystems. Food Products Press Inc., New York, NY.

ALTIERI, M. A., AND LETOURNEAU, D. K. 1982. Vegetation management and biological control in agroecosystems. Crop Prot. 1: 405-430.

ALTIERI, M. A., AND NICHOLS, C. I. 2004a. Biodiversity and Pest Management in Agroecosystems 2nd Edition. Food Products Press, Binghamton, NY.

ALTIERI, M. A., AND NICHOLS, C. I. 2004b. Effects of agroforestry systems on the ecology and management of insect pest populations, pp. 142-154 *In* G. M. Gurr, S. D. Wratten, and M. A. Altieri [eds.], Ecological Engineering for Pest Management: Advances in Habitat Manipulation for Arthropods. Comstock Pub. Associates/Cornell University Press, Ithaca, N.Y.

ANDOW, D. A. 1991. Vegetational diversity and arthropod population response. Annu. Rev. Entomol. 36: 561-586.

BACH, C. E. 1984. Plant spatial pattern and herbivore population dynamics: Plant factors affecting the movement patterns of a tropical cucurbit specialist (*Acalymma innubum*). Ecology 65: 175-190.

BÀRBERI, P. 2002. Weed management in organic agriculture: Are we addressing the right issues? Weed Res. 42: 177-193.

BASU, A. N. 1995. *Bemisia tabaci* (Gennadius) Crop Pest and Principal Whitefly Vector of Plant Viruses. Westview Press, Boulder, CO.

BONTE, D., LUKAC, M., AND LENS, L. 2008. Starvation affects pre-dispersal behaviour of Erigone spiders. Bas. Appl. Ecol. 9: 308-315.

BUGG, R. L., EHLER, L. E., AND WILSON, L. T. 1987. Effect of common knotweed (*Polygonum aviculare*) on abundance and efficiency of insect predators of crop pests. Hilgardia 55: 1-51.

CAPINERA, J. L. 2005. Relationships between insect pests and weeds: An evolutionary perspective. Weed Sci. 53: 892-901.

COMPTON, S. G. 2002. Sailing with the wind: Dispersal by small flying insects, pp. 113-133 *In* J. M. Bullock, R. E. Kenward, and R. S. Hails [eds.], Dispersal Ecology. Blackwell Publishing, Malden, MA.

CROMARTIE, JR., W. J. 1975. The effect of stand size and vegetational background on the colonization of cruciferous plants by herbivorous insects. J. Appl. Ecol. 12: 517-533.

DAMICONE, J. P., EDELSON, J. V., SHERWOOD, J. L., MYERS, L. D., AND MOTES, J. E. 2006. Effects of border crops and intercrops on control of cucurbit virus diseases. Plant Dis. 91: 506-516.

DENYS, C., AND TSCHARNTKE, T. 2002. Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows. Oecologia 130: 315-324.

DOSDALL, L. M., DOLINSKI, M. G., AND CONWA, P. M. 1999. The effect of tillage regime, row spacing, and seeding rate on feeding damage by flea beetles, *Phyllotreta* spp. (Coleoptera: Chrysomelidae), in canola in central Alberta, Canada. Crop Prot. 18: 217-224.

(FAWN) FLORIDA AUTOMATED WEATHER NETWORK. 2009. IFAS, University of Florida, Gainesville, FL. http://fawn.ifas.ufl.edu.

FERERES, A. 2000. Barrier crops as a cultural control measure of non-persistently transmitted aphid-borne viruses. Virus Res. 71: 221-231.

FLINT, M. L., AND GOUVEIA, P. 2001. IPM in practice: Principles and Methods of Integrated Pest Management. Publication 3418. University of California Statewide Integrated Pest Management Project: Agriculture and Natural Resources. Regents of the University of California Division of Agriculture and Natural Resources, Oakland, CA.

GURR, G., WRATTEN, S. D., AND BARBOSA, P. 2000. Success in conservation biological control of arthropods, pp. 105-132 *In* G. Gurr and S. D. Wratten [eds.], Biological Control: Measures of Success. Kluwer Academic Publishers Dordrecht, The Netherlands.

HOOKS, C. R. R., AND JOHNSON, M. 2003. Impact of agricultural diversification on the insect community of cruciferous crops. Crop Prot. 22: 223-238.

KEMP, J. C., AND BARRETT, G. W. 1989. Spatial patterning: impact of uncultivated corridors on arthropod populations within soybean agroecosystems. Ecology 70: 114-128.

LANDIS, D. A., MENALLED, F. D., COSTAMAGNA, A. C., AND WILKINSON, T. K. 2005. Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. Weed Sci. 53: 902-908.

LANDIS, D. A., WRATTEN, S. D., AND GURR, G. M. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45: 145-201.

LEWIS, T. 1997. Flight and dispersal, pp. 175-196 *In* T. Lewis [ed.], Thrips as Crop Pests. CAB International, New York, NY.

LEWIS, T. 1969. The distribution of flying insects near a low hedgerow. J. Appl. Ecol. 6: 443-452.

LIBURD, O. E., SARZYNSKI, E. M., AREVALO, H. A., AND MACKENZIE, K. 2009. Monitoring and emergence of flower thrips species in rabbiteye and southern highbush blueberries. Acta Hort. 810: 251-258.

