Tillage and Chlorpyrifos Treatment Effects on Peanut Arthropods — An Incidence of Severe Burrower Bug Injury

J. W. Chapin[1]*, J. S. Thomas[1], and P. H. Joost[2]

ABSTRACT

A 2-yr study was conducted on the effects of tillage and soil insecticide (chlorpyrifos) treatment on peanut arthropod pests. A 3 by 2 split-plot experiment with five replications was subjected to factorial ANOVA. Main plot treatments consisted of three tillage systems: conventional moldboard plow, strip tillage into a killed wheat cover crop, and strip tillage into corn stubble residue. Subplot insecticide treatments were granular chlorpyrifos applied at early pegging (growth stage R2) and untreated. Populations of corn earworm, *Helicoverpa zea* (Boddie), and velevetbean caterpillar, *Anticarsia gemmatalis* Hübner, were lower in strip tillage systems. Chlorpyrifos applications caused corn earworm outbreaks in all tillage systems, but these applications were more disruptive in strip tillage. Chlorpyrifos treatment also increased populations of fall armyworm, *Spodoptera frugiperda* (J.E. Smith), but had no measurable effect on velvetbean caterpillar populations. Pod damage from lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller), and wireworms, *Conoderus* spp., was lower in strip tillage systems, and chlorpyrifos suppressed pod damage in all systems. Threecornered alfalfa hopper, *Spissistilus festinus* (Say), damage to peanut was greater in the wheat residue strip tillage system. Chlorpyrifos treatment reduced threecornered alfalfa hopper damage in all systems. Spider mite injury was not affected by tillage, but chlorpyrifos treatments resulted in mite outbreaks in all tillage systems. Burrower bug, *Pangaeus bilineatus* Say, injury to peanut kernels was greater in the strip tillage systems in 1999; and burrower bug injury was suppressed in the strip tillage systems by chlorpyrifos treatment. There was a significant interaction effect for burrower bug injury between tillage and insecticide treatment. Incidence of tomato spotted wilt virus also was reduced by strip tillage. Use of an effective fungicide program and a 3-yr crop rotation out of peanut production probably obscured any potential tillage effects on fungal diseases (southern stem rot, Rhizoctonia limb rot, and leaf spot). However, chlorpyrifos treatment increased Rhizoctonia limb rot incidence. Weed populations were generally greater in strip tillage systems, but postemergence herbicides effectively eliminated any potential confounding effect on yield and grade. Yield was not affected by tillage in either year, and chlorpyrifos had no effect on yield in 1998. In 1999, however, chlorpyrifos increased yield in both strip tillage systems. Neither tillage nor insecticide treatment affected grade (percentage total mature kernels) in 1998, but in 1999 grade was highest in conventional tillage and grade was improved by chlorpyrifos treatment in strip tillage systems. Crop value losses of $249 and $388/ha were attributed to burrower bug injury in untreated corn and wheat residue strip tillage systems, respectively. This injury may have been an anomaly of drought conditions but, given the potential economic impact, burrower bug merits further study in conservation tillage peanut production.

Key Words: *Anticarsia gemmatalis, Elasmopalpus lignosellus,* fall armyworm, insecticides, insects, lesser cornstalk borer, *Pangaeus bilineatus, Spissistilus festinus, Spodoptera frugiperda,* threecornered alfalfa hopper, velvetbean caterpillar, weed control, wireworms, *Conoderus* spp.

Previous studies have found lower levels of some insect pests in reduced tillage peanut production systems. Campbell (1986) reported fewer corn earworms, *Helicoverpa zea* (Boddie), in conservation tillage peanut. Minton *et al.* (1991) also found lower velvetbean caterpillar, *Anticarsia gemmatalis* Hübner, populations in reduced tillage. Potato leafhopper, *Empoasca fabae* (Harris), injury is reduced by conservation tillage (Campbell *et al.*, 1985; Campbell, 1986) as is thrips injury, *Frankliniella fusca* (Hinds) (Campbell *et al.*, 1985; Campbell, 1986; Minton *et al.*, 1991; Brandenburg *et al.*, 1998). Infection by tomato spotted wilt virus, which is thrips-vectored, also is suppressed by conservation tillage (Hagen *et al.*, 1997; Weeks and Hagen, 1997; Culbreath *et al.*, 1999). Minton *et al.* (1991) reported no tillage effect on threecornered alfalfa hopper, *Spissistilus festinus* (Say), in peanut. Similarly, Mack and Backman (1990) found no tillage effect on lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); and Cheshire *et al.* (1984) reported no difference in wireworm injury in reduced tillage peanut. Campbell (1986) found more pod damage from southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber, in reduced tillage peanut. However, Brust (1990) showed that pod damage from southern corn rootworm can be suppressed in peanut systems with the more diverse root complex that occurs in reduced tillage. Increased oviposition by southern corn rootworm in conservation tillage peanut tends to be offset by increased predator abundance and efficiency relative to conventional tillage (Brust, 1991).

Adoption of reduced tillage peanut production has been limited by pest management and other production concerns (Boswell and Grichar, 1981; Wright and Porter, 1995; Grichar, 1998); as well as evidence of lower economic returns (Lamb *et al.*, 1998; Hewitt *et al.*, 1999). The objective of this study was to examine the effects of a soil insecticide (chlorpyrifos) in conservation and conventional peanut tillage systems. Chlorpyrifos is used widely on peanut for suppression of the soil insect com-

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[1] Dept. of Entomology, Edisto Res. and Educ. Center, Clemson Univ., 64 Research Rd., Blackville, SC 29817.

