Use of Winter Legumes as Banker Plants for Beneficial Insect Species in a Sorghum and Cotton Rotation System[1]

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Abstract Use of novel crops for bio-fuel production requires evaluating the potential for sound ecological and economical implementation in a particular region. We examined the pest and generalist beneficial insect species associated with various winter cover crops (including narrowleaf lupin, white vetch, Austrian winter pea, crimson clover, faba bean, and rye) as sources of colonists in 2 subsequent summer crops, sorghum and cotton. Sorghum is a potential cellulosic bio-fuel crop and cotton is commonly grown in the region and could be a viable low-input rotation for biofuel sorghum. Insects were sampled weekly over 3 ys in winter cover plots beginning in early spring and in the later planted crop plots beginning at the 15 cm height stage of the crops and continuing for 3 - 6 wks. Of the predators, coccinellids (Coleoptera: Coccinellidae) dominated and were consistently abundant in vetch, faba and lupin, as was the pea aphid, *Acyrthosiphon pisum* Harris (Hemiptera: Aphididae) and the aphid parasitoid, *Lysiphlebus testaceipes* Cresson (Hymenoptera: Aphiidae). *Orius* spp. (Hemiptera: Anthocoridae) dominated in lupin. Of the pest species, thrips spp. (Thysanoptera: Thipidae) were highest in lupin and pea, and stink bugs (Hemiptera: Pentatomidae) were highest in clover. No differences in chinch bugs (Hemiptera: Lygaeidae) were found among the covers. There was a 'relay' of these species into all of the summer crop plots from living winter crops. Boll damage from stink bugs was highest in the cotton following lupin, pea and fallow with fertilizer; there was no damage from chinch bugs in sorghum. Faba beans had declining stands over the 3 ys, suggesting that this species would not be a reliable winter crop in this system. Vetch and lupin may be the best candidates as banker plants because of their ability to consistently sustain pea aphids and coccinellids, the former which is a nonpest of sorghum and cotton.

Key words narrow-leaf lupin, white vetch, coccinellids, pea aphids, thrips, beneficial insects, biofuel crops, rotation systems

Agricultural practices that use conservation tillage and cover crops are promoted for their benefits to soil quality, weed suppression and water conservation (Schomberg et al. 2003). Also, they are noted for the ability to encourage biological control, with numerous cases where cover crops have been shown to increase beneficial species and/or reduce pest species in spatially and temporally associated crops (Broad et al. 2008a, 2008b, Danne et al. 2010, Mangan et al. 1995, Pullaro et al. 2006, Lundgren and

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Fergen 2010). Creating banker plant habitats for insect development and dispersal is also a benefit of cover cropping but entails building populations of generalist beneficial species on noncrop pests in the banker plant habitat for pest control in later-planted crops (Huang et al. 2011). Conversely, these banker plant cover crops may also promote the presence of pests and diseases (Bone et al. 2009), or may not target pests of the crop (Baggen and Gurr 1998). These efforts must focus on designing the best pest management strategy after assessing the costs and benefits of strategies for a specific cropping system.

For the last 3 yrs, several leguminous cover crops have been examined for their potential use in conservation and enhancement of beneficial insects for biological control in a biomass sorghum-cotton rotation system. Biomass sorghum is not currently grown in the region but is under consideration as a potential cellulosic bio-fuel feedstock. However, data are needed on production potential and management options for biomass sorghum grown integrated into rotation with a regional cropping system including cotton.

The objectives of this study were to determine (1) the insect pest and generalist beneficial assemblages associated with various leguminous winter covers, and (2) the potential for these assemblages to be 'relayed' into the later-planted sorghum and cotton crops.

