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Research Article

Incorporating a Sorghum Habitat for Enhancing Lady Beetles (Coleoptera: Coccinellidae) in Cotton

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Lady beetles (Coleoptera: Coccinellidae) prey on insect pests in cotton. The objective of this 2 yr on-farm study was to document the impact of a grain sorghum trap crop on the density of Coccinellidae on nearby cotton. *Scymnus* spp., *Coccinella septempunctata* (L.), *Hippodamia convergens* Guérin-Méneville, *Harmonia axyridis* (Pallas), *Coleomegilla maculata* (De Geer), *Cycloneda munda* (Say), and *Olla v-nigrum* (Mulsant) were found in sorghum over both years. Lady beetle compositions in sorghum and cotton and in yellow pyramidal traps were similar. For both years, density of lady beetles generally was higher on cotton with sorghum than on control cotton. Our results indicate that sorghum was a source of lady beetles in cotton, and thus incorporation of a sorghum habitat in farmscapes with cotton has great potential to enhance biocontrol of insect pests in cotton.

1. Introduction

Lady beetles (Coleoptera: Coccinellidae) have a significant impact on aphids (Hemiptera: Aphididae) [1–4], including the cotton aphid (*Aphis gossypii* Glover) attacking cotton (*Gossypium hirsutum* L.) [5] and the corn leaf aphid (*Rhopalosiphum maidis* (Fitch) and greenbug (*Schizaphis graminum* (Rondani) attacking grain sorghum (*Sorghum bicolor* (L.) Moench spp. *bicolor*) [6–8]. In the southeastern USA, cotton fields commonly are closely associated with other agronomic crops, especially corn (*Zea mays* L.) and peanut (*Arachis hypogea* L.), and in these farmscapes polysphagous pest species are known to move from corn and peanut into cotton to find newly available, suitable food, or oviposition sites [9]. As part of a larger pest management strategy, strips of grain sorghum planted between a source crop and cotton have proved useful as a trap crop to reduce pest movement, especially stink bugs (Hemiptera: Pentatomidae), into cotton [10, 11]. Additionally, a grain sorghum trap crop is beneficial to natural enemies by hosting the corn leaf aphid and greenbug [12]. Thus, grain sorghum, when planted adjacent to cotton, can perform as a trap crop for stink bugs and possibly as a source of natural enemies moving into cotton. In fact, many species of Coccinellidae are commonly found inhabiting grain sorghum: *Harmonia axyridis* (Pallas), *Hippodamia convergens* Guérin-Méneville, *H. sinuata* Mulsant, *H. parenthesis* (Say), *Coccinella septempunctata* L., *Coleomegilla maculata* (De Geer), *Cycloneda munda* (Say), *Scymnus* spp., *Olla v-nigrum* (Mulsant), *Exochomus* sp., and *Psyllobora vigintimaculata* (Say) [13–16]. These same species colonize cotton [4, 16, 17], and their presence within a grain sorghum trap crop may lead to these predators moving into cotton and facilitating insect pest management.

The objective of this study was to document the impact of a grain sorghum trap crop on the density of Coccinellidae on nearby cotton. Two treatments were used: (1) cotton fields without sorghum and (2) cotton fields bordered on one side by a strip of grain sorghum. Within the grain sorghum, Coccinellidae were not only sampled on plants but also from yellow pyramid traps that predominantly served in the larger pest management scheme to kill stink bugs in sorghum.

2. Materials and Methods

2.1. Study Sites. Six cotton fields, ranging from 5 to 18 ha in size, were sampled each year, 2006 and 2007, in Irwin County GA (Table 1). Recommended agricultural practices

Table 1: Planting date (PD) and variety for cotton (Ct) with sorghum trap crops, control cotton, and sorghum (So) in 2006 and 2007.