[2] Dept. of Entomology, Coastal Plain Exp. Sta., Univ. of Georgia, P. O. Box 748, Tifton, GA 31793-0748.

*Corresponding author (email: jchapin@clemson.edu).

plex to include lesser cornstalk borer (Gilreath *et al.*, 1989; Mack *et al.*, 1989, 1991), southern corn rootworm (Herbert *et al.*, 1997), and wireworms, *Conoderus* spp. (Brown and Todd, 1997). Chlorpyrifos treatment is a significant expense (*ca.* $62/ha for material and application). Therefore, if conservation tillage systems respond substantially differently to chlorpyrifos treatment, there may be a marked effect on the overall profitability of reduced tillage production systems. Also, the future availability of chlorpyrifos for use on peanut is uncertain; and at present, there are no efficacious chemical alternatives for peanut soil insect control. Thus, it is important to understand the extent to which conservation tillage systems offer an alternative to, or increase reliance on, chemical suppression of specific pests.

Materials and Methods

Experimental Site, Design, Treatments. Experiments were conducted in 1998 and 1999 on cultivar Georgia Green at the Edisto Res. and Educ. Center near Blackville (Barnwell Co), SC. The soil type was a Dothan loamy sand for both experiments, and neither experiment was irrigated. The experimental design was a 3 by 2 split-plot with five replications. Main plots consisted of three peanut tillage treatments—conventional moldboard plow with no surface residue, strip tillage into corn residue, and strip tillage into a killed wheat cover crop. The main plots were 32 rows wide (0.96-m row spacing) by 18.3 m long. The 16-row subplots were either treated with chlorpyrifos (2.24 kg ai/ha Lorsban 15G, Dow AgroSciences, Midland, MI) or left untreated. Chlorpyrifos treatment was applied with a two-row electric Gandy applicator (Gandy Co., Owatonna, MN) at the pegging or R2 growth stage (Boote, 1982). A 12.7-cm wide bander was positioned directly over each row so that chlorpyrifos granules were concentrated in the pegging zone. The application dates were 7 July (50 d after planting, DAP) and 6 July (55 DAP) in 1998 and 1999, respectively.

Production Practices. The preceding crop history for both experimental years was peanut, corn, wheat and summer fallow, corn, then peanut. This 3-yr rotation out of peanut production also was maintained over the previous 20-yr cropping interval. The corn crop preceding the 1998 experiment was conventionally tilled, while strip tilled corn preceded the 1999 experiment. In the conventional tillage peanut system, the corn residue was disked twice during the previous winter and then plowed under to a depth of approximately 30 cm with a Harrell Switch Plow (Harrell Co. Inc., Pelham, GA) about 10 d before planting. The corn residue strip tillage system was mowed after corn harvest in September. In the wheat residue strip tillage plots, cultivar Pioneer 2691 wheat was planted into corn residue with a John Deere 750 no-till grain drill (Deere and Co., Moline, IL) on 2 Dec. 1997 and 3 Dec. 1998. The wheat residue strip tillage systems were deep-tilled with a Worksaver Terramax (Worksaver, Inc., Litchfield, IL) before planting wheat. Approximately 34 kg/ha of nitrogen was applied to the wheat cover crop in early February. Both the corn and wheat residue strip tillage plots were sprayed with 1.68 kg ai/ha of glyphosate-trimesium (Touchdown 6 LC, Syngenta Crop Protection, Greensboro, NC) and 0.25% nonionic surfactant to kill winter weeds and the wheat cover crop in mid-Apr. 1998. In 1999, 2.24 kg ai/ha of glyphosate (Roundup Ultra 4 WSL, Monsanto Co., St. Louis, MO) was substituted for glyphosate-trimesium.

Peanut was planted at a rate of 16 seeds per row-m with a four-row John Deere Max-Emerge II vacuum planter (Deere and Co., Moline, IL) attached to a Powell Ro-till strip till unit (Powell Manufacturing Co., Bennettsville, SC) on 18 May 1998 and 12 May 1999. Rhizoflo granular inoculant (Urbana Laboratories, St. Joseph, MO) was applied in-furrow at a rate of 3.4 kg/ha in 1998 and 4.3 kg/ha in 1999. The planter-tiller unit had a coulter mounted in front of each subsoil shank. Behind each subsoil shank were four fluted coulters and a crumbler. The planter unit was mounted behind the rolling basket and Yetter trash handlers (Yetter Manufacturing Co., Colchester, IL) were used to direct residue away from the furrow openers. This strip tillage unit resulted in a residue-free strip about 30 cm wide. There was a 12-m alley between each plot range to allow for operation of tillage equipment. Traffic rows were established at eight-row intervals for herbicide and fungicide applications and, other than for chlorpyrifos and gypsum (calcium sulfate) application, there was no traffic on yield rows.

Soil test calcium exceeded 1000 kg/ha in 1998 and no gypsum was applied. In 1999, 370 kg/ha of gypsum was applied in a 40-cm band on 9 July (58 DAP). Soil test levels of phosphorus and potassium were adequate; therefore no preplant fertilizer was applied in either year. Foliar boron was applied at a rate of 0.56 kg/ha on 9 July (52 DAP) and 8 July (57 DAP) in 1998 and 1999, respectively.