MURPHY, J. F., MOSJIDIS, J., EUBANKS, M. D., AND MASIRI, J. 2008. Inter-row soil cover to reduce incidence of aphid-borne viruses in pumpkin. Intl. J. Veg. Sci. 14: 290-303.

NENTWIG, W. 1988. Augmentation of beneficial arthropods by strip-management. Oecologia 76: 597-606.

NORRIS, R. F., AND KOGAN, M. 2000. Interactions between weeds, arthropod pests and their natural enemies in managed ecosystems. Weed Sci. 48: 94-158.

NORRIS, R. F., AND KOGAN, M. 2005. Ecology of interactions between weeds and arthropods. Annu. Rev. Entomol. 50: 479-503.

NYOIKE, T. W., LIBURD, O. E., AND WEBB, S. E. 2008. Suppression of whiteflies, *Bemisia tabaci* (hemiptera: Aleyrodidae) and incidence of Cucurbit leaf crumple virus, A whitefly-transmitted virus of zucchini squash new to Florida, with mulches and imidacloprid. Florida Entomol. 91: 460-465.

NYOIKE, T. W., AND LIBURD, O. E. 2010. Effect of living (buckwheat) and UV reflective mulches with and without imidacloprid on whiteflies, aphids and marketable yields of zucchini squash. Intl. J. Pest Manag. 56: 31-39.

PASCUAL-VILLALOBOS, M. J., LACASA, A., GONZÁLEZ, A., VARÓ, P., AND GARCÍA, M. J. 2006. Effect of flowering plant strips on aphid and syrphid populations in lettuce. Europ. J. of Agron. 24: 182-185.

PIMENTEL, D. 1961. Species diversity and insect population outbreaks. Ann. Entomol. Soc. America 54: 76-86.

POWELL, W., WALTON, M. P., AND JERVIS, M. A. 1996. Populations and communities, pp. 225-231 *In* M. A. Jervis and N. Kidd [eds.], Insect Natural Enemies. Practical Approaches to their Study and Evaluation. Chapman and Hall, London, UK

POWERS, L., AND MCSORLEY, R. 2000. Ecological Principles of Agriculture. Delmar Thompson Learning, Albany, N.Y.

ROOT, R. B. 1973. Organization of plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracea*). Ecol. Monogr. 43: 9-124.

RUSSELL, E. P. 1989. Enemies hypothesis: a review of the effect of the vegetational diversity on predatory insects and parasitoids. Environ. Entomol. 19: 590-599.

SAS INSTITUTE. 2008. The SAS system 9.1 for Windows. SAS Institute, Cary, NC.

SHEEHAN, W. 1986. Response by specialist and generalist natural enemies to agroecosystem diversification: a selective review. Environ. Entomol. 15: 456-461.

SHOWLER, A. T., AND GREENBERG, S. M. 2003. Effects of weeds on selected arthropod herbivore and natural enemy populations and on cotton growth and yield. Environ. Entomol. 32: 39-50.

SMITH, H. A., AND MCSORLEY, R. 2000. Intercropping and pest management: a review of major concepts. American Entomol. 46: 153-161.

SOUTHWOOD, T. R. E., AND HENDERSON, P. A. 2000. Ecological Methods. 3rd ed. Blackwell Science Ltd./University Press, Cambridge, UK.

TAHVANAINEN, J. O., AND ROOT, R. B. 1972. The influence of vegetational diversity on the population ecology of a specialized herbivore, *Phyllotreta cruciferase* (Coleoptera: Chrysomelidae). Oecologia 10: 321-246.

THOMAS, B. P., LAW, JR., L., AND STANKEY, D. L. 1979. Soil Survey of Marion County Area, Florida. U.S. Department of Agriculture, Soil Conservation Service, Washington, D.C.

TRENBATH, B. R. 1993. Intercropping for the management of pests and diseases. Field Crops Res. 34: 381-405.

TRENBATH, B. R. 1977. Interactions among diverse hosts and diverse parasites. Ann. New York Acad. Sci. 287: 124-150.

TRIPLEHORN, C. A., AND JOHNSON, N. F. 2005. Borror and DeLong's Introduction to the Study of Insects. 7th ed. Thompson Brooks/Cole, Pacific Grove, CA.

TSCHARNTKE, T., BOMMARCO, R., CLOUGH, Y., CRIST, T. O., KLEIJN, D., RAND, T. A., TYLIANAKIS, J. M., NOUHUYS, S. V., AND VIDAL, S. 2007. Conservation biological control and enemy diversity on a landscape scale. Biol. Control 43: 294-309.

VAN EMDEN, H. F. 1965. The role of uncultivated land in the biology of crop pests and beneficial insects. Sci. Hort. 17: 121-136.

WILKINSON, T. K., AND LANDIS, D. A. 2005. Habitat diversification in biological control: The role of plant resources, pp. 305-325 *In* F. L. Wäckers, P. C. J. van Rijn, and J. Bruin [eds.], Plant Provided Food and Plant-carnivore Mutualism. Cambridge University Press, Cambridge, UK.