# Sorghum as a Trap Crop for *Nezara viridula* L. (Heteroptera: Pentatomidae) in Cotton in the Southern United States

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**ABSTRACT** The southern green stink bug, *Nezara viridula* L., may disperse from alternate host plants, especially corn, *Zea mays* L., and peanuts, *Arachis hypogaea* L., into cotton, *Gossypium hirsutum* L. Trap crops may be useful to intercept dispersing stink bugs. Therefore, the ability of sorghum, *Sorghum bicolor* L. Moench, to trap *N. viridula* adults in cotton was studied for 3 yr. The 2002 experiment was designed to compare the ability of small plots of sorghum and cotton to trap *N. viridula* along the interface, or common boundary, of a corn and cotton field. In the 2003 experiment, cotton fields with sorghum and cotton plots planted along the interface of a corn–cotton farmscape were compared with cotton fields without these interface plots. In both experiments, *N. viridula* adults strongly preferred sorghum to cotton, and marking studies revealed that most *N. viridula* adults that dispersed into sorghum remained in sorghum instead of moving into cotton. Overall, percent parasitism of *N. viridula* adults by *T. pennipes* was higher in sorghum trap crop plots than in interface cotton control plots. In 2003, density of *N. viridula* adults was lower in cotton fields adjoining sorghum trap crop plots than in control cotton fields. Furthermore, economic threshold for *N. viridula* was not reached along the interface of the corn–cotton farmscape in any cotton field with sorghum plots. In contrast, economic threshold was reached in 61.5% of the control cotton fields. In the third season, a full-scale field experiment was conducted to determine the effectiveness of sorghum, planted in a strip along the length of the interface of a peanut–cotton farmscape, as a trap crop in cotton. Before the test, each cotton field was partitioned into eight side-edge and three interior block locations. Each field had four sides with side A occurring along the interface of the field. Edge 1 was 0–3.66 m from the outside edge of the field, and edge 2 was 3.66–7.31 m from the outside edge of the field. In control cotton fields, density of *N. viridula* adults was much higher in the interface side in edge one than in any other side-edge location, strongly indicating that *N. viridula* adults dispersed from peanuts into these cotton fields. Control cotton fields had higher numbers of *N. viridula* adults in the interface side in edge one compared with cotton fields with sorghum trap crops. Overall, in 2004, control cotton fields were treated with insecticides for control of *N. viridula* 1.4 times, whereas cotton fields with sorghum trap crops were treated for control of this stink bug only 0.2 times. These results show that sorghum can serve as a trap crop for *N. viridula* adults in cotton fields.

**KEY WORDS** Southern green stink bug, *Trichopoda pennipes*, trap crop, preference, dispersal

The southern green stink bug, *Nezara viridula* L., is a widely distributed pest in tropical and subtropical regions of the world, causing economic damage to various field crops including corn, *Zea mays* L., and soybean, *Glycine max* L. Merrill (McPherson and McPherson 2000). In the United States, *N. viridula* has increased in importance as a pest in cotton, *Gossypium hirsutum* L., mainly because of the decrease in use of broad-spectrum insecticides in this crop (Greene and Turnipseed 1996). For example, total losses during 2004 for stink bug pests, including *N. viridula*, *Acrosternum hilare* (Say), and *Euschistus servus* (Say), were estimated at $9.7 million for the cotton industry across the United States (Williams 2005).

The host plant range of *N. viridula* encompasses over 30 dicotyledon families and a few monocotyledon families (Todd 1989, Panizzi 1997). Phenology of stink bugs is closely tied to crop phenology and seasonal succession of host plants (Velasco and Walter 1992). Host plants are most susceptible to stink bugs during fruit/pod formation (Hall and Teetes 1982, Schumann and Todd 1982, Riley et al. 1987, Bundy and McPherson 2000). As fruit of host plants reach maturity and harden, plants become less attractive, and stink bugs disperse to more succulent plants (Toscano and Stern 1976, Todd and Herzog 1980, Hall and Teetes 1982,

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Jones and Sullivan 1982). In northern California, stink bugs tend to move from one vegetational patch to another in a farmscape, a within-farm configuration of many patches of vegetation (Ehler 2000). In the southeastern United States, a farmscape can consist of wooded areas, weedy field edges, and a variety of field crops including corn, peanuts, *Arachis hypogaea* L., and cotton. In this farmscape, *N. viridula* can develop on alternate host plants before dispersing into cotton (Turnipseed et al. 1995). Corn and peanuts in particular can be major sources of *N. viridula* for cotton fields (unpublished data).

One strategy for managing dispersing pests is trap cropping where an attractive plant species is used to arrest these pests and reduce the likelihood of them entering the cash crop (Hokkanen 1991). In the United States, early-maturing or early-planted soybean can be used to trap *N. viridula* in soybean fields (Newsom and Herzog 1977, McPherson and Newsom 1984, Todd and Schumann 1988). In New Zealand, trap cropping using black mustard, *Brassica nigra* L., is an effective control strategy for *N. viridula* (Rea et al. 2002). Researchers have recognized that stink bugs can devastate bolls in edges of cotton when they disperse from other crops into cotton and so planting a trap crop for *N. viridula* at the right time and place in this farmscape could be a good approach for control of these pests (S. G. Turnipseed, personal communication).

In the United States, the tachinid fly, *Trichopoda pennipes* (F.), is one of the most successful parasitoids of *N. viridula* nymphs and adults (Todd and Lewis 1976, Buschman and Whitcomb 1980, Jones and Sullivan 1982, McPherson et al. 1982, Temerak and Whitcomb 1984, Menezes et al. 1985, Jones 1988). These parasitoids may have difficulty in shifting their habitats to follow the seasonal movement of their hosts. The problem of dispersal by these natural enemies can be mitigated by incorporating a trap crop to provide the basic resources, including hosts, in relatively close temporal and spatial association within the farmscape. In soybean, 70–85% of the stink bug population can be concentrated in a trap crop that covers only 1–10% of the total crop area (McPherson and Newsom 1984). This localized aggregation of *N. viridula* could lead to an enhanced numerical and functional response of *T. pennipes.* Under this scenario, trap crops that enhance *T. pennipes* may be able to reduce the likelihood of *N. viridula* populations increasing and dispersing to the main crop.

Sorghum is an important host plant for panicle-feeding stink bugs including *N. viridula* in several southern states in the United States, including Georgia (Wiseman and McMillian 1971), Texas (Hall and Teetes 1982), Arkansas (J. K. Greene, personal communication), and Mississippi (J. Gore, personal communication), and thus it was considered to have potential as a trap crop for this stink bug. Consequently, the primary objective of this project was to evaluate the ability of sorghum to trap *N. viridula* adults as they disperse from corn or peanuts into adjacent cotton fields. In addition, parasitism of *N. viridula* adults by *T. pennipes* was measured and compared between sorghum and cotton treatments. This paper describes three trap crop experiments, the first comparing the ability of small plots of sorghum and cotton to trap *N. viridula* along the interface, or common boundary, of a corn and cotton field. In the second season, cotton fields with sorghum trap crop plots and cotton control plots planted along the interface of a corn–cotton farmscape were compared with cotton fields without these plots. Last, a full-scale field experiment was conducted to determine the effectiveness of sorghum, planted in a strip along the length of the interface of a peanut–cotton farmscape, as a trap crop for *N. viridula* in cotton.

## Materials and Methods

**Insect Species.** Adult *N. viridula* were identified using the species key in McPherson and McPherson (2000). The descriptions of male and female *N. viridula* from Jones (1918) were used to determine sex of observed adults. In 2002 and 2003, ≈200 *N. viridula* adults with at least one tachinid egg on the exoskeleton were collected from the field and held for emergence of adult parasitoids in the laboratory. *Trichopoda pennipes* was the only parasitoid that emerged from these field-collected adults. Voucher specimens of all insects are held in the USDA–ARS, Crop Protection and Management Research Laboratory, Tifton, GA.