The same post planting herbicide program was used on all tillage systems. A preemergent treatment of 2.14 kg ai/ha metolachlor (Dual Magnum 7.62 EC, Syngenta Crop Protection, Greensboro, NC) and 2.24 kg ai/ha glyphosate (Roundup 4 WSL) was applied on 21 May (3 DAP) in 1998 and on 14 May (2 DAP) in 1999. The postemergence program consisted of a 0.15-kg ai/ha application of paraquat (Starfire LC, Syngenta Crop Protection, Greensboro, NC) plus 0.06 kg ai/ha of bentazon (Basagran 4, BASF Corp., Research Triangle, NC) on 2 June (15 DAP) in 1998. In 1999, a 0.42-kg ai/ha application of acifluorfen (Blazer 2 LC, BASF Corp., Research Triangle, NC) plus a 0.25 % volume-to-volume dilution of 80% nonionic surfactant was applied on 7 June (26 DAP). An application of 0.51 kg ai/ha imazapic (Cadre 2 LC, American Cyanamid Co., Parsippany, NJ) was applied on 20 June (33 DAP) in 1998 and on 17 June (37 DAP) in 1999.

In 1998, the fungicide program consisted of a 1.26-kg ai/ha application of chlorothalonil (Bravo Weather Stik 6 F, Syngenta Crop Protection, Greensboro, NC) on 24 June (37 DAP) and 8 July (51 DAP), followed by 0.22 kg ai/ha azoxystrobin (Abound 2.08 F, Syngenta Crop Protection, Greensboro, NC) on 22 July (65 DAP), 5 Aug. (79 DAP) and 19 Aug. (93 DAP). A final 0.22-kg ai/ha application of tebuconazole (Folicur 3.2 F, Bayer Corp., Kansas City, MO) was applied on 1 Sept. (106 DAP). In 1999, the fungicide program consisted of a 1.26-kg ai/ha application of chlorothalonil on 17 June (37 DAP) and 30 June (50 DAP), followed by a 0.22-kg ai/ha application of azoxystrobin on 12 July 62 (DAP), 29 July (78 DAP), and 13 Aug. (93 DAP). A final 0.22-kg ai/ha application of tebuconazole was applied on 1 Sept. 1999 (112 DAP).

Aldicarb (Temik 15 G, Aventis CropScience, Research Triangle, NC) was applied in-furrow at a rate of 0.84 kg ai/ha for thrips control in both years. In 1998, 0.03 kg ai/ha lambda-cyhalothrin (Karate 1 EC, Syngenta Crop Protection, Greensboro, NC) was applied to all plots on 28 Sept. (133 DAP) to prevent late season velvetbean caterpillar defoliation. Herbicides, fungicides, and the foliar insecticide were applied with a three-point-hitch sprayer equipped with a diaphragm pump and eight-row boom equipped with Tee Jet 8003 flat fan tips (Spraying Systems, Wheaton, IL) delivering 214 L/ha at 569 kg/cm^2.

Arthropod and Arthropod Damage Sampling. Canopy pest populations were sampled by taking two 1-m beat cloth counts per experimental unit on 20 July, 27 July, and 3 Aug. in both years. The wooden dowel handle on one side of the beat cloth was placed under the peanut lateral branches as close as possible to the plant crowns on one side of the row. The entire plant canopy of one row m was then bent over the sampling cloth and vigorously slapped 20X to dislodge insects. Lepidopterous pests were counted on the beat cloth as well as on the soil surface on both sides of the sampled row. Data were analyzed only for the highest sampled population of corn earworm and fall armyworm on 27 July in 1998 and the peak population for corn earworm on 28 July in 1999. Fall armyworm, *Spodoptera frugiperda* (J.E. Smith), was not present in 1999. Velvetbean caterpillar population counts were taken on 28 Sept. in 1998. There was no measurable infestation of velvetbean caterpillar in 1999. Defoliation estimates were taken only in 1998 because defoliation was uniformly low (< 3%) in all treatments in 1999. To estimate defoliation, five leaves were blindly removed from both the interior and exterior of the plant canopy (10 leaves per treatment) on 6 Aug. Each leaf was given a score of 0 to 4 to represent the portion of the tetrafoliate leaf that was missing. This score was converted to a percentage defoliation value for analysis.

Damage caused by twospotted spider mite, *Tetranychus urticae* Koch, was evaluated on 17 Sept. 1999 by scanning the interior 14 rows of the 16-row subplots and totaling the number of row m with severe spider mite injury. Severe injury was defined as entire plants that were chlorotic or necrotic and having the plant terminal encased in mite silk. This row m total was converted to a percentage of plot area for analysis. There was no measurable spider mite infestation in 1998.

Threecornered alfalfa hopper damage was evaluated by counting the number of feeding sites characteristic for this pest on the lateral branches and main stem of three randomly selected plants per plot after crop inversion. No thrips counts were taken because all plots received a standard aldicarb application to eliminate plant stunting from direct thrips injury and insecticide treatment has been generally ineffective in reducing tomato spotted wilt disease progress (Todd *et al.*, 1996; Culbreath *et al.*, 1999).

Pod damage from soil insects was measured by counting the number of scarified or penetrated pods in 100- and 150-pod samples per experimental unit in 1998 and 1999, respectively. Pod sampling was done on inverted plants before combining. Based on pitfall and soil sampling in the experimental plots, pod damage was caused by lesser cornstalk borer and several species of wireworms (P.H. Joost, unpubl. data). Pod feeding cannot be distinguished conclusively between lesser cornstalk borer and wireworms, and no attempt was made to do so.