Materials and Methods

Field plots. Thirty-six plots (11 by 11 m) were established at the ARS Sanders and Belflower research farms near Tifton, GA, in a completely randomized design with 9 cover treatments as insect refugia and 4 replications in late November in 2009, 2010 and 2011. Plots were separated on all sides by 1-m buffer strips. The winter cover treatments were Austrian winter pea (*Pisum sativum* L.), faba bean cv Banner (*Vicia faba* L.), blue lupin cv TifBlue-78 (*Lupinus pilosus* L.), white vetch cv Cahaba (*Vicia sativa* x *Vicia cordata* L.), crimson clover cv Dixie (*Trifolium incarnatum* L.), winter rye cv Wrens Arbuzzi (*Secale cearale* L.), and 3 controls: (1) fallow with standard fertilizer, (2) fallow with a natural fertilizer (Bulldog Soda), and (3) fallow with no fertilizer. Winter pea was planted in 20-cm rows, 1.25 cm depth at 78 kg per ha. Faba bean was planted in 46-cm rows by 19.0 cm spacing, 1.50 depth at 116 plants per ha. White vetch was planted in 20-cm rows, 1.25 cm depth at 22 kg per ha. Narrow-leaf lupin was planted in 20-cm rows, 1.25 cm depth at 78 kg per ha. Crimson clover was planted in 20-cm rows, 0.13 cm depth at 22.4 kg per ha. Rye was planted in 20-cm rows, 1.25 cm depth at 100 kg per ha. The previous summer rotation crops on these plots were forage pearl millet (2009), biomass sorghum (2010, 2011) or cotton (2009 - 2011). Pearl millet cv Tift 102 (*Pennisetum glaucum* L.) was planted 1 May in 2009. Cotton (*Gossypium hirsutum* L.) cv DP949B2RF was planted on 20 May in 2010 (Sanders) and cv DP1050B2RF was planted on 5 May in 2011 (Belflower) in 91-cm rows and 1 cm depth both years. Biomass sorghum cv Blade ES 5,200 (*Sorghum bicolor* Walp.) was planted on 21 May in 2010 (Belflower) and 5 May in 2011 (Sanders).

Insect sampling. Insects were sampled weekly in the winter cover crops using sticky cards (Olson Products, Medina) maintained under the crop canopy from 23 March to 30 June in 2009, 23 March to 23 June in 2010 and sweep nets in 2011 from 11 April to 25 April. Insects were similarly sampled weekly in the pearl millet from 7 May to 24 June in 2009, cotton and sorghum from 15 June to 30 June in 2010 and from 3 May to 15 June in 2011.

Insect pest species sampled included thrips (Thysanoptera: Thripidae) in cotton, the chinch bugs, *Blissus leucopterus* Say and *Nysius raphanus* Howard combined (Heteroptera: Lygaeidae), the greenbug aphid (*Schizaphis gramiuum* Rondani), the cornleaf aphid (*Rhopalosiphum maidis* Fitch) and the yellow sugarcane aphid (*Sipha flava* Forbes) combined (Heteroptera: Aphididae) and the sorghum midge (*Contarinia sorghicola* Coquillett) (Diptera: Cecidomyiidae), in sorghum, and the stink bug species, *Euschistus servus* Say, *Chinava hilaris* Say and *Nezara viridula* L. combined (Heteroptera: Pentatomidae) in both crops in 2011. In all 3 ys, no sorghum aphids or sorghum midges were found in the cover crops or in the sorghum, so we do not discuss these species further. Thrips numbers were estimated by counting all adults and larvae within two 2.5 by 2.5 cm randomly selected areas on each side of the card.

Generalist insect predators sampled included, *Geocoris* spp., *Orius* spp., and the coccinellid species, combined, *Coleomegilla maculata* De Geer, *Coccinella septempunctata* L., *Harmonia axyridis* Pallas, *Hippodamia covergens* Guérin-Méneville, *Scymnus* spp. (Coleoptera: Coccellinidae). Generalist parasitoids sample included the tachinid larval parasitoids, combined, *Eucelatoria bryani* Sabrosky and *Lespesia archippivora* Riley (Diptera: Tachinidae), the aphid parasitoid, *Lysiphlebus testaceipes* Cresson, and scelonid egg parasitoids (Hymenoptera: Scelionidae).

Cotton and sorghum plants. In 2010 and 2011, damage was assessed from stink bugs in cotton and chinch bugs in sorghum. Blade is photoperiod sensitive and flowers after November in southeastern GA. Because stink bugs are primarily seed and fruit feeders, this biofuel cultivar evaded attack and damage. Three cotton bolls were collected from the top 1/3 of 10 randomly-selected plants per plot to assess boll damage from stink bugs. The lower sheaths of sorghum were removed from 10 randomly selected plants per plot to assess chinch bug damage.