**Effectiveness of Sampling Technique.** To verify that the sampling technique was effective for sampling *N. viridula* adults in both sorghum and cotton, random samples of insects in one commercial field of sorghum and two commercial fields of cotton were obtained before and after an application of dicrotophos (Bidrin 8; Amvac, Los Angeles, CA). For both sorghum and cotton, whole plant sampling was used, and a sample consisted of all *N. viridula* adults within 0.91 m of a row. Dicrotophos, the standard organophosphate used for control of *N. viridula* in cotton (Greene et al. 2001), was applied at a rate of 292.3 ml/ha using normal agronomic practices. *Nezara viridula* adults were alive in all samples acquired before insecticide application and dead in all samples obtained after application of dicrotophos. In the sorghum field, live insects (108 samples) were sampled 3 d before application of dicrotophos, and dead stink bugs (108 samples) were sampled 2 d after insecticide treatment. In cotton field A, live stink bugs (120 samples) were sampled 3 d before insecticide application, and numbers of dead stink bugs (162 samples) were determined 2 d later. In cotton field B, live stink bugs (37 samples) were counted in the morning, the field was sprayed with the insecticide on the afternoon of the same day, and dead stink bugs (62 samples) were sampled 3 d later.

**2002 Experiment.** This trap crop experiment was conducted on an ≈8-ha commercial corn–cotton farmscape in Mystic, GA. The corn field associated with this cotton field was ≈8 ha. An open-panicle sorghum variety, DeKalb E57, was planted at a rate of

| Corn Field | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cotton control plot R1** | | | **Sorghum trap crop plot R1** | | | **Sorghum trap crop plot R2** | | | **Cotton control plot R2** | | | **Cotton control plot R3** | | | **Sorghum trap crop plot R3** | | |
| **Field Cotton Plot** | | | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | 45 | | | 45 | | | 45 | | | 45 | | | 45 | | | 45 | |
| 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| | 90 | | | 90 | | | 90 | | | 90 | | | 90 | | | 90 | |
| 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 | 120 |
| | 150 | | | 150 | | | 150 | | | 150 | | | 150 | | | 150 | |
| 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 | 180 |

**Fig. 1.** Diagrammatic representation of the trap crop experimental plots for 2002 and 2003 (not drawn to scale). Each interface treatment, sorghum trap crop or cotton control, was randomly assigned to a plot within a block for each of three blocks (R1–R3) in a randomized complete block (RCB) design (2 treatments × 3 replicates). This diagram represents the randomization for 2002. The cotton field adjacent to the interface plots was divided into six field cotton plots so that each interface plot was associated with a field cotton plot. In the cotton field, each block refers to a 15 by 15-m area in which a random sample was obtained. The number represents the greatest distance (m) in the block away from the interface plots, i.e., 15 means 1–15 m away from the interface plots.

25,500 seeds/ha using a two-row John Deere (Deere & Co., Moline, IL) planter. Delta Pine 5690 Roundup Ready cotton was used. In sorghum and cotton, *N. viridula* fifth instars and adults, including those parasitized by the tachinid *T. pennipes*, were monitored weekly to biweekly throughout the cotton season. Whole plant sampling was used in both crops, and a sample consisted of all *N. viridula* adults on all plants within 0.91 m of a row.

The experiment was designed to compare the ability of small plots of sorghum and cotton to trap *N. viridula* along the interface, or common boundary, of a corn and cotton field as stink bugs dispersed from corn. Six equally sized (45 m long by 11 m [12 rows] deep) plots (experimental units) were established along the interface of the farmscape. These six plots were divided into three blocks. Each treatment, sorghum trap crop and cotton control, was randomly assigned to a plot within a block for each of three blocks in a randomized complete block (RCB) design (2 treatments × 3 replicates). For the first experiment, the three treatment replicates, or blocks, appeared along the interface of the field as follows: (1) cotton–sorghum, (2) sorghum–cotton, and (3) cotton–sorghum (Fig. 1). For sampling purposes, each cotton and sorghum treatment plot was subdivided into three 15-m sections (length of row). In sorghum, three random samples were obtained per 15-m section of row per planting date (9 samples per row; 36 samples per planting date). All rows with sorghum panicles were sampled. In cotton control plots, six randomly selected plants per section were sampled (18 plants/plot). Regarding collected data, each RCB was a split-split plot in space (sampling location) and time (sampling date).

Sorghum was planted on three dates (2 wk between plantings) in all three experiments to ensure that a sufficient supply of panicles was available to *N. viridula* adults during the time they could be dispersing from corn. For many years, stink bug populations have been observed to disperse into the edge of a cotton field from a source of these pests (unpublished data). Therefore, the first planting date was placed adjacent to corn or peanuts, sources of stink bugs. The second and third planting of sorghum followed the first and second planting, respectively. The three planting dates for sorghum were 13 May, 23 May, and 3 June 2002. For each planting date, sorghum was planted in four rows. All cotton treatments were planted on the same date (4 June 2002). Sorghum and cotton rows were parallel to the edge of the corn field.

The cotton field adjacent to the above arrangement of sorghum trap crop and cotton control plots was divided into six cotton field plots, 45 m long by 180 m deep, in a manner such that each interface plot was associated with a field cotton plot (Fig. 1). The purpose of these field cotton plots was to determine the extent the interface treatments could reduce dispersal of *N. viridula* adults into the cotton field adjacent to these plots. Cotton rows in these field plots were planted parallel to the edge of the corn field. For sampling purposes, each field cotton plot was subdivided into three 15-m sections (length of row; Fig. 1). The field cotton plots were further subdivided in 15 by 15-m sampling units representing distance away (1–15, 16–30, 31–45, 46–60, 61–90, 91–120, 121–150, and 151–180 m) from the interface plots. A single random sample was obtained in each sampling unit designated by a number in the field cotton plots in Fig. 1. Regarding collected data, each RCB was a split-split plot in space (sampling location) and time (sampling date). A 9-m cotton buffer occurred between adjacent plots (not shown on Fig. 1). This buffer and the large size of the plots were used to ensure that the plots were independent of each other, and no insect samples were obtained from these cotton buffers.

**2003 Experiment.** In the second season, cotton fields with sorghum trap crop and cotton control plots planted along the interface of a corn–cotton farmscape were compared with cotton fields without these interface plots. Before the study, 17 corn–cotton commercial farmscapes were found in various locations in Irwin County, GA. Cotton fields ranged from 8 to 10 ha, and corn fields associated with these cotton fields ranged from 8 to 12 ha. Cotton fields with and without sorghum traps were assigned randomly to 4 and 13 farmscapes, respectively, similar to a completely randomized design (Box et al. 1978).

In fields with sorghum trap crop plots, an arrangement of interface plots and field cotton plots similar to that of the 2002 experiment was established for each of the treatment farmscapes (Fig. 1). In field 1, the randomization of treatments resulted in the following three pairs of blocks: (1) cotton–sorghum, (2) sorghum–cotton, and (3) cotton–sorghum. In field 2, the randomization of treatments resulted in the following three pairs of blocks: (1) sorghum–cotton, (2) sorghum–cotton, and (3) cotton–sorghum. In field 3, the randomization of treatments resulted in the following three pairs of blocks: (1) cotton–sorghum, (2) cotton–sorghum, and (3) sorghum–cotton. In field 4, the randomization of treatments resulted in the following three pairs of blocks: (1) cotton–sorghum, (2) sorghum–cotton, and (3) cotton–sorghum. The DeKalb E57 variety of sorghum was planted on 12, 20, and 28 May 2003. Delta Pine 5690 Roundup Ready cotton was planted on 22 April 2003. In these cotton fields with sorghum trap crop plots, sampling was accomplished in the same manner as in the previous experiment. For sampling purposes, each of 13 control cotton fields without trap crops was subdivided into four sections. These sections were further subdivided into sampling units representing distance away (1–15, 16–30, 31–45, 46–60, 61–90, 91–120, 121–150, and 151–180 m) from the interface of the farmscape. Three random samples were obtained in each of these sampling areas.