In 1999, injury was noticed initially on a few split kernels during the grading process. The observed damage was identical to that attributed to a burrower bug, *Pangaeus bilineatus* (Say), by Smith and Pitts (1974). This damage was evaluated by randomly selecting 100 kernels from each grade sample. Samples were placed in a microwave oven for 2 min on the high setting to facilitate removal of the testa. The percentage of kernels with burrower bug feeding injury was then calculated. Subsequent pitfall sampling of the experimental field in the fall of 1999 and throughout the 2000 growing season demonstrated that > 98% of burrower bugs captured were *P. bilineatus*. Reference specimens of *P. bilineatus* were sent to the USDA-ARS Systematic Entomology Lab., Beltsville, MD for identity verification; and voucher specimens were deposited in the Clemson Univ. Arthropod Collection.

Disease Sampling. Two observers measured tomato spotted wilt virus severity by counting symptomatic row lengths as described by Culbreath *et al.* (1997) on four rows (73 row m) per plot on 5 Oct. in 1998 and 23 Sept. in 1999. Southern stem rot, *Sclerotium rolfsii* Sacc., and Rhizoctonia limb rot, *Rhizoctoia solani* Kuhn AG-4, were rated within 2 hr of digging by scanning one harvest row per plot and counting the number of 0.3-m row increments which were symptomatic for these two diseases. Plots were examined for leaf spot diseases, *Cercospora arachidicola* Hori and *Cercosporidium personatum* (Berk. and Curt.), 1 wk prior to harvest by parting the canopy with a meter stick and examining the lower foliage. All treatments had < 0.5 % of leaflets affected by leaf spot and no ratings were taken.

Weed Sampling. Weeds were sampled by counting the number of plants on two rows per main plot at 31 DAP in both study years. The weed taxa sampled were bermudagrass, *Cynodon dactylon* (L.) Pers.; crabgrass, *Digitaria* spp.; carpetweed, *Mollugo verticillata* L.; Palmer amaranth, *Amaranthus palmeri* S. Wats.; Florida pusley, *Richardia scabra* L.; morningglory, *Ipomoea* spp.; and yellow nutsedge, *Cyperus esculentus* L.

Peanut Stand and Canopy Width. Peanut stand counts were taken on 7 June (20 DAP) in 1998 and 10 June (29 DAP) in 1999 by dropping a meter stick next to a row and counting the number of plants. Two 1-m row length subsamples per replicate were taken for each tillage treatment. Canopy width measurements were taken 17 July (60 DAP) in 1998 and 28 June (47 DAP) in 1999. Five canopy subsample measurements per tillage treatment were taken in each of five replicates.

Yield, Grade, and Crop Value. Peanuts were inverted with a KMC peanut digger (Kelly Manufacturing Co., Tifton, GA) on 5 Oct. (140 DAP) in 1998 and 23 Sept. (134 DAP) in 1999. Yield rows were harvested on 12-13 Oct. (147-148 DAP) in 1998 and 7 Oct. (148 DAP) in 1999 with a Hobbs 525 combine (Hobbs Manufacturing Co., Albany, GA) modified with a bagging attachment. Yield was taken from three two-row subsamples (110 row m) per experimental unit. Samples were weighed in the field and a subsample (ca. 500 g) was removed for grading. Grade samples were oven dried at approximately 32 C for 4 d, then stored at room temperature until graded in accordance with USDA standards (Anon., 1998), with the exception that a kernel splitter was not available to evaluate concealed damage. Yields were adjusted to 7.0% moisture before statistical analysis. Crop value was based on yield and grade (percentage total mature kernels) according to the 1998 and 1999 quota peanut loan schedules.

Data Analysis. The data were subjected to factorial analysis using the PROC GLM mixed model analysis of variance (SAS Inst., 1985). A protected LSD test ($P \leq 0.05$) was used to make the following preplanned individual comparisons: chlorpyrifos treated vs. untreated within tillage systems, and untreated among tillage systems. Arthropod counts (x) were transformed using [sqrt(x + 0.5)]. Percentage data for defoliation, mite damage, virus incidence, pod damage, burrower bug injury, yield, and grade were transformed using arcsin (x). Results were not pooled over years because a significant year effect (F > 4.08; df = 1,41; P < 0.05) was found for each of the variables analyzed.

Results and Discussion

Corn Earworm, Fall Armyworm, Velvetbean Caterpillar. There was a significant tillage effect on corn