Nitrogen levels in cotton bolls and the whole plant of sorghum also were analyzed. For cotton, boll tissue nitrogen levels were determined from the seed and lint combined and from the boll husks. Whole cotton plants were removed from two 1.52 m (L) by 0.91 m (W) rows for a total area per plot of 2.77 m^2 and dried at 60°C for > 10 d. Lint and seeds of cotton were separated from boll husks for all the bolls that were open after drying and ground separately in a Wiley mill. Whole sorghum plants were harvested from the inner plot 3 rows (2 m) along the entire plot length (11 m) using a silage chopper. Total nitrogen for all plant tissue was analyzed by combustion on an Elementar Americas Vario EL III nitrogen analyzer.

Statistics. As the insect data were heteroscadastic and the error variance could not be stabilized, a non parametric Kruskal-Wallace test (Statsoft, Inc. 2003) was used to analyze the effect of cover crop on species numbers. Boll damage was analyzed with a Chi-square test. Untransformed (2010) and log (2011) transformed (Levene's test > 0.05.) nitrogen levels in cotton seed and lint combined, boll husks and sorghum whole plants were analyzed with ANOVA with Tukey's HSD used to separate the means (SAS Institute, Inc. 1998).

Results

Sanders 2009 sorghum. Parasitoids were significantly higher in faba and significantly lower in rye (Fig. 1a, chi-square$_8$ = 52.80, $P < 0.001$), whereas predators were significantly higher in pea and significantly lower in rye (Fig. 1a, chi-square$_8$ = 69.51, P = < 0.001). Chinch bugs did not differ among the winter covers (Fig. 1a, chi-square$_8$ = 7.12, P = 0.524). Parasitoids were significantly higher in sorghum

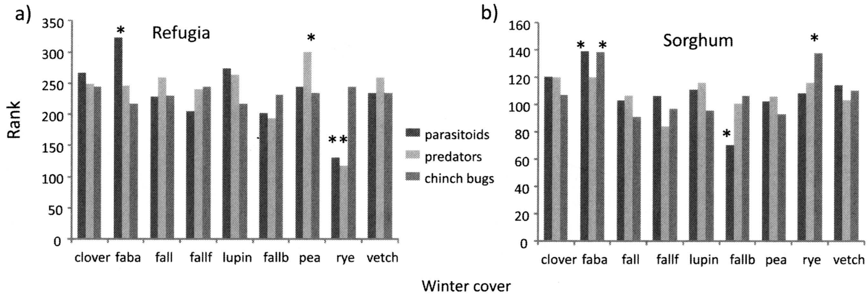

Fig. 1. Kruskal-Wallace test of parasitoids, predators and chinch bugs collected with sticky cards across all plots in a) the refugia and b) the sorghum at Sanders in 2009. * $P < 0.05$.

following faba and significantly lower following fallow with natural fertilizer (Fig. 1b, chi-square$_8$ = 17.10, P = 0.029). Predators did not differ in sorghum following any of the covers (Fig. 1b, chi-square$_8$ = 7.16, P = 0.519). Chinch bugs were significantly higher in sorghum following faba and rye (Fig. 1b, chi-square$_8$ = 52.80, P < 0.001).

Sanders 2010 cotton. Parasitoids did not differ among the winter covers (Fig. 2a, chi-square$_8$ = 7.12, P = 0.523), but predators were significantly higher in lupin and vetch and significantly lower in rye (Fig. 2a, chi-square$_8$ = 30.60, P = < 0.001). Thrips were significantly higher in lupin and significantly lower in fallow with no fertilizer (Fig. 2a, chi-square$_8$ = 22.29, P = 0.004). There were no significant differences in parasitoids (Fig. 2b, chi-square$_8$ = 5.66, P = 0.684), predators (Fig. 2b, chi-square$_8$ = 4.44, P = 0.397) and thrips spp. (Fig. 2b, chi-square$_8$ = 13.51, P = 0.094) in cotton following any winter covers.

Belflower 2010 sorghum. Parasitoids were significantly higher in lupin and significantly lower in vetch (Fig. 2c, chi-square$_8$ = 18.00, P = 0.021), whereas predators were significantly higher in clover, faba, lupin, pea, and vetch and significantly lower in rye (Fig. 2c, chi-square$_8$ = 36.42, P < 0.001). Chinch bugs were significantly higher in rye (Fig. 2c, chi-square$_8$ = 25.42, P = 0.001). There were no significant differences in parasitoids (Fig. 2d, chi-square$_8$ = 11.29, P = 0.186), predators (Fig. 2d, chi-square$_8$ = 6.07, P = 0.639) or chinch bugs (Fig. 2d, chi-square$_8$ = 1.84, P = 0.986) in sorghum following any winter covers. Although chinch bugs were present on the lower stem of the sorghum plants, no plant damage was observed.