**Dispersal.** To examine the propensity of *N. viridula* adults to disperse from the treatment plots in which they were observed, every adult was marked as it was located during the sampling process. A medium line, opaque, oil-based paint marker (Sanford, Bellwood, IL) was used to paint a specific mark on the prothorax of the captured insect. In 2002, a combination of color and type of mark was used to designate the specific treatment plot (e.g., sorghum interface plot replicate 1) and the date the insect was found. In 2003, the mark indicated only the specific treatment plot in which the stink bug was originally located. When marked insects were located in subsequent sampling events, the type of mark and specific treatment plot in which the insect was found at that time was recorded.

**2004 Experiment.** A full-scale field experiment was conducted to further examine the effectiveness of sorghum to trap *N. viridula* as they disperse into cotton from a major source of this pest. Sorghum was planted in a strip along the length of the interface of the two crops in peanut–cotton farmscapes. The two treatments were cotton fields with sorghum trap crops and cotton control fields without sorghum trap crops. Originally, the study also included similar treatments in corn–cotton farmscapes, but two of three of the sorghum trap crops in these farmscapes were accidentally destroyed. At the beginning of the study, 10 peanut–cotton commercial farmscapes were found in various locations in Irwin County, GA. Cotton fields ranged from 8 to 10 ha, and peanut fields associated with these cotton fields ranged from 8 to 12 ha. Each trap crop treatment was assigned randomly to five farmscapes similar to a completely randomized design (Box et al. 1978). Each cotton field had four sides (A–D), with side A occurring along the sorghum trap crop in fields with a trap crop (Fig. 2) and along peanuts in fields without a trap crop. Each cotton field was partitioned into eight side-edge and three interior block sampling locations (Fig. 2). There were two edge locations along each of the four sides of the field. Edge 1 was 0–3.66 m from the outside edge of the field, and edge 2 was 3.66–7.31 m from the outside edge of the field. The interior of the field was subdivided into three equally sized blocks with block 1 occurring adjacent to side A-edge 2. For sampling purposes, each cotton block and sorghum trap crop was divided into three equally sized sections.

The fields were sampled on 13, 20, and 27 July and 17 August 2004. Fields could not be sampled from 3 to 15 August because of Tropical Storm Bonnie and Hurricane Charley. Whole plant sampling was used in both cotton and sorghum, and a sample consisted of all *N. viridula* adults, including those parasitized by the tachinid *T. pennipes*, on all plants within 1.82 m of a row. In each cotton field, 54–58 samples were obtained as follows: 8–10 random samples from side A-edge 1 and also side C-edge 1, 6 random samples

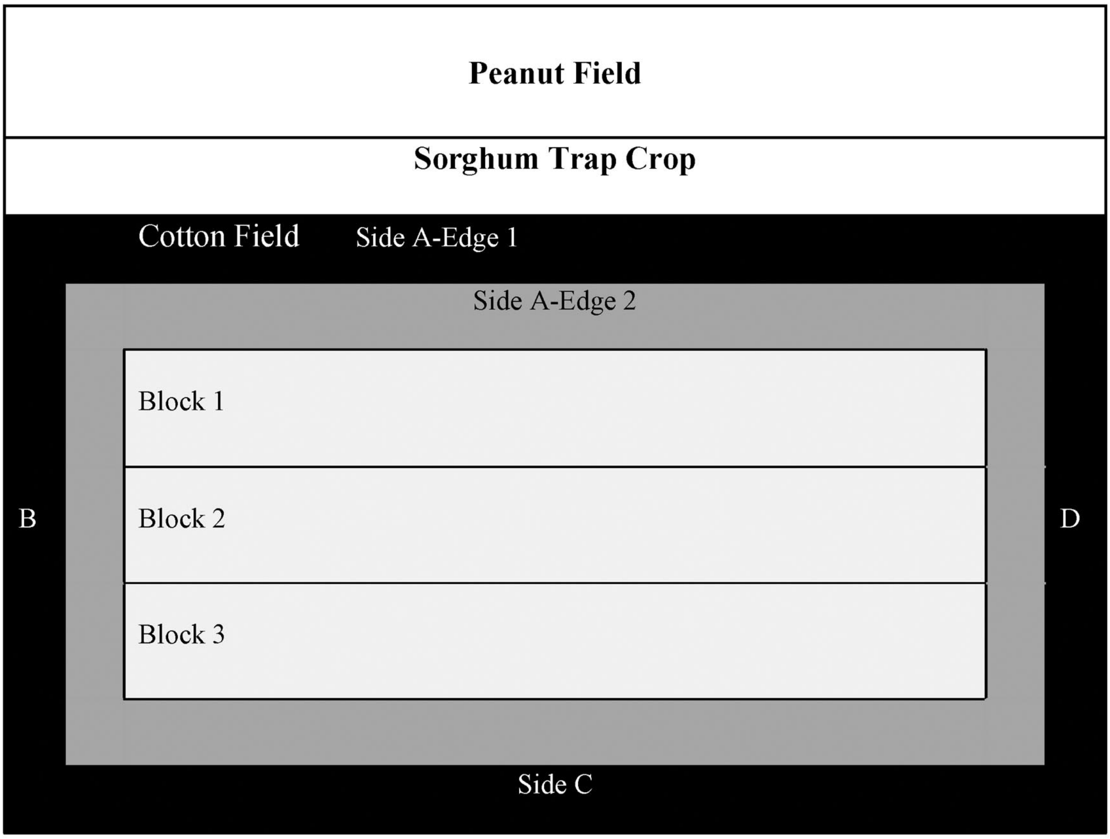


**Fig. 2.** Diagrammatic representation of a cotton field with a sorghum trap crop in 2004 (not drawn to scale). The field was partitioned into eight side-edge and three interior block locations. Each field had four sides (A–D), with side A occurring along the sorghum trap crop. For each side there were two edge locations. Edge 1 was 0–3.66 m from the outside edge of the field, and edge 2 was 3.66–7.31 m from the outside edge of the field. The interior of the field was subdivided into three equally sized blocks. A similar sampling scheme was used for control cotton fields except sorghum trap crops were not present in these fields.

from side B-edge 2 and side D-edge 1, 2 random samples from each side in edge 2, and 2 random samples from the center of each of the three sections for each of the three inside blocks. In each sorghum trap crop, six random samples were obtained for each of the three sections.

The DeKalb E57 variety of sorghum was planted on 5 May, 26 May, and 16 June 2004 in all trap crop treatment fields. Delta Pine 5690 Roundup Ready cotton was planted on the following dates in 2004: replicate 1 treatment and control fields on 23 and 29 April, respectively, replicate 2 and 3 treatment and control fields on 6 May, replicate 4 treatment and control fields on 10 and 12 May, respectively, and replicate 5 treatment and control fields on 15 May.

**Statistical Analysis.** Number of live *N. viridula* adults per 0.91 m of a row before application of dicrotophos and number of dead insects after the insecticide treatment were compared using one-tailed *t*-tests. Number of total and parasitized males, females, and all adults were recorded for live and dead stink bugs in the sorghum and in cotton field B. Only total females, males, and all adults were recorded for these stink bugs in cotton field A.

Means and SEs associated with these means also were obtained for percent parasitism of *N. viridula* fifth instars by *T. pennipes* over all treatments using PROC MEANS for 2002 and 2003 data (SAS Institute 1999). Overall means for these nymphs included all dates.