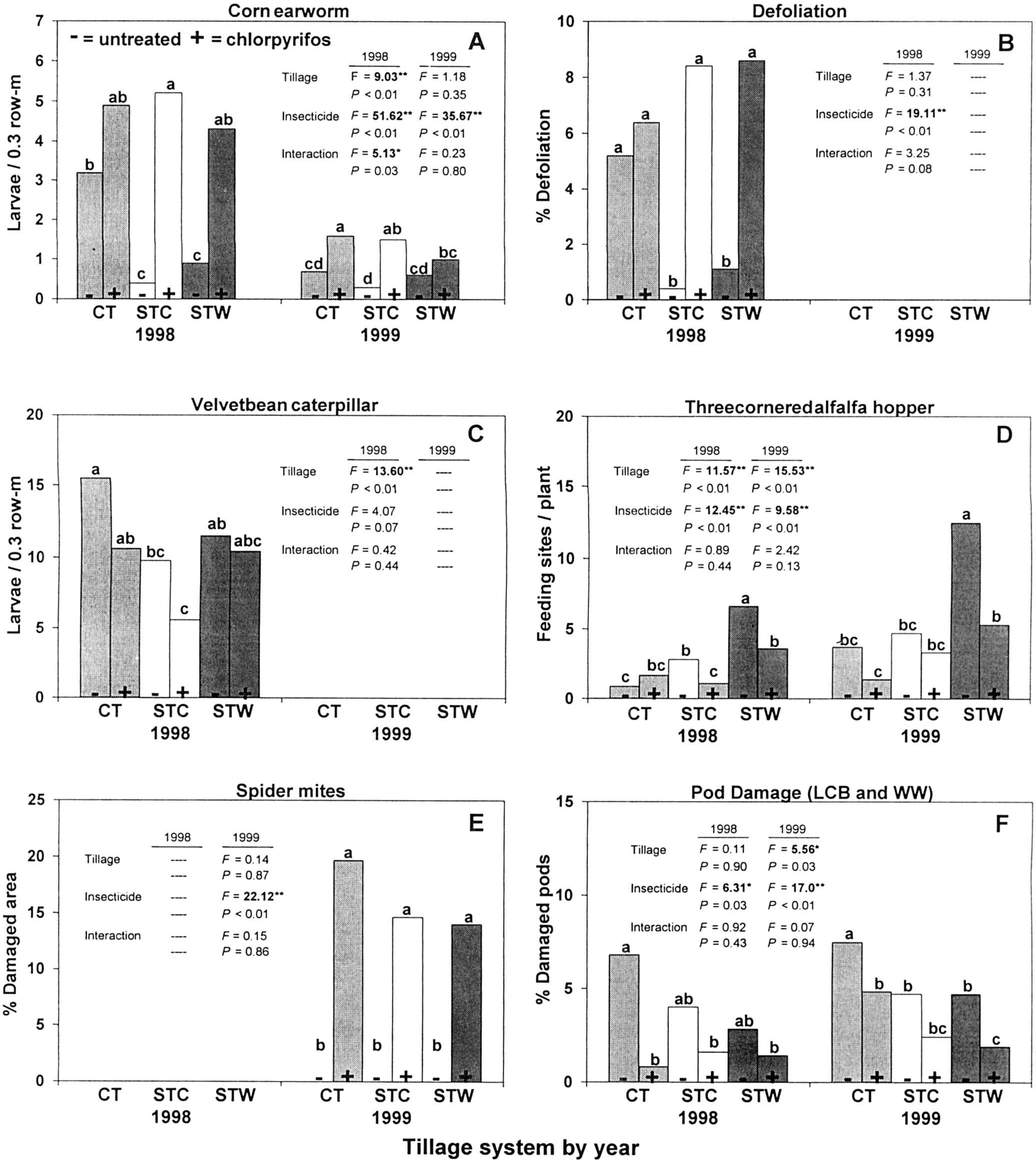

Fig. 1. Effect of peanut tillage system and chlorpyrifos treatment on corn earworm infestation (A), peanut defoliation by corn earworm (B), velvetbean caterpillar infestation (C), threecornered alfalfa hopper damage (D), spider mite damage (E), and pod damage from lesser cornstalk borer and wireworms (F) at Blackville, SC. CT = conventional tillage; STC = strip tillage into corn residue; STW = strip tillage into killed wheat cover crop residue. Chlorpyrifos treated = +, untreated = -. Histogram bars sharing the same letter within the same year are not significantly different as determined by protected LSD test (P = 0.05). Single and double asterisks highlight significant F tests at *a* = 0.05 and *a* = 0.01, respectively.

earworm in 1998, when untreated strip tillage systems had lower levels of this pest than did the untreated conventional tillage system (Fig. 1A). There was a significant insecticide effect on corn earworm during both years, with chlorpyrifos treatment resulting in higher corn earworm populations. There was a significant interaction effect for corn earworm in 1998, when chlorpyrifos treatment caused greater increases in corn earworm levels in strip tillage systems than in conventional tillage.

In 1998, there was significantly less defoliation from corn earworm in the untreated strip tillage systems than in untreated conventional tillage (Fig. 1B). Although there was no measurable interaction effect for defoliation, chlorpyrifos treatment significantly increased defoliation in both strip tillage systems, but not in conventional tillage.

Velvetbean caterpillar populations were lower in corn residue systems than in conventional tillage in 1998 (Fig. 1C). There were no significant insecticide or interaction effects for velvetbean caterpillar.

Fall armyworm populations were too low (<3/row-m, data not shown) to detect a tillage effect in either year (F = 3.43; df = 2, 8; P = 0.08 and F =1.00; df = 2, 8; P = 0.38 for 1998 and 1999, respectively). However, chlorpyrifos treatment increased fall armyworm populations in 1998 (F = 10.22; df = 1, 12; P < 0.01).

Granulate cutworms, *Agrotis subterranea* (Fabricius), also were collected on the beat cloth. However, beat cloth sampling is only effective in measuring the early instars of this pest, which feed preferentially on peanut blooms, while later instars are typically hidden under plant debris and soil (Dietz *et al.*,1992). Using pitfall traps, P.H. Joost (unpubl. data) has found that granulate cutworm is suppressed by conservation tillage, and that chlorpyrifos is more disruptive in conservation tillage.

Lower levels of canopy-feeding lepidopterans such as corn earworm and velvetbean caterpillar in reduced tillage systems are consistent with previously cited research results and with the presence of higher predator populations, particularly the red imported fire ant, Solenopsis invicta Buren, in our conservation tillage systems (P.H. Joost, unpubl. data). Corn earworm infestations typically are most abundant in South Carolina peanut fields from the last week of July until mid-August. Suppression of predators with chlorpyrifos approximately 2 wk prior to peak oviposition triggered the consistent corn earworm outbreaks in our treated plots. A similar response to chlorpyrifos treatment was reported by Funderburk *et al.* (1990). The interaction effect for corn earworm in 1998 indicated that chlorpyrifos treatment was more disruptive in a conservation tillage system; and, in fact, larval populations did not approach the economic threshold of 12 larvae per row m (Brown and Todd, 2000) in either reduced tillage system when chlorpyrifos was not applied. Chlorpyrifos did not trigger velvetbean caterpillar outbreaks, presumably because this pest colonized peanut in late September, approximately 2 mo after chlorpyrifos treatment. Funderburk *et al.* (1990) found that chlorpyrifos directly controlled velvetbean caterpillar populations. Minton *et al.* (1990) reported no effect of chlorpyrifos treatment on insect populations in minimum or conventional tillage systems, but the smaller plot size used (two rows) in what was primarily a disease experiment may have negated most predator effects.