Year	Treatment	Rep	Crop	Variety[a]	PD
2006	Cotton w/trap crop	1	Ct	DP 555	4/28
	Cotton w/trap crop	2	Ct	DP 555	5/4
	Cotton w/trap crop	3	Ct	DP 555	5/10
	Sorghum trap crop	1–3	So	DK 54	4/14
	Control cotton	1	Ct	DP 555	5/1
	Control cotton	2	Ct	DP 555	5/4
	Control cotton	3	Ct	DP 555	5/26
2007	Cotton w/trap crop	1	Ct	DP 555	5/9
	Cotton w/trap crop	2	Ct	DP 555	6/7
	Cotton w/trap crop	3	Ct	DP 555	6/11
	Sorghum trap crop	1–3	So	DK 54	6/13
	Control cotton	1	Ct	DP 555	5/11
	Control cotton	2	Ct	DP 555	5/11
	Control cotton	3	Ct	DP 555	6/11

[a] Seed companies; DK: DeKalb; DP: Deltapine.

for production of sorghum [18] and cotton [19] were followed. Row width was 0.91 m for each crop, and rows for each crop were parallel to each other.

2.2. Yellow Pyramidal Traps. These traps consisted of a 2.84-liter clear plastic polyethylene terephthalate jar (United States Plastic Corp., Lima, OH, USA) on top of a 1.22 m-tall yellow pyramidal base [20, 21]. An insecticidal ear tag (Saber Extra, Coppers Animal Health Inc., Kansas City, KS, USA) was placed in the plastic jar at the beginning of a test to prevent escape of captured specimens. Active ingredients in the ear tag were lambda-cyhalothrin (10%) and piperonyl butoxide (13%). As part of the larger strategy to reduce pest movement into cotton, stink bug attraction to the traps was enhanced by placing *Euschistus* spp. stink bug lures (40 μL of the *Euschistus* spp. pheromone, methyl (*E, Z*)-2,4-decadienoate (CAS registry no. 4493-42-9) (Degussa AG Fine Chemicals, Marl, Germany, loaded onto rubber septa) in traps and replacing lures weekly. Insects from weekly collections were taken to the laboratory for identification.

2.3. Experimental Design. Two treatments were used each year: control cotton (without a sorghum trap crop) and cotton bordered by a sorghum trap crop and yellow pyramidal traps within the trap crop. At the beginning of the study, six commercial cotton fields were selected in Irwin County, Georgia, and each treatment was assigned randomly to three cotton fields similar to a completely randomized design. For the sorghum trap crop treatment, sorghum was planted in a strip (4 rows) along one edge of the cotton field; row 1 of sorghum was adjacent to a peanut field and row 4 was adjacent to the cotton field. Then 25–28 yellow pyramidal traps (depending on field width) were placed 12 m apart in row 1 of sorghum.

2.4. Insect Sampling. Each year of the study, crops and yellow pyramidal traps were examined weekly for the presence of lady beetles; from the week of 5 July to the week of 16 August in 2006 and from the week of 19 July to the week of 23 August in 2007. Due to time constraints of sampling these large fields, not all farmscapes were sampled on the same day of the week, but crops and/or yellow pyramidal traps within a field were sampled on the same day. For each sorghum sample, all plant parts within a 1.83 m length of row were visually checked for all lady beetles. For each cotton sample, all plants within a 1.83 m length of row were shaken over a drop cloth, and the aerial parts of all plants were visually checked thoroughly for all lady beetles. Voucher specimens are stored in the USDA-ARS, Crop Protection and Management Research Laboratory in Tifton, GA, USA.

For sampling purposes, the edge of a cotton field adjacent to a peanut field was labeled as side A, and in a clockwise direction the other 3 sides of a field were labeled as sides B, C, and D. Each year, samples were obtained from within the cotton field at 3 distances from the edge of side A (i.e., at rows 1, 2, and 5), and at 6 interior locations along the length of the field (i.e., rows 16, 33, 100, 167, 233, and 300 from the edge of the field on side A). In both years, the 300-row samples were not close to the edge of side C; 24–31 m from side C in 2006 and 61 m from side C in 2007. For sides B–D, samples were taken from 2 edge locations, rows 1 and 5 from the edge of the field. The number of samples from each field on each date was as follows: 9 from each row on side A, 3 from each row on sides B–D, and 6 from each interior location. For both years, the 4-row strip of sorghum was sampled by taking 9 samples from each of the 4 rows.