For the 2002 experiment, preliminary analyses of stink bug density and parasitization data using Cochran's variance test (Steel and Torrie 1960) showed that the requirement for homogeneity of variances would not be met for analysis of variance (ANOVA). Neither square-root transformation nor log transformation resolved the problem of heterogeneity of variances. In the sorghum trap crops, two of the date means for *N. viridula* adults were further away from all other date means. Also, there were many dates in which *N. viridula* adults were present in sorghum, but they did not occur in cotton treatments. Therefore, means and SE associated with these means were obtained for *N. viridula* adults per sample and percent parasitism of *N.*

*viridula* adults by *T. pennipes* for each treatment–date combination for all treatments (sorghum trap crop plots, cotton control plots, field cotton plots adjoining sorghum trap crop plots, and field cotton plots adjoining cotton control plots) using PROC MEANS (SAS Institute 1999). One-tailed *t*-tests, which do not require homogeneity of variances, were used to make comparisons of interest among the treatments with or without consideration of dates (Steel and Torrie 1960). When any mean for any treatment–date combination had a value of zero, no variance could be added to the computation of the variance associated with combining means and variances using one-tailed *t*-tests. Therefore, for stink bug density data, only the seven dates where positive, nonzero data were found in both sorghum and cotton plots were considered in the analyses. Similarly, parasitization data were analyzed for the 1 d where positive, nonzero data were found. Overall means for percent parasitism were compared using a one-tailed *t*-test.

For the 2003 experiment, preliminary analyses of stink bug density and parasitization data using Cochran's variance test (Steel and Torrie 1960) again showed that the requirement for homogeneity of variances would not be met for ANOVA. Neither square-root transformation nor log transformation resolved the problem of heterogeneity of variances. In contrast to the 2002 data, however, the 2003 date means for *N. viridula* adults in the sorghum trap crops were relatively close together, and, except for two cases, *N. viridula* adults occurred on cotton plants for each treatment–date combination. Thus, sorghum trap crop plots and cotton control plots along the interface of the farmscape, cotton fields with sorghum trap crop plots, and control cotton fields each were analyzed to obtain appropriate least squares means and SE associated with the means for *N. viridula* adults per sample and percentage parasitism by *T. pennipes* for each treatment–date combination using PROC MIXED (SAS Institute 1999). Fixed effects were treatment and date within treatment. Random effects were planting date within treatment by date and residual error. Comparisons between treatments of interest were performed for stink bug density and parasitization using one-tailed *t*-tests. For percent parasitism data, comparisons between control cotton fields and interface (sorghum + cotton) plots were performed only for 1, 9, and 21 August and 2 September because these were the only sampling dates that control cotton fields either had never been treated with insecticides or had not been treated with insecticides for at least 8 d. Comparisons of parasitization data between control cotton fields and cotton fields with trap crop plots also were performed on 9 and 21 August and 2 September, but not on 1 August, because stink bugs were not present in cotton fields with trap crop plots on this date.

For 2002 and 2003 data, means and SE [square-root (pHq/n)] for proportions (p) of marked *N. viridula* adults remaining in their original sorghum trap crop plots were calculated. Binomial tests were used to determine if p was sufficiently removed from q (proportion of adults moving to other plots) to be considered significantly different from q (Steel and Torrie 1960).

$\chi^2$ analyses (PROC FREQ, CHISQ option; SAS Institute 1999) were conducted for homogeneity of a 1:1 ratio for male and female parasitism by *T. pennipes* for the sorghum interface plots in 2002 and the sorghum and cotton interface plots in 2003. Correlation coefficients between the number of *N. viridula* adults per sample and the number of adults with at least one *T. pennipes* egg per sample were determined for all treatments for both years of the study (PROC CORR; SAS Institute 1999).

For 2004 stink bug density data, treatments and locations were analyzed to obtain appropriate least squares means and SE associated with the means using PROC MIXED (SAS Institute 1999). Fixed effects were treatment, location, and treatment by location. Random effects were replicate within treatment; replicate by location within treatment; replicate by week within treatment; replicate by location by week within treatment; and residual error. Only data for the latter three sampling dates were included in the analyses because stink bugs were present only on these dates. Comparisons between treatments of interest were performed for stink bug density data using one-tailed *t*-tests. Means and SE for percent parasitism data were obtained for treatments and locations using PROC MEANS (SAS Institute 1999), but no comparisons were performed between fields with sorghum trap crops and control fields for percent parasitism data because the fields were not treated equally with insecticides.

## Results

**Effectiveness of Sampling Technique.** Dead stink bugs were easily recovered. Treated stink bugs did not crawl into the soil or cracks in the ground because they die very quickly when exposed to dicrotophos (Tillman and Mullinix 2004). Generally, dead stink bugs were not eaten by predators because they, too, were killed by the insecticide. Occasionally, red imported fire ants, *Solenopsis invicta* Buren, were observed beginning to feed on dead stink bugs a couple of days after insecticide application, but these predators generally did not move the stink bugs.

Whole plant sampling was a very effective sampling technique for determining the number of *N. viridula* adults per 0.91 m of a row in both sorghum and cotton because densities of adults killed by dicrotophos were similar to those of live adults before insecticide application in these crops. In the sorghum field, there were no significant differences in number and percent parasitism of males, females, and all adults per sample between live insects before application of dicrotophos and dead insects after application of this toxicant (Table 1). Similarly, no significant differences in number of males, females, and total adults were detected between live and dead stink bugs in cotton fields A and B. In addition, there were no significant differences in

**Table 1. Mean ± SE no. of live and dead *N. viridula* adults per 0.91 m of a row before and after application of dicrotophos in sorghum and cotton**

| Crop | Variable | Live adults before dicrotophos application | Dead adults after dicrotophos application | $\lvert t \rvert$[a] | df |
|---|---|---|---|---|---|
| Sorghum | Total females | 0.39 ± 0.06 | 0.43 ± 0.06 | 0.42 | 214 |
| | Parasitized females | 0.13 ± 0.04 | 0.14 ± 0.04 | 0.18 | 214 |
| | Total males | 0.45 ± 0.07 | 0.46 ± 0.06 | 0.1 | 214 |
| | Parasitized males | 0.23 ± 0.05 | 0.27 ± 0.05 | 0.55 | 214 |
| | Total adults | 0.84 ± 0.11 | 0.89 ± 0.11 | 0.3 | 214 |
| | Parasitized adults | 0.36 ± 0.07 | 0.41 ± 0.07 | 0.46 | 214 |
| CottonA | Total females | 0.09 ± 0.03 | 0.11 ± 0.02 | 0.33 | 280 |
| | Total males | 0.06 ± 0.03 | 0.07 ± 0.02 | 0.25 | 206 |
| | Total adults | 0.15 ± 0.06 | 0.17 ± 0.03 | 0.33 | 173 |
| CottonB | Total females | 0.11 ± 0.07 | 0.10 ± 0.05 | 0.14 | 97 |
| | Parasitized females | 0.03 ± 0.03 | 0.02 ± 0.02 | 0.37 | 97 |
| | Total males | 0.05 ± 0.04 | 0.07 ± 0.04 | 0.18 | 97 |
| | Parasitized males | 0.03 ± 0.03 | 0.02 ± 0.02 | 0.37 | 97 |
| | Total adults | 0.16 ± 0.09 | 0.16 ± 0.09 | 0.01 | 97 |
| | Parasitized adults | 0.05 ± 0.05 | 0.03 ± 0.03 | 0.37 | 97 |

[a] All row means are not significantly different using one-tailed *t*-tests ($P > 0.05$).

percent parasitism of any group of adults before and after application of dicrotophos in cotton field B.

**2002 Experiment.** In 2002, *N. viridula* adults were present in sorghum for every sampling date: 5, 8, 13, 15, 19, 22, and 27 August and 3, 6, 17, and 20 September (Fig. 3A). However, they occurred in cotton for only seven dates: 8, 13, 15, and 22 August and 6, 17, and 20 September. Two population peaks of *N. viridula* adults occurred in sorghum. The highest peak, 11.23 *N. viridula* adults per sample, was on 8 August, and the second highest peak, 2.98 stink bug adults per sample, occurred on 3 September. The overall mean number of *N. viridula* adults per 0.91 m of a row in field cotton plots associated with sorghum trap crop plots (0.016 ± 0.003) was not significantly different ($t = 1.36$, df = 5542, $P > 0.05$) from that in field cotton plots associated with the cotton control plots (0.012 ± 0.002). Therefore, data from these two treatments were combined for date comparisons.