Belflower 2011 cotton. Parasitoids were significantly higher in lupin, pea and vetch (Fig. 3a, chi-square$_8$ = 28.89, P < 0.001). Predators were significantly higher in clover, lupin and vetch and significantly lower in rye, and fallow with synthetic and natural fertilizer and fallow without fertilizer (Fig. 3a, chi-square$_8$ = 79.15, P = < 0.001). Thrips were significantly higher in pea and significantly lower in fallow with natural fertilizer and fallow with no fertilizer (Fig. 3a, chi-square$_8$ = 36.18, P < 0.001). Stink bugs were significantly higher in clover (Fig. 3a, chi-square$_8$ = 25.54, P = 0.001), and there were no significant differences in parasitoids (Fig. 4b, chi-square$_8$ = 11.06, P = 0.423 and predators (Fig. 3b, chi-square$_8$ = 11.06, P = 0.198) in cotton following any winter covers. No thrips and stink bugs were found in cotton.

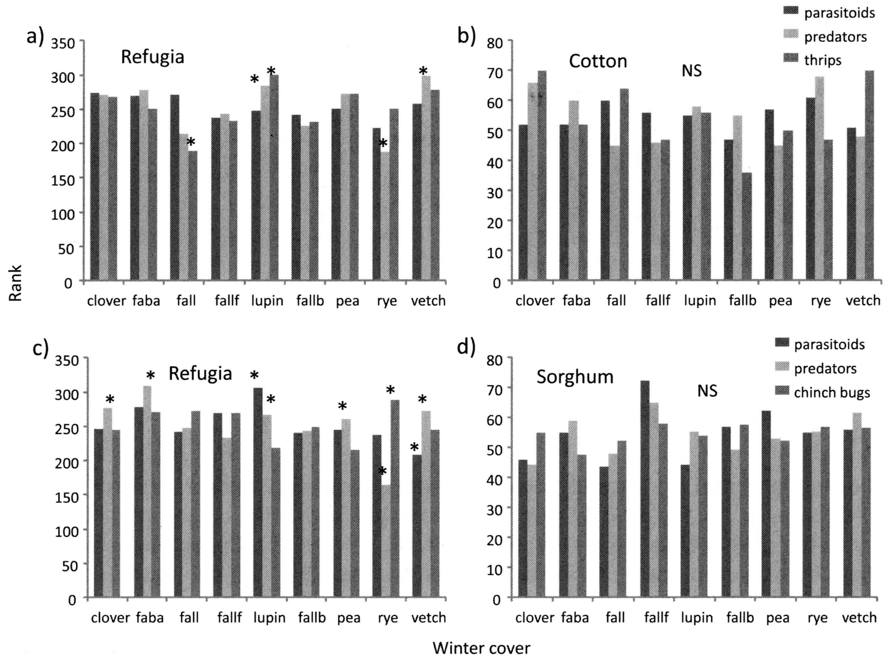

Fig. 2. Kruskal-Wallace test of parasitoids, predators and thrips collected with sticky cards across all plots in a) the refugia and b) the cotton at Sanders in 2010, and parasitoids, predators and chinch bugs in c) the refugia and d) the sorghum at Belflower 2010. * $P < 0.05$.

Sanders 2011 sorghum. Parasitoids did not differ among the covers (Fig. 3c, chi-square$_8$ = 6.92, P = 0.545), but predators were significantly higher in the clover, lupin and vetch and significantly lower in the rye, fallow natural fertilizer, fallow with synthetic fertilizer, and fallow without fertilizer (Fig. 3c, chi-square$_8$ = 69.51, P = < 0.001). No differences were detected among the cover crops for chinch bugs (Fig. 3c, chi-square$_8$ = 14.81, P = 0.063). Stink bugs, however, were significantly higher in clover (Fig. 3c, chi-square$_8$ = 30.96, P < 0.001). No differences in predators (Fig. 3d, chi-square$_8$ = 6.17, P = 0.628) or chinch bugs (Fig. 3d, chi-square$_8$ = 8.00, P = 0.435) were found in the sorghum following any of the covers. No parasitoids and stink bugs were found in the sorghum. On 4 September, chinch bugs were significantly higher in the sorghum following vetch and lupin and significantly lower in sorghum following fallow with no fertilizer (χ^2_8 = 723.48, P < 0.001). Although chinch bugs were present on the lower stem of the sorghum plants, no plant damage was observed.