Threecornered Alfalfa Hopper. A significant tillage effect was observed for threecornered alfalfa hopper injury in both study years, with consistently higher damage in the wheat residue system (Fig. 1D). There also was a consistent insecticide effect on threecornered alfalfa hopper, but no interaction effect. Chlorpyrifos reduced threecornered alfalfa hopper injury in all systems, with the exception of the 1998 conventional tillage plots which had relatively little injury in either treated or untreated subplots. We are not aware of any previous reports of increased threecornered alfalfa hopper damage in reduced tillage peanut, but higher populations of this pest have been found where soybean is doublecropped into wheat stubble (Troxclair and Boethel, 1984). Our results are contrary to those of Minton *et al.* (1991), but we sampled for cumulative seasonal injury rather than for the pest itself. It may be more difficult to detect differences in actual threecornered alfalfa hopper populations among tillage systems at any given point in the growing season. Our results demonstrate that threecornered alfalfa hopper damage may increase where peanut is planted into wheat residue. However, the economic consequences of threecornered alfalfa hopper are poorly understood on peanut, and at present there are no economic thresholds for damage from this insect. It is not surprising that granular chlorpyrifos suppressed threecornered alfalfa hopper because their nymphs are found at or just beneath the soil line around peanut plant crowns where the insecticide treatment is concentrated.

Spider Mites. There was no significant tillage effect on spider mite damage, but chlorpyrifos treatment resulted in severe spider mite outbreaks in all tillage systems in 1999 (Fig. 1E). No interaction effects were detected for spider mite injury. The threat of chlorpyrifos-induced mite outbreaks is a significant incentive to avoid treatment for soil insects. Miticides currently labeled for use on peanut (propargite and fenpropathrin) cost about $94/ha and, therefore, the potential benefits of chlorpyrifos use must be balanced against the risk of incurring this additional cost. Although no direct tillage effect was found on spider mites, strip tillage systems would significantly reduce the risk of mite outbreaks if disruptive soil insecticides were avoided. Drought stress conditions, which are most likely to encourage chlorpyrifos use for lesser cornstalk borer control, are conducive also to spider mite outbreaks (Funderburk and Brandenburg, 1995). This study indicates that strip tillage systems may offer a reduced risk of lesser cornstalk borer and wireworm injury as discussed below.

Insect Pod Damage. Pod damage from lesser cornstalk borer and wireworm was significantly lower in the strip tillage systems than in conventional tillage in 1999 (Fig. 1F). Chlorpyrifos treatment reduced pod damage in both years. Chlorpyrifos is known to suppress both lesser cornstalk borer and wireworm injury as previously cited. There were no interaction effects for pod damage, reflecting the fact that chlorpyrifos treatment tended to reduce pod damage counts in all tillage systems. Less pod dam-