For every date in which stink bugs occurred in cotton, the number of *N. viridula* adults per sample was significantly higher in sorghum trap crop plots than in cotton control plots (8 August: $t = 8.42$, df = 101, $P < 0.01$; 13 August: $t = 5.94$, df = 98, $P < 0.01$; 15 August: $t = 7.79$, df = 132, $P < 0.01$; 22 August: $t = 5.2$, df = 133, $P < 0.01$; 6 September: $t = 8.61$, df = 204, $P < 0.01$; 17 September: $t = 2.08$, df = 178, $P < 0.05$; 20 September: $t = 7.82$, df = 178, $P < 0.01$; Fig. 3A). For one date, 17 September, *N. viridula* adults were significantly higher in cotton control plots (0.69 adults/sample) than in field cotton plots (0.03 adults/sample; $t = 20.34$, df = 970, $P < 0.0001$; Fig. 3A). Economic threshold for *N. viridula,* a mean of one adult per 1.82 m of a row of cotton (Jost 2004), was not reached in field cotton throughout the growing season.

**2003 Experiment.** In 2003, *N. viridula* adults occurred in sorghum and cotton from 24 July through 14 September (Fig. 4A). Unlike 2002, there was not a distinct peak for *N. viridula* adults in any of the treatments, and, except for two cases, they occurred on cotton plants for every treatment–date combination. Generally, *N. viridula* adult density was low in cotton

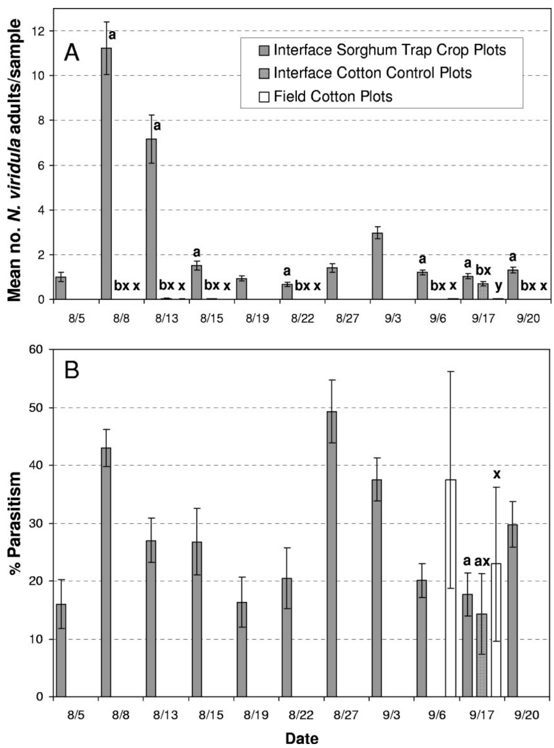


**Fig. 3.** Mean ± SE no. of *N. viridula* adults per 0.91 m of row (A) and percent parasitism of *N. viridula* adults by *T. pennipes* (B) per date in sorghum trap crop plots and cotton control plots along the interface of the corn–cotton farmscape and in field cotton plots associated with these interface plots in 2002. The series order is sorghum trap crop plots, cotton control plots, and field cotton plots. Treatments were not compared on dates when zero data were found in cotton plots. Means followed by the same lowercase letter (a and b) are not significantly different between sorghum trap crop plots and cotton control plots for a single sampling date (one-tailed *t*-test; $P > 0.05$). Means followed by the same lowercase letter (x and y) are not significantly different between cotton control plots and field cotton plots for a single sampling date (one-tailed *t*-test; $P > 0.05$).

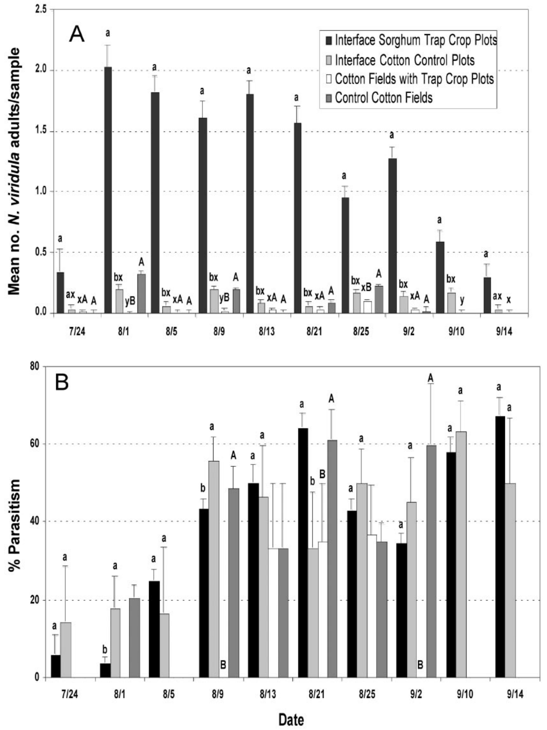


**Fig. 4.** Least squares mean + SE no. of *N. viridula* adults per 0.91 m of row (A) and percent parasitism of *N. viridula* adults by *T. pennipes* (B) per date in sorghum trap crop plots and cotton control plots along the interface of the corn–cotton farmscape, cotton fields with these interface plots, and control cotton fields in 2003. Control cotton fields were not sampled on 10 and 14 September. Means followed by the same lowercase letter (a and b) are not significantly different between sorghum trap crop plots and interface cotton control plots for a single sampling date (one-tailed *t*-test; $P > 0.05$). Means followed by the same lowercase letter (x and y) are not significantly different between interface cotton control plots and cotton fields associated with these interface plots for a single sampling date (one-tailed *t*-test; $P > 0.05$). Means followed by the same capital letter (A and B) are not significantly different between cotton fields with sorghum trap crop plots and control cotton fields for a single sampling date (one-tailed *t*-test; $P > 0.05$).

fields with sorghum trap crop plots, and on 1 August, no stink bugs were present in these fields. The absence of *N. viridula* adults in control cotton fields on 5 August was caused in part by the fact that dicrotophos recently had been applied to 4 of the 13 fields. Control cotton fields were not sampled on 10 and 14 September. The overall mean number of *N. viridula* adults per sample in field cotton plots adjacent to sorghum trap crops ($0.026 \pm 0.149$) was not significantly different ($t = 0.045$, df = 2321, $P > 0.05$) from that in field cotton plots adjacent to cotton control plots ($0.035 \pm 0.149$), and so these two treatments again were combined for date comparisons.

Except for the first and last sampling date, the number of *N. viridula* adults per sample was significantly higher in sorghum trap crop plots than in cotton control plots (1 August: $t = 4.92$, df = 268, $P < 0.01$; 5 August: $t = 7.12$, df = 412, $P < 0.01$; 9 August: $t = 5.23$, df = 421, $P < 0.01$; 13 August: $t = 7.84$, df = 646, $P < 0.01$; 21 August: $t = 5.68$, df = 431, $P < 0.01$; 25 August: $t = 4.09$, df = 650, $P < 0.01$; 2 September: $t = 5.89$, df = 595, $P < 0.01$; 10 September: $t = 2.14$, df = 662, $P < 0.05$; Fig. 4A). *N. viridula* adults were significantly higher in cotton control plots along the interface of the farmscape compared with cotton field plots next to the interface plots for three dates, 1 August ($t = 2.82$, df = 424, $P < 0.05$), 9 August ($t = 2.94$, df = 385, $P < 0.05$), and 10 September ($t = 2.65$, df = 326, $P < 0.05$; Fig. 4A). Density of *N. viridula* adults was also significantly higher in control cotton fields compared with cotton fields with sorghum trap crop plots for three dates, 1 ($t = 6.75$, df = 884, $P < 0.01$), 9 ($t = 3.88$, df = 1029, $P < 0.05$), and 25 August ($t = 2.65$, df = 980, $P < 0.05$; Fig. 4A). In control cotton fields, sampling location one (1–15 m) was not set back from the edge of the field by 11 m (width of interface plot), and so cotton was somewhat closer to corn in control fields compared with trap crop fields. This did not influence the difference in stink bug numbers between these two treatments because overall mean stink bug density was equally high in the 1–15 ($0.72 \pm 1.24$) and 16–30 m ($0.68 \pm 1.41$) sampling locations in control cotton fields ($t = 0.02$, df = 34, $P > 0.05$).