Cotton and sorghum. In 2010, boll husk nitrogen levels were significantly higher in cotton grown after lupin than in cotton grown after rye (Table 1, $F_{8/71}$ = 2.79, df = 8, P = 0.010). In 2010, nitrogen levels in boll lint and seed combined did not differ among any of the winter cover plots (Table 1, $F_{8/71}$ = 0.36, df = 8, P = 0.939). In 2010, nitrogen levels from whole sorghum plants were significantly higher in sorghum after lupin than sorghum after rye, and all three fallow controls (Table 1, $F_{8/71}$ = 2.84, P < 0.010).

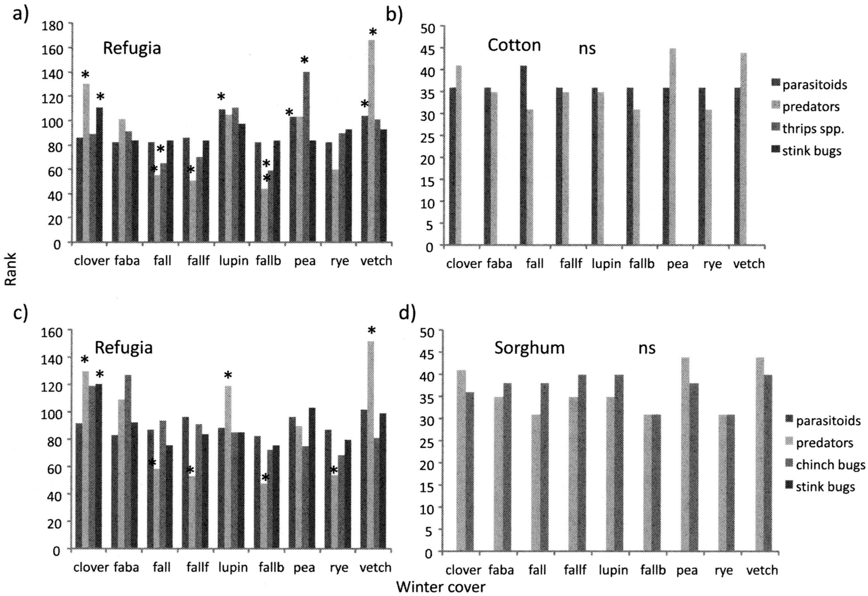

Fig. 3. Kruskal-Wallace test of parasitoids, predators, thrips and stink bugs collected with sweep nets across all plots in a) the refugia and b) the cotton at Belflower in 2011, and parasitoids, predators, chinch bugs and stink bugs in c) the refugia and d) the sorghum at Sanders 2011. * $P < 0.05$.

In 2011, boll husk nitrogen levels did not differ among any of the winter covers (Table 1, $F_{8/71} = 1.44$, $P = 0.198$). In 2011, nitrogen levels in boll lint and seed combined were significantly higher in the crop following lupin and vetch than after faba, rye, fallow with no fertilizer and clover (Table 1, $F_{8/71} = 5.42$, $P < 0.001$). In 2011, although nitrogen levels in whole plants of sorghum were marginally significant, there were statistical differences among the winter cover means (Table 1, $F_{8/71} = 2.16$, $P = 0.049$).

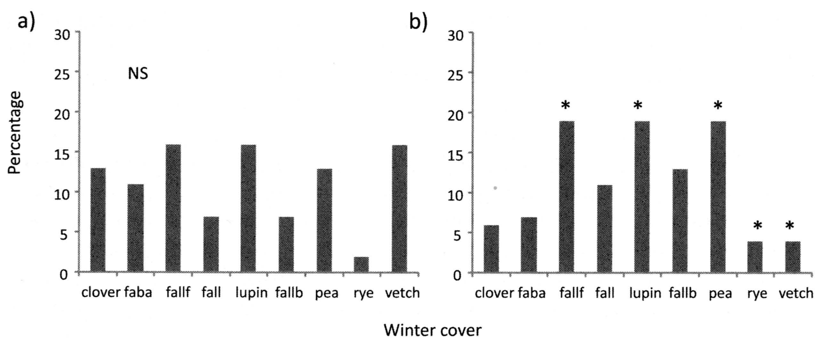

Fig. 4. Boll damage from stink bugs from 10 plants per plot in a) 2010 and b) 2011. $n = 120$. * $P < 0.05$.