2.5. Statistical Analysis. Lady beetle species compositions in sorghum strips, cotton fields, and yellow pyramidal traps were similar for both years, and then data for the two years were combined. Means were obtained for number of lady beetle adults per sample for sorghum and yellow pyramidal traps using PROC MEANS [22]. The number of lady beetle adults per sample in cotton with sorghum trap crops and control cotton was compared using *t*-tests. In 2007, one cotton field with a sorghum trap crop was excluded from data analysis on week 6 due to an insecticide application after sampling on week 5. One control cotton field was excluded from data analysis on weeks 5 and 6 due to an insecticide application after sampling on week 4.

3. Results and Discussion

Scymnus spp., *C. septempunctata*, *H. convergens*, *H. axyridis*, *C. maculata*, *C. munda*, and *O. v-nigrum* were found in crops and yellow pyramidal traps over both years in Georgia. The corn leaf aphid was observed feeding on sorghum mainly during the vegetative stage, and the greenbug was observed mainly feeding in sorghum grain heads. Cotton aphids were present on cotton for much of the growing season, but they were mainly observed on this crop early in the season (late June-early July).

Scymnus spp. and *C. septempunctata* were the predominant species in sorghum; however, *C. septempunctata* and

Table 2: Percentage composition (within columns) of lady beetle species in sorghum trap crops, yellow pyramidal traps, cotton with sorghum trap crops, and control cotton.

Species	Percentage in sorghum trap crops ($n = 1789$)	Percentage in yellow pyramidal traps ($n = 20,313$)	Percentage in cotton w/sorghum trap crops ($n = 4804$)	Percentage in control cotton ($n = 2879$)
Scymnus spp.	51.9	16.5	28.6	43.0
C. septempunctata	33.9	38.1	13.7	14.8
H. convergens	6.3	6.3	31.7	22.6
H. axyridis	5.4	32.1	24.6	18.3
C. maculata	2.0	5.7	1.1	0.9
O. v-nigrum	0.4	0.1	0.2	0.2
C. munda	0.1	1.2	0.1	0.2

H. axyridis were the most abundant coccinellids captured in the yellow pyramidal traps (Table 2). Species composition was similar for cotton with or without (i.e., control) a trap crop with the predominant species being *Scymnus* spp., *C. septempunctata*, *H. convergens*, and *H. axyridis*. The lady beetle species in sorghum and cotton have been previously reported to colonize these crops [4, 13–17].

It was not surprising that yellow pyramidal traps (baited with an aggregation pheromone for *Euschistus* spp. stink bugs) captured adult lady beetles. Captures of lady beetles in this yellow trap, with or without the stink bug pheromone, are common (T.E.C., personal observation), and yellow sticky cards have been used in previous studies to sample adult Coccinellidae [23–27]. The similarity in lady beetle captures in traps and those sampled on sorghum may indicate that the yellow trap itself does not attract lady beetles from significant distances; lady beetle capture in the trap was likely facilitated by the attractiveness of the surrounding sorghum. Nevertheless, modifying the yellow pyramidal traps (intended to attract and kill stink bugs) to reduce lady beetle capture could conserve these predators in sorghum.

In 2006, lady beetle density remained relatively low in flowering and milking sorghum and then peaked during the soft dough stage of seed development (Figure 1). Generally, corn leaf aphids are first observed on sorghum when plants have three to five leaves, and then their numbers increase on vegetative sorghum until declining around the boot or early bloom stages [7]. Greenbugs also are present on sorghum during the three to five leaf stage, but their numbers do not increase until after plants have about 10 leaves, with peak abundance at the half bloom or soft dough stage and then declining as sorghum matures [7]. After week 4, density of adult lady beetles began an overall decline in sorghum, a likely result of prey depletion on sorghum. Apparently, as prey were depleted on sorghum, beetles moved from sorghum to yellow pyramidal traps during week 5 but their capture in these traps dropped precipitously thereafter (Figure 1). Density of lady beetles increased slightly on sorghum during the hard dough stage (i.e., when 75% of the grain dry weight has accumulated) and then declined as sorghum heads matured. In cotton, lady beetles first appeared in relatively low numbers in early July and peaked on cotton in late July-early August. Lady beetle density was significantly