Even though the mean number of *N. viridula* adults over all cotton fields was less than one adult per 1.82 m of a row for all treatment–date combinations, economic threshold for this stink bug was reached in individual cotton fields during the experiment. Over the season, economic threshold was reached in 8 of the 13 (61.5%) control cotton fields. Regarding these eight control fields, three, two, one, and two fields (no duplicates) were treated with dicrotophos by growers for *N. viridula* control on 1, 9, 21, and 25 August, respectively. Also, it was necessary to treat the whole field for *N. viridula* in these control fields. Economic threshold for *N. viridula* was reached in only one of the four fields (25%) with sorghum trap crop plots on 25 August. Only 15 m along one side (side D on Fig. 2) of the field had to be treated. Stink bugs had dispersed into this side of the cotton field from corn across the road.

**Dispersal.** Marking studies revealed that *N. viridula* adults for the most part remained in sorghum instead of moving into cotton. The mark could remain on a *N. viridula* adult for at least 54 d, indicating that this was an effective method for marking stink bugs in the field. In 2002, *N. viridula* adults dispersed from sorghum plots into other interface sorghum plots, cotton control plots, and field cotton plots. However, movement from sorghum plots into interface cotton control plots was detected for only two stink bugs, representing <1% of all marked adults recaptured. Movement from sorghum plots into field cotton in 2002 was detected for only four adults, two in cotton row 1, one in cotton row 5, and one in cotton row 10 away from the interface. Only six marked stink bugs from field cotton were recaptured, and all of these had moved into sorghum. Movement from cotton interface plots to any other

**Table 2. Mean ± SE proportions of marked *N. viridula* adults remaining in sorghum trap crop plots in 2002 and 2003**

| Year | n | Prop. adults remaining in sorghum (p) | Prop. adults moving to other plots (q)[a] | LSD[b] |
|---|---|---|---|---|
| 2002 | 299 | Remain in any sorghum plot 97.66 ± 0.88 | Move to field cotton plots 2.43 | 2.45[c] |
| | | Remain in same sorghum plot | Move to other sorghum or field cotton plots | |
| 2002 | 299 | 84.95 ± 2.07 | 15.05 | 5.79[c] |
| 2003 | 47 | 80.85 ± 5.74 | 19.15 | 16.36[c] |

[a] No marked stink bug adults were found in field cotton plots in 2003.
[b] Proportion of marked *N. viridula* adults remaining in plots (p) was significantly greater than proportion moving to other plots (q) at [c] $P < 0.0001$ (binomial test).
*n*, no. samples.

location was not detected. In 2003, only movement from one sorghum interface plot to another was detected. For 2002 and 2003 data, the proportion of marked *N. viridula* adults remaining in the same sorghum interface plots in which they were originally painted was significantly greater than the proportion of stink bugs moving to other (sorghum and/or field cotton) plots (Table 2). Additionally, in 2002, the proportion of *N. viridula* adults remaining in any sorghum plot was significantly higher than the proportion of adults moving into field cotton.

**2004 Experiment.** In 2004, the overall mean ± SE (range) number of *N. viridula* adults per 1.82 m of a row in the sorghum trap crops was 3.29 ± 0.24 (0–25). In comparisons between cotton fields with sorghum trap crops and control cotton fields without these trap crops, a significant difference in mean number of *N. viridula* per 1.82 m of a row was detected for only edge one along the interface (side A) of the peanut–cotton farmscape (Table 3). At this location, the number of *N. viridula* adults per sample was higher in control fields compared with fields with trap crops. Comparisons between field locations revealed that in control cotton fields the mean number of *N. viridula* adults per sample was significantly higher in side A–edge 1 than in any other side-edge location (Table 3). In contrast, no significant differences in *N. viridula* density were detected between side-edge locations in cotton fields with sorghum trap crops. A significant difference in mean number of *N. adults* was not detected between blocks for both control cotton fields and cotton fields with sorghum trap crops.

Over the 2004 growing season, economic threshold for *N. viridula* was reached in four of the five control cotton fields. This threshold was reached twice in three fields and once in one field. *N. viridula* adults reached economic threshold once in one of the five cotton fields with sorghum trap crops. Overall, control cotton fields were treated with insecticides for control of *N. viridula* 1.4 times, whereas cotton fields with sorghum trap crops were treated for control of this stink bug only 0.2 times.

**Parasitization.** Because parasitized fifth-instar *N. viridula* can shed a *T. pennipes* egg at molting, some of the apparently unparasitized adults observed in the field can in actuality be parasitized by this larval endoparasitoid. However, during 2002 and 2003, percent parasitism of fifth-instar *N. viridula* by *T. pennipes* was

**Table 3. Least squares mean ± SE (range) no. of *N. viridula* adults per 1.82 m of a row in different side-edge and block locations in trap crop and control cotton fields in peanut–cotton farmscapes in 2004**

| Location | Trap crop fields | Control fields | Trap crop versus control |
|---|---|---|---|
| Side A-edge 1 | 0.12 ± 0.13 (0–2) | 1.16 ± 0.13 (0–13) | $|t| = 5.55$, df = 28, $P < 0.0001$ |
| Side B-edge 1 | 0.0007 ± 0.15 (0–1) | 0.11 ± 0.15 (0–3) | $|t| = 0.53$, df = 28, $P > 0.05$ |
| Side C-edge 1 | 0.13 ± 0.15 (0–1) | 0.06 ± 0.14 (0–1) | $|t| = 0.32$, df = 28, $P > 0.05$ |
| Side D-edge 1 | 0.26 ± 0.15 (0–1) | 0.15 ± 0.15 (0–1) | $|t| = 0.56$, df = 28, $P > 0.05$ |
| Side A-edge 2 | 0.03 ± 0.16 (0–1) | 0.21 ± 0.17 (0–2) | $|t| = 0.75$, df = 28, $P > 0.05$ |
| Side B-edge 2 | 0.03 ± 0.18 (0–1) | 0.03 ± 0.18 (0–1) | $|t| = 0$, df = 28, $P > 0.05$ |
| Side C-edge 2 | 0 ± 0.19 | 0.07 ± 0.19 (0–1) | $|t| = 0.26$, df = 28, $P > 0.05$ |
| Side D-edge 2 | 0.2 ± 0.18 (0–6) | 0.07 ± 0.18 (0–1) | $|t| = 0.53$, df = 28, $P > 0.05$ |
| Block 1 | 0.02 ± 0.14 (0–1) | 0.11 ± 0.14 (0–1) | $|t| = 0.43$, df = 28, $P > 0.05$ |
| Block 2 | 0.03 ± 0.14 (0–1) | 0.03 ± 0.14 (0–3) | $|t| = 0.03$, df = 28, $P > 0.05$ |
| Block 3 | 0.01 ± 0.14 (0–1) | 0.26 ± 0.14 (0–11) | $|t| = 1.21$, df = 28, $P > 0.05$ |
| **Other comparisons of interest** | **Control** | | **Trap** |
| Side A-edge 1 versus side B-edge 1 | $|t| = 5.67$, df = 28, $P < 0.0001$ | | $|t| = 0.63$, df = 28, $P > 0.05$ |
| Side A-edge 1 versus side C-edge 1 | $|t| = 6.08$, df = 28, $P < 0.0001$ | | $|t| = 0.06$, df = 28, $P > 0.05$ |
| Side A-edge 1 versus side D-edge 1 | $|t| = 5.46$, df = 28, $P < 0.0001$ | | $|t| = 0.8$, df = 28, $P > 0.05$ |
| Side A-edge 1 versus side A-edge 2 | $|t| = 4.73$, df = 28, $P < 0.0001$ | | $|t| = 0.41$, df = 28, $P > 0.05$ |
| Side A-edge 1 versus side B-edge 2 | $|t| = 5.34$, df = 28, $P < 0.0001$ | | $|t| = 0.39$, df = 28, $P > 0.05$ |
| Side A-edge 1 versus side C-edge 2 | $|t| = 5.18$, df = 28, $P < 0.0001$ | | $|t| = 0.55$, df = 28, $P > 0.05$ |
| Side A-edge 1 versus side D-edge 2 | $|t| = 5.18$, df = 28, $P < 0.0001$ | | $|t| = 0.8$, df = 28, $P > 0.05$ |
| Block 1 versus block 2 | $|t| = 0.37$, df = 28, $P > 0.05$ | | $|t| = 0.06$, df = 28, $P > 0.05$ |
| Block 1 versus block 3 | $|t| = 0.79$, df = 28, $P > 0.05$ | | $|t| = 0.03$, df = 28, $P > 0.05$ |
| Block 2 versus block 3 | $|t| = 1.16$, df = 28, $P > 0.05$ | | $|t| = 0.09$, df = 28, $P > 0.05$ |