Table 1. Dry weight nitrogen (kg/ha) levels in cotton boll lint and seed combined, cotton boll husks, and the whole plant of sorghum planted after winter covers: fallow with synthetic fertilizer (fallf), faba, lupin, rye, pea, clover, vetch, fallow with natural fertilizer (fallb), and fallow with no fertilizer (fall).

2010	Sanders		Belflower
	Lint and seed	Boll husk	Sorghum
Fallf	15.42 ± 2.38a	4.50 ± 0.34ab	35.57 ± 5.81b
Faba	13.44 ± 1.61a	4.24 ± 0.28ab	46.15 ± 13.29ab
Lupin	12.33 ± 1.27a	5.48 ± 0.56a	78.35 ± 15.77a
Rye	13.27 ± 0.91a	3.47 ± 0.20b	29.27 ± 4.19b
Pea	12.87 ± 2.66a	5.03 ± 0.40ab	37.03 ± 8.18ab
Clover	14.48 ± 1.51a	5.07 ± 0.48ab	36.96 ± 7.29ab
Vetch	13.05 ± 1.88a	4.02 ± 0.44ab	50.59 ± 9.60ab
Fallb	14.20 ± 1.49a	4.32 ± 0.30ab	27.54 ± 7.05b
Fall	14.98 ± 1.82a	3.93 ± 0.31ab	32.09 ± 6.43b
2011	Belflower		Sanders
	Lint and seed	Boll husk	Sorghum
Fallf	14.50 ± 1.94abc	2.32 ± 0.28a	37.52 ± 5.70a
Faba	10.16 ± 1.14bc	1.25 ± 0.12a	29.77 ± 3.46a
Lupin	23.43 ± 5.15a	3.15 ± 0.63a	53.24 ± 14.16a
Rye	9.72 ± 0.96bc	1.08 ± 0.07a	19.37 ± 2.10a
Pea	20.63 ± 3.81ab	2.79 ± 0.56a	49.28 ± 13.19a
Clover	7.75 ± 1.24c	2.76 ± 1.69a	23.97 ± 4.39a
Vetch	24.15 ± 3.60a	2.47 ± 0.24a	47.69 ± 10.54a
Fallb	15.97 ± 2.79abc	1.97 ± 0.21a	39.62 ± 4.16a
Fall	8.17 ± 0.92bc	1.23 ± 0.29a	26.30 ± 6.52a

Means (± SEM) followed by the same lower case letter are not significantly different ($P > 0.05$)

Boll damage from stink bugs did not differ among the plots associated with any of the winter covers in 2010 (Fig. 4a, chi-square$_8$ = 7.97, P = 0.437). In 2011, boll damage was significantly higher in the cotton following lupin, pea and fallow with fertilizer, and significantly lower in the cotton following rye and vetch (Fig. 4b, chi-square$_8$ = 16.57, P = 0.035). There was no significant replication effect on boll damage in 2010 (χ^2_{35} = 49.10, P = 0.057). There was significant replication effect in 2011 on boll damage (χ^2_{35} = 53.74, P = 0.022), but no correlation between boll damage and nitrogen content of seeds and lint (0.004) and boll husks (0.25) was found (Spearman Rank, $P > 0.05$).

Species patterns. There was a significant correlation between thrips and *Orius* spp. numbers both years cotton was planted among all of the covers (Spearman Rank

Order Correlations, 0.640, $P < 0.05$), especially in lupin (0.715, $P < 0.05$) and pea (0.761, $P < 0.05$). Over all years, coccinellids were the dominant generalist predators and were consistently found in high numbers in faba, vetch, and lupin. The dominant species all 3 ys was the convergent lady beetle, *H. convergens.* The pea aphid, *Acyrthosiphon pisum* Harris (Heteroptera: Aphididae) and aphid parasitoid, *L. testaceipes,* were consistently found in the faba, vetch, and lupin covers, although *L. testaceipes* numbers were low, and they were never found in pea. *Geocoris* spp. numbers consistently dominated in vetch and clover and tachinid spp., scelionids and *Orius* spp. dominated in the lupin and pea covers.