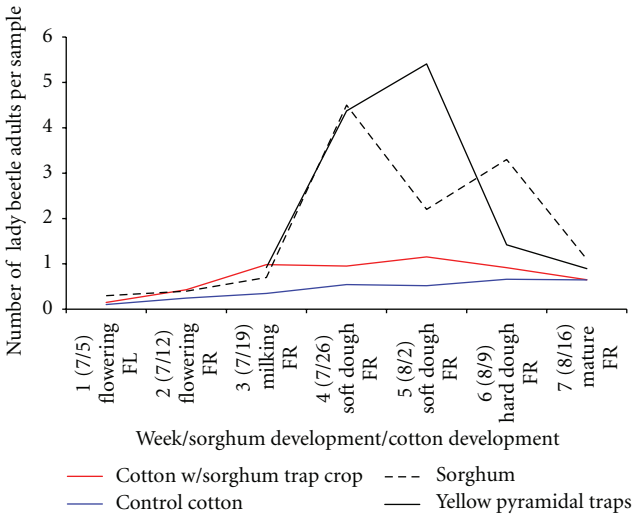

Figure 1: Mean number of lady beetle adults per sample in cotton with a sorghum trap crop, control cotton, sorghum, and yellow pyramidal traps in 2006. FL: flowers; FR: fruit. Number of lady beetles in yellow pyramidal traps divided by 10. Date refers to middle of sampling week.

higher on cotton with sorghum trap crops than on control cotton during weeks 2 through 6 (Table 3). Altogether, these results indicate that sorghum was a source of adult lady beetles moving into cotton fields. Because cotton aphids were observed on cotton early in the season, lady beetles were likely responding to populations of cotton aphids in cotton. Aphidophagous lady beetles, though, can be generalist predators; therefore, when they moved into fruiting cotton, they were likely also preying on other pest insects that feed on cotton fruit such as lepidopteran pests and stink bug eggs [28, 29].

In 2007, lady beetle abundance on sorghum followed a similar pattern as seen during 2006. Beetles first moved to flowering sorghum, and density peaked when sorghum heads reached the soft dough stage (Figure 2). Lady beetle density was significantly higher on cotton with sorghum trap crops than on control cotton during weeks 1 through 5 (Table 3). As above, these results suggest that sorghum can serve as a source of lady beetles dispersing to cotton.

Table 3: Number (mean ± SE) of lady beetle adults per 1.83 m of row in cotton with sorghum trap crops and control cotton in 2006 and 2007.

Year	Week	Cotton w/sorghum trap crop	Control cotton	$\lvert t \rvert$	df	P
2006	1	0.15 ± 0.02	0.106 ± 0.022	1.45	937	0.1465
	2	0.431 ± 0.039	0.246 ± 0.04	3.2	937	0.0014
	3	0.982 ± 0.076	0.349 ± 0.038	7.47	1132	0.0001
	4	0.952 ± 0.075	0.545 ± 0.052	4.51	1132	0.0001
	5	1.153 ± 0.094	0.52 ± 0.057	5.79	1132	0.0001
	6	0.918 ± 0.072	0.66 ± 0.053	2.91	1132	0.0037
	7	0.65 ± 0.059	0.648 ± 0.065	0.02	1327	0.9819
2007	1	0.611 ± 0.051	0.302 ± 0.039	4.6	503	0.0001
	2	0.447 ± 0.045	0.309 ± 0.036	2.4	536	0.0168
	3	0.732 ± 0.058	0.411 ± 0.045	4.39	563	0.0001
	4	0.637 ± 0.059	0.487 ± 0.049	1.97	413	0.049
	5	0.696 ± 0.075	0.479 ± 0.066	2.03	476	0.0432
	6	0.412 ± 0.047	0.338 ± 0.05	1.07	341	0.2845