very low (2002: $n = 133$, mean = 3.76%, SE = 1.66; 2003: $n = 463$, mean = 0.86%, SE = 0.4025). Therefore, I chose to estimate parasitism as the number of adults with a tachinid egg on the exoskeleton excluding parasitism of fifth instars. More *N. viridula* males than females were parasitized by *T. pennipes* in the sorghum interface plots in 2002 ($\chi^2 = 78.45$, df = 1, $P < 0.0001$) and 2003 ($\chi^2 = 29.82$, df = 1, $P < 0.0001$) and in cotton interface plots in 2003 ($\chi^2 = 7.25$, df = 1, $P < 0.0071$). Because there was no significant difference in percentage parasitism of *N. viridula* adults by *T. pennipes* between field cotton plots next to sorghum interface plots and those adjacent to cotton interface plots in 2002 ($t = 1.57$, df = 35, $P > 0.05$) and 2003 ($t = 1.55$, df = 84, $P > 0.05$), these two cotton treatments were pooled for date comparisons.

In 2002, parasitism of *N. viridula* adults by *T. pennipes* occurred for every date and ranged from 14 to 49% in sorghum trap crops (Fig. 3B). Unsurprisingly, the pattern for percent parasitism over time in sorghum was similar to that for the stink bug adult data. On the six dates *N. viridula* adults were found in very low numbers in cotton (Fig. 3A), none of the adults were parasitized by *T. pennipes.* Because parasitization data were analyzed only when positive, nonzero data were found in treatment plots, comparisons between sorghum and cotton were not performed on these six dates. However, percent parasitism of *N. viridula* adults by *T. pennipes* was numerically higher in sorghum trap crop plots than in cotton control plots on each of these dates, and overall percent parasitism of these stink bugs was significantly higher in sorghum trap crop plots (27.71 ± 1.16%) than in cotton control plots (13.04 ± 1.86%; $t = 8.75$, df = 738, $P < 0.0001$). Rates of parasitization were similar in sorghum trap crop plots and cotton control plots on the one date, 17 September, in which *N. viridula* adults were present in substantial numbers (≥0.03 stink bugs/sample) in both interface cotton control plots and field cotton plots ($t = 0.52$, df = 94, $P > 0.05$). Also, percent parasitism of *N. viridula* adults was not significantly different between cotton control plots and field cotton plots on this date ($t = 0.14$, df = 27, $P > 0.05$).

In 2003, percent parasitism of *N. viridula* adults by *T. pennipes* ranged from 4 to 67% in sorghum trap crop plots (Fig. 4B). Similar to 2002, parasitized *N. viridula* adults were found every sampling date in these sorghum plots. Unlike 2002, parasitized stink bug adults also were present in interface cotton control plots every sampling date. This was probably caused in part by the fact that, in the second year of the experiment, *N. viridula* adults occurred in substantial numbers (≥0.03 stink bugs/sample) in these plots every sampling date (Fig. 4A). The overall trend for percent parasitism of *N. viridula* adults was an increase over time for the first six sampling dates, a slight decrease around late August, and finally another increase around mid-September.

Percent parasitism of *N. viridula* adults by *T. pennipes* was significantly different between the sorghum and cotton control interface plots for only three dates in 2003 (Fig. 4B). Percent parasitism of stink bug adults was significantly higher in interface cotton control plots than sorghum trap crops for two dates: 1 ($t = 2.19$, df = 59, $P < 0.05$) and 9 August ($t = 2.46$, df = 164, $P < 0.05$). Later, on 21 August, percent parasitism of stink bug adults was significantly higher in sorghum than in cotton control plots ($t = 4.67$, df = 219, $P < 0.01$). These data indicate that *T. pennipes* females moved into cotton and then sorghum. Overall, percent parasitism of these stink bugs by *T. pennipes* was significantly higher in sorghum trap crop plots (49.85 ± 0.93%) than in cotton control plots (45.11 ± 1.71%; $t = 3.2$, df = 1495, $P < 0.05$).

For the three dates where comparisons were performed between control cotton fields and fields with sorghum trap crop plots in 2003, percent parasitism of *N. viridula* adults was significantly higher in control fields than in trap crop fields (9 August: $t = 6.15$, df = 118, $P < 0.01$; 21 August: $t = 2.12$, df = 31, $P < 0.05$; 2 September: $t = 3.67$, df = 10, $P < 0.05$; Fig. 4B). Percent parasitism could not be determined for field cotton on 1 August because *N. viridula* were not present in these plots on that sampling date. Mean percent parasitism of *N. viridula* adults in interface (sorghum + cotton) plots was 10.88 ± 4.69, 49.44 ± 4.46, 48.83 ± 8.81, and 39.77 ± 6.96 on 1, 9, and 21 August, and 2 September, respectively. Percent parasitism of these insects was not significantly different between interface (sorghum + cotton) plots and control cotton fields for the four dates: 1 August ($t = 1.89$, df = 149, $P > 0.05$), 9 August ($t = 0.11$, df = 195, $P > 0.05$), 21 August ($t = 1.03$, df = 138, $P > 0.05$), and 2 September ($t = 1.89$, df = 137, $P > 0.05$). Comparisons were made between these treatments.

The number of parasitized *N. viridula* adults was highly correlated with the number of stink bug adults in sorghum interface plots for both years of the study (Table 4). The number of parasitized adults was not correlated with stink bug density for cotton plots in 2002, but parasitism was correlated with host density for these plots in 2003. Generally, parasitized stink bug adults were present in plots only if mean stink bug density was greater than or equal to 0.03 per sample. The two exceptions occurred on 6 September 2002 in field cotton plots and on 13 August 2003 in control cotton fields.

In 2004, overall mean ± SE (range) percent parasitism was 22.93 ± 1.82% (0–100%) in sorghum trap crops, 2.94 ± 2.94% (0–100%) in cotton fields with sorghum trap crops, and 17.67 ± 3.28% (0–100%) in control cotton fields. No comparisons were performed between fields with sorghum trap crop fields and control fields because some control fields were treated more than once with insecticides.