Discussion

Over the 3-yr research period, generalist predator and parasitoid assemblages were highest in the faba, vetch and lupin crops. Of the pest species, thrips were highest in the lupin and pea covers, chinch bugs were highest in rye covers, and stink bugs were highest in the clover covers. Predators, parasitoids, thrips and chinch bugs were 60 - 80% lower than their peak abundance in the winter covers at the time of the first sample in the crops in 2009 and 2010 but were found in equal numbers in the covers as in the crops, indicating relay from the winter cover crops to the summer crops. There was no obvious relationship between any winter cover with species presence in the summer crops. In 2011, crops were first sampled on 2 June, but no species except chinch bugs were found in either the refugia or the newly-planted crops, suggesting no relay of beneficial species into the cotton or sorghum. Chinch bugs remained relatively abundant in faba, which had a very poor stand in 2011, and the fallow no fertilizer controls likely because of the presence of cutleaf evening primrose (*Oenothera laciniata* Hill, Onagraceae).

By the third year, faba stands were very poor, indicating that this species may not be a reliable cover for this system. Although thrips were highest in lupin in 2010, their numbers in lupin in 2011 were no higher than the other covers. There also was a significantly higher number of their predator, *Orius* spp., in the lupin compared with the other covers. *Orius* species were not as high in lupin in 2010, but there was a strong correlation among all covers both years between *Orius* spp. and thrips numbers. *Orius* spp. can move rapidly; Prasifka et al. (1999) found that they moved 22 - 32 m per day in a cotton-sorghum system. Ramachandran et al. (2001) found that high suppression of thrips by *Orius* spp. in peppers occurs when the pest-to-predator ratio was 40:1. Thus, the risk to later-planted cotton seedlings from thrips population build-up in winter covers may depend in part on the density of *Orius* spp. in the cover.

In 1 of the 2 years, cotton plants following lupin, pea and fallow with fertilizer winter covers had higher boll damage from stink bugs, and cotton after rye and vetch had the lowest boll damage. There was no correlation between nitrogen content of bolls and stink bug damage, suggesting that other factor(s) influence stink bug feeding. We found stink bugs in all of the winter covers, but more so in clover. Stink bugs prefer fruiting structures of cotton which were not present until late June each year when plants had several squares. Therefore, it is not likely that stink bugs colonized directly from the winter covers. Stink bugs are highly mobile; Kiritani et al. (1967) found that *N. viridula* readily flies 1 km or more. Stink bugs are highly polyphagous (McPherson and McPherson 2000) and may have left senescing winter covers to find other suitable hosts, such as corn. Nevertheless, it would be undesirable to build populations of stink bugs in the winter covers. Stink bugs differ in their ability to develop and survive on noncrop vegetation (Panizzi 1997). To prevent stink bug population build-up early in the year, different winter varieties of prospective covers could be tested and implemented with the variety chosen that has the greatest negative effect on stink bug longevity and fecundity.

The bio-fuel sorghum cultivar harbored very few insects overall during the sampling period. Although we found chinch bugs on the sorghum plants later in the season, there was no plant damage from these species. The stalks of this sorghum variety are extremely sclerified, suggesting that chinch bugs may not be able to pierce them, but no research has examined insects associated with this sorghum variety. Future efforts will sample a broader range of pest species, especially lepidopteran larvae, during the growing season to ascertain other potential pests of this crop.

Of the winter cover crops, lupin and vetch have the highest potential to build beneficial species for potential control of pests in cotton and sorghum. This is evidenced by coccinellid species assemblages that were promoted in the covers by the presence of the pea aphid, which is a nonpest of cotton and sorghum. However, the relay of thrips onto cotton seedlings from these covers is a potential drawback to their use in this rotation system. But, a portion of the cover crop could be maintained as a refuge for beneficial species and the remainder of the cover crop area rolled so that there is ground cover in the field. This has been shown to reduce thrips colonization onto cotton seedlings (Olson et al. 2006). Altering the rotation to a sorghum-sorghum-cotton may also help to reduce thrips numbers.

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