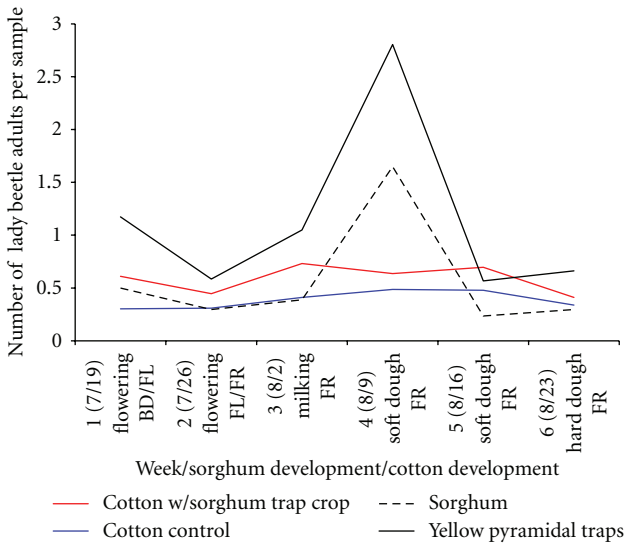

Figure 2: Mean number of lady beetle adults per sample in cotton with a sorghum trap crop, control cotton, sorghum, and yellow pyramidal traps in 2007. BD: buds; FL: flowers; FR: fruit. Number of lady beetles in yellow pyramidal traps divided by 10. Date refers to middle of sampling week.

In the current study, results suggest that adult lady beetles dispersed from sorghum into cotton. Previous studies also have demonstrated sorghum as a source of lady beetles moving into cotton. For example, populations of insect predators, including *H. convergens*, increased when feeding on greenbug in grain sorghum fields adjacent to cotton in Arizona [30, 31]. These predators dispersed into cotton as sorghum matured and the greenbug population declined. Cage studies also indicate that adult lady beetles disperse from sorghum into cotton in response to crop phenology and prey abundance [32]. In the current study, lady beetle density similarly declined as sorghum matured. In a study in Texas, as greenbug and corn leaf aphid numbers increased in sorghum, predators, including the predominant *Hippodamia* spp. predators, also increased [33]. They reported that predator levels in cotton began to increase at about the same time that predator density began to decrease in sorghum indicating that predators dispersed from sorghum into cotton. In fact, fluorescent dust marking demonstrated predator dispersal from sorghum into cotton. In another study using rubidium to mark predators in sorghum and cotton, *H. convergens* and *Scymnus loewii* Mulsant were documented to move from sorghum into cotton [32].

In these previous studies, adult lady beetles dispersed from sorghum into cotton in response to sorghum senescence and prey decline, but in our study, lady beetles continuously moved from sorghum to cotton throughout development of fruit in cotton. Although the reason for lady beetles continuously moving from sorghum into cotton was not determined, it was likely due to resource availability (e.g., prey, pollen, and extrafloral nectaries) in cotton. Perhaps, planting sorghum earlier would result in relaying lady beetles from senescing sorghum into cotton as documented in a 3 yr relay intercropping study in Texas [34]. There, the intercrops acted as a reservoir for predators, including lady beetles, during the noncotton season. These intercrops "relayed" the aphid predators from canola and wheat in the winter to sorghum in the spring and finally to cotton in the summer. Of the intercrop species tested, predator numbers were highest in sorghum. Average aphid abundance was lower in relay intercropped cotton than in isolated cotton, and average predator numbers were higher in relay intercropped cotton than in isolated cotton. Predators appeared in higher numbers earlier in the summer in relay intercropped cotton than in isolated cotton suggesting that this management strategy aids early colonization of predators in cotton, thereby inhibiting increase of the cotton aphid. In a 2 yr study in Texas, a sorghum relay strip-crop system enhanced numbers of predators, including lady beetles, and suppressed cotton aphid abundance in cotton [35]. It can be concluded from these two studies and the current study that incorporating a source crop for lady beetles in a cotton field can be a successful management tactic for control of cotton aphids. Also,

a multifunctional habitat of sorghum to detract stink bugs from feeding and ovipositing on cash crops, and using pheromone traps to capture and kill stink bugs has great potential for suppressing stink bugs in cotton while preserving lady beetles.

Lady beetles in this study were present in cotton fields with or without sorghum indicating that these natural enemies disperse into cotton from other plants. Peanut fields were adjacent to all the cotton fields, but early-season host plants such as corn and rye were also prevalent in these agricultural landscapes. Because each of these crops harbors lady beetles [29, 36, 37], they likely contributed lady beetles to sorghum and cotton. Nevertheless, placement of a strip of sorghum along the cotton field edge near peanut enhanced abundance of lady beetles in cotton. Possible explanations for this enhancement include providing newly abundant prey during senescence of corn and rye, providing new or preferred prey for adults developing in peanut, concentrating abundant prey, and thus lady beetles, next to cotton fields. Regardless of the mechanisms involved, a habitat of sorghum can be utilized in conserving biocontrol of these natural enemies in cotton.

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