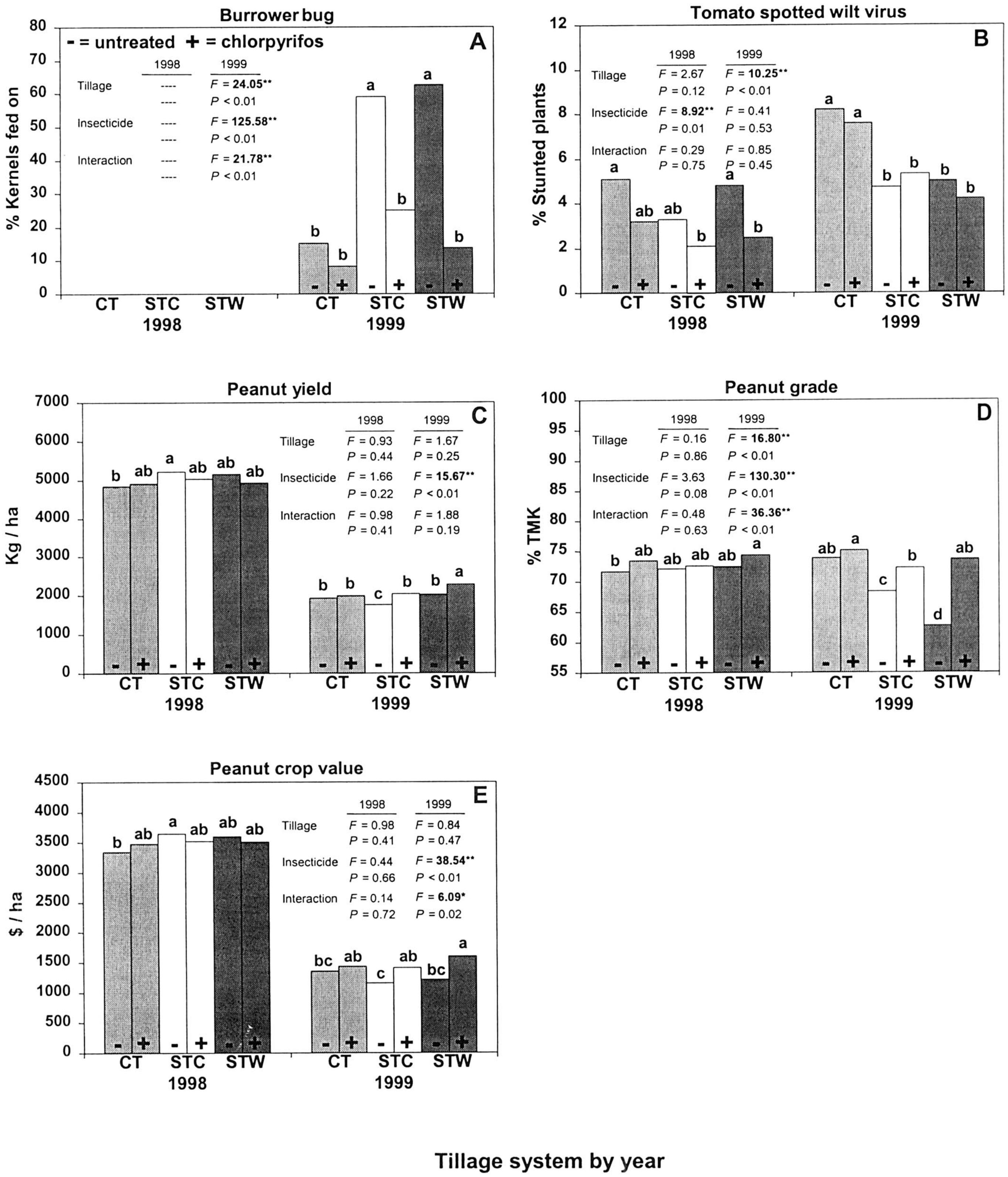

Fig. 2. Effect of peanut tillage system and chlorpyrifos treatment on burrower bug damage (A), tomato spotted wilt virus incidence (B), peanut yield (C), peanut grade (D), and peanut crop value (E) at Blackville, SC. CT = conventional tillage; STC = strip tillage into corn residue; STW = strip tillage into killed wheat cover crop residue. Chlorpyrifos treated = +, untreated = -. Histogram bars sharing the same letter within the same year are not significantly different as determined by protected LSD test (P = 0.05). Single and double asterisks highlight significant F tests at $a = 0.05$ and $a = 0.01$, respectively.

age from lesser cornstalk borer and wireworm in the strip tillage systems is consistent with reduced pitfall catches of lesser cornstalk borer larvae and adult wireworm beetles in these strip tillage systems (P.H. Joost, unpubl data).

Burrower Bug Damage. A significant tillage effect was observed on burrower bug kernel feeding in 1999, when the untreated corn and wheat residue systems had higher levels of burrower bug injury than untreated conventional tillage (Fig. 2A). Chlorpyrifos treatment significantly reduced burrower bug damage in the corn and wheat strip tillage systems. There was a significant interaction effect for burrower bug injury, reflecting the fact that the lower levels of injury in conventional tillage responded less to insecticide treatment. Burrower bug is a significant, but sporadic pest in south Texas (Smith and Pitts, 1974; Lis *et al.*, 2000). Although peanut injury occurred in Alabama in 1966 (Smith and Pitts, 1974), burrower bug generally has not been considered an economic pest in the Southeastern U.S. Increased burrower bug injury in conservation tillage peanut has not been reported previously. In contrast, reduced tillage maize fields are reported to have less injury from another burrower bug, *Cyrtomenus bergi* Froeschner, in Costa Rica (Lis *et al.*, 2000). There have been few reports on insecticidal efficacy against burrower bugs in peanut (Smith and Pitts, 1974; Lis *et al.*, 2000), and very little is known about what triggers burrower bug injury. The high incidence of burrower bug injury which occurred in our 1999 test may have been related to strip tillage corn production in the experimental field during the previous year, or drought during the growing season. From 1 July until 15 Sept., the plots received only 11.6 cm of rainfall and only 5.1 cm of that total occurred after 15 July. The significant interaction of tillage and chlorpyrifos treatment indicates that suppression or avoidance of burrower bug may be of greater concern in reduced tillage peanut production.

Disease Ratings. Tomato spotted wilt virus (TSWV) infections were lower in strip tillage systems in 1999 (Fig. 2B). In 1998 there was a significant insecticide effect on spotted wilt incidence, although chlorpyrifos treatment measurably reduced virus symptoms only in the wheat residue system. There were no interaction effects for TSWV. A reduction of spotted wilt in conservation tillage is consistent with the previously cited research; however, suppression of this disease by chlorpyrifos would not be expected. Results presented from 1999 and a subsequent test in 2000 (data not shown) indicate that spotted wilt suppression by chlorpyrifos is at best an inconsistent event. Chlorpyrifos is a nonsystemic organophosphate and, therefore, would not control the thrips vectors by ingestion. Chlorpyrifos is volatile (Getzin, 1985); and it is conceivable that some thrips could have been controlled in the peanut canopy, thus affecting disease progress. Other than chance, alternative explanations are that chlorpyrifos treatment could have caused a plant physiological response which affected thrips landing rates or otherwise altered disease progress. Phorate, a systemic organophosphate, is believed to affect TSWV by a similar mechanism (Culbreath *et al.*, 1999).

Southern stem rot injury ratings were < 0.5% of plot area for all treatments in both years (data not shown). There were no measurable effects of tillage ($F < 4.46$; df = 2,8; $P > 0.05$) or insecticide treatment ($F < 4.75$; df = 1,12; $P > 0.05$) on southern stem rot incidence in either year. The use of tebuconazole and azoxystrobin fungicides in combination with a 3-yr rotation out of peanut production would minimize southern stem rot infection. Although conservation tillage practices generally have not had a major impact on the soil disease complex (Minton *et al.*, 1991; Grichar, 1998; Hartzog and Adams, 1999), it is necessary to document disease incidence because chlorpyrifos has fungicidal activity which can confound soil insecticide experiments (Chapin and Thomas, 1993).