## Discussion

The use of trap cropping for managing any insect pest depends on a strong host plant preference by the pest for the trap crop over the cash crop (Hokkanen 1991). In both the 2002 and 2003 experiments, *N. viridula* adults strongly preferred sorghum to cotton along the interface of corn–cotton farmscapes, be-

**Table 4. Correlation of no. of *N. viridula* adults per 0.91 m of a row with no. of *N. viridula* adults with a least one *T. pennipes* egg per sample when adults were present in a sample in 2002 and 2003**

| Treatment | $n$ | No. *N. viridula* adults | | No. *N. viridula* adults with *T. pennipes* egg | | $r^a$ |
|---|---|---|---|---|---|---|
| | | Mean ± SE | Range | Mean ± SE | Range | |
| 2002 | | | | | | |
| Sorghum trap crop plot | 776 | 3.51 ± 4.81 | 1–49 | 1.10 ± 1.95 | 0–18 | $0.8597^a$ |
| Cotton control plot | 23 | 1.17 ± 0.39 | 1–2 | 0.17 ± 0.39 | 1–1 | 0.3947 |
| Field cotton plot | 37 | 1.19 ± 0.47 | 1–3 | 0.22 ± 0.48 | 0–2 | 0.0611 |
| 2003 | | | | | | |
| Sorghum trap crop plot | 1321 | 2.52 ± 2.29 | 1–24 | 1.0 ± 1.31 | 0–14 | $0.6583^{a,b}$ |
| Cotton control plot | 176 | 1.26 ± 0.49 | 1–4 | 0.52 ± 0.60 | 0–2 | $0.1889^b$ |
| Field cotton plot | 86 | 0.88 ± 0.42 | 1–2 | 0.34 ± 0.48 | 0–1 | $0.2128^b$ |

Correlation coefficient significantly greater at $^a P < 0.0001$ and $^b P < 0.05$ (PROC CORR; SAS Institute 1999).
*n*, no. samples.

cause density of *N. viridula* adults was higher in sorghum trap crops compared with cotton control plots for almost every sampling date. The exceptions were dates in which stink bug numbers were very low in both sorghum and cotton. Density of *N. viridula* adults was never higher in cotton than sorghum for any sampling date. Southern green stink bug adults were not counted every day in the sorghum and cotton interface plots. However, visual observations of stink bugs in these plots made every 1–2 d throughout the week revealed that the level of stink bugs was always much lower in cotton control plots than in sorghum trap crop plots. Populations of *N. viridula* generally do not disperse quickly (<3 d). For example, density of *N. viridula* adults after dicrotophos application was similar to that found 3 d before application of the insecticide in sampling comparison tests. Populations of stink bugs can disperse relatively fast if they are mechanically flushed out of a crop, e.g., when fungicides are applied with a tractor to peanuts (unpublished data), but this phenomenon did not occur in these corn–cotton farmscapes. Hence, it is highly unlikely that populations of *N. viridula* dispersed in high numbers into cotton plots and moved into sorghum plots where they were counted. Therefore, I conclude that adults of *N. viridula* preferred to disperse into sorghum over cotton.

An ideal trap crop also would be able to arrest the pests reducing the likelihood of them dispersing into the main crop (Hokkanen 1991). The 2002 and 2003 marking studies revealed that most *N. viridula* adults that dispersed into sorghum remained there instead of moving into cotton. Even the small proportion of marked *N. viridula* adults that dispersed from their original sorghum trap crop plot to another location preferred to move into sorghum over cotton. For both years of the study, very few *N. viridula* adults were present in field cotton plots compared with interface sorghum and cotton plots. Also, in 2003, density of *N. viridula* adults was lower in cotton fields adjoining sorghum trap crop plots than in control cotton fields. These experiments clearly demonstrate that sorghum arrested *N. viridula* adults. The sorghum trap crop plots were not just barriers to stink bug adults dispersing from corn.

The full-scale field experiment in the third season further showed the effectiveness of sorghum in trapping *N. viridula* in cotton. In control cotton fields, density of *N. viridula* adults was much higher in edge one along the interface of peanut–cotton farmscape than in any other side-edge location, strongly indicating that *N. viridula* adults dispersed from peanuts, a source of these stink bugs, into this edge in control cotton fields. Compared with the control cotton fields, density of *N. viridula* adults was much lower in cotton fields with sorghum trap crops at the interface of the two crops demonstrating that the sorghum was serving as a trap crop for these stink bugs in cotton.

Because *N. viridula* adults sometimes were present in sides B, C, and D in cotton fields in the full-scale experiment, there were other sources of stink bugs around the edges of the fields on these sides. These sources generally consisted of mixtures of grass and broadleaf weeds commonly found in and around cotton and peanuts. Also, stink bugs can concentrate on chinaberry trees and abandoned pecans trees. More specific information on other sources of stink bugs will be provided in future publications.

*Trichopoda pennipes* is the only tachinid that successfully attacks *N. viridula* in the United States (Jones 1988). It has been reported to attack *N. viridula* on several plant species in the southern states. Morrill (1910) first reported *T. pennipes* as a parasitoid of *N. viridula* in cotton. In soybean, parasitism of *N. viridula* by *T. pennipes* has been reported to be as high as 82% in South Carolina (Jones et al. 1996), as high as 60% in Georgia (Todd and Lewis 1976), and often exceeding 40% in Louisiana (McPherson et al. 1982). In Florida, 72% of the *N. viridula* adults collected from various plants were parasitized (Buschman and Whitcomb 1980). *T. pennipes* also has been reported to attack *N. viridula* in Texas (Eger 1981). The rate of parasitism of *N. viridula* by *T. pennipes* has been reported to be as high as 85% on a mallow (*Hibiscus esculentus* L.), 78% on a grass (*Triticum aestivum* L.), and 70% on a legume (*Vigna unguiculata* L. Walp.) (Todd and Lewis 1976). Our results on percent parasitism of *N. viridula* adults by *T. pennipes* in the sorghum are consistent with these previous reports on rates of parasitism of the host on other plant species. Similar to our findings, natural field parasitization of *N. viridula* adults was higher on males than on females (Mitchell and Mau 1971).

Sorghum very effectively arrested *N. viridula* adults reducing the number of stink bugs in the field cotton, and parasitism of this stink bug species by *T. pennipes* was highly correlated to density of stink bugs. Consequently, percent parasitism of these stink bugs was high in sorghum and low in field cotton in farmscapes with sorghum trap crops. Control fields had higher parasitism of stink bugs compared with trap crop cotton fields indicating that *T. pennipes* would readily disperse into cotton when substantial numbers of stink bugs were present. Because percent parasitism of these stink bugs in the combined interface plots was similar to that in control cotton fields, overall parasitization in trap crop fields was not negatively impacted by the presence of sorghum.

Trap cropping can be an effective strategy to manage *N. viridula.* My results show that sorghum can trap crop *N. viridula* adults in cotton fields. Furthermore, economic threshold for *N. viridula* was not reached along the interface of the corn–cotton farmscape in any cotton field with sorghum plots. In contrast, economic threshold was reached in 61.5% of the control cotton fields in 2003. In 2004, density of *N. viridula* adults along the interface of a peanut–cotton farmscape was higher in control cotton fields than in cotton fields with sorghum trap crops, and control cotton fields were treated with insecticides for control of *N. viridula* 1.4 times while cotton fields with sorghum trap crops were treated only 0.2 times. Researchers working in other farmscapes or locations have been able to successfully use other species of plants as a trap crops for *N. viridula* because local populations of polyphagous pentatomids can show specific feeding habits (Fox and Morrow 1981). Early-planted or early maturing soybean can trap stink bugs in soybean fields (Newsom and Herzog 1977, McPherson and Newsom 1984, Todd and Schumann 1988). Rea et al. (2002) conducted experiments to study the use of white mustard, *Sinapis alba* L., with pea, *Psium sativum* L., and black mustard as trap crops to reduce *N. viridula* in sweet corn. For each experiment, *N. viridula* populations were much higher in the trap crops compared with the sweet corn. In the field-scale experiment, the trap crop protected the cash crop from *N. viridula.* In conclusion, these studies, along with two other studies, show that the trap cropping technique can be a useful strategy for managing *N. viridula.*

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