Rhizoctonia limb rot ratings were not affected by tillage in either year ($F < 4.46$; df = 2,8; $P > 0.05$) and there was no insecticidal effect in 1998 ($F < 4.75$; df = 1,12; $P > 0.05$). However, in 1999, Rhizoctonia ratings were significantly higher in chlorpyrifos-treated plots ($F = 12.37$; df = 1,12; $P < 0.01$). Previously we have observed higher levels of limb rot in chlorpyrifos-treated plots (Chapin and Thomas, 1993), but we are not aware of why this occurs. The Georgia Green cultivar is known to exhibit relatively high levels of Rhizoctonia symptoms on leaf tissue in contact with the soil, but relatively low levels of limb rot incidence on lateral stems (Franke and Brenneman, 2000). Differences in Rhizoctonia incidence in this study are based on necrotic leaf tissue ratings and very little limb rot was observed on lateral stems or pegs. The higher yields measured in plots with chlorpyrifos treatments would indicate that the observed Rhizoctonia symptoms on leaf tissue had minimal effect on yield. The low levels of disease observed in all tillage systems make it unlikely that southern stem rot, Rhizoctonia limb rot, or leaf spot had any substantial confounding effect on yield, grade, or crop value in the experiments.

Weeds. Bermudagrass populations were higher in corn residue plots in 1998; and during both years, crabgrass populations were higher in corn residue plots than in the other two tillage systems (Table 1). Carpetweed populations were greater in both strip tillage systems than in conventional tillage plots in 1998, but there were no measurable levels of carpetweed in 1999. Morningglory populations were greater in conventional tillage than in corn residue plots in 1999. Yellow nutsedge populations were higher in the corn and wheat residue treatments than in conventional tillage in 1998. There was more Palmer amaranth in wheat residue plots than in conventional tillage in 1998. Florida pusley populations were greater in corn residue plots than in conventional tillage in 1999. Reduced tillage peanut production systems are known to require more intensive weed management (Wilcut *et al.*, 1987). Although our strip tillage systems had greater overall weed densities than conventional tillage at 31 DAP, all weed species were effectively controlled with the previously described postemergence herbicide program and, thus, did not confound our yield, grade, or crop value results.

Plant Stand and Canopy Width. Tillage did not affect peanut stand counts in either year ($F = 1.16$; df = 2,12; $P = 0.35$ and $F = 0.98$; df = 2,12; $P = 0.40$ for 1998 and 1999, respectively). In 1998, tillage affected early season canopy growth ($F = 6.71$; df = 2,12; $P = 0.01$), with

Table 1. Effect of tillage on peanut weed populations at Blackville, SC.[a]

	Bermuda-grass[b]		Carpetweed		Crabgrass		Morningglory		Yellow nutsedge		Palmer amaranth		Florida pusley	
Tillage[c]	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
CT	0.2 b	0.3 a	0.0 b	---	0.2 b	9.1 b	0.4 a	11.6 a	0.2 b	6.8 a	0.0 b	3.0 a	---	0.4 b
STC	1.2 a	0.0 a	5.1 a	---	31.1 a	23.0 a	0.0 a	0.7 b	6.3 a	0.2 a	4.0 ab	4.3 a	---	14.4 a
STW	0.2 b	0.0 a	3.6 a	---	1.7 b	10.4 b	0.3 a	5.2 ab	5.1 a	7.5 a	15.2 a	4.0 a	---	7.8 ab

[a] Column means with the same letter are not significantly different. Fisher's projected LSD, $P < 0.05$.

[b] Weed populations expressed as mean number of plants per row m at 31 d after planting.

[c] CT = conventional bottomplow tillage; STC = strip till into corn residue; STW = strip till into killed wheat cover crop residue.

conventional tillage having a wider canopy than either strip tillage treatments at 60 DAP. There was no measurable tillage effect on early season canopy growth in 1999 ($F = 2.0$; $df = 2,12$; $P = 0.20$). The 1998 delay in strip tillage canopy growth had no measurable detrimental effect on crop yield or grade.

Yield. Peanut yields were not affected by tillage in either year (Fig. 2C). Chlorpyrifos treatment had no effect on yield in 1998, but in 1999 chlorpyrifos treatment resulted in higher yields in the strip tillage systems. There was no measurable interaction effect for yield. The fact that tillage had no effect on peanut yield demonstrates that reduced tillage systems have adequate yield potential on some South Carolina soils. One potential explanation for the positive yield response to chlorpyrifos treatment in 1999 would be the reduced pod damage from lesser cornstalk borer or wireworms in treated plots. However, in 1998, approximately the same relatively low levels of pod scarification occurred with no detrimental yield effect. In fact, 1998 yields were numerically lower in the chlorpyrifos-treated strip tillage plots, perhaps due to the increased canopy feeding by corn earworm in chlorpyrifos-treated plots. Also, in 1999, pod damage levels from lesser cornstalk borer and wireworm were greatest in conventional tillage (Fig. 1F), but chlorpyrifos increased yield only in the strip tillage systems (Fig. 2C). Thus, it seems unlikely that lesser cornstalk borer or wireworm injury caused the observed yield reductions. The positive yield response of strip tillage systems to chlorpyrifos in 1999 was likely due to the marked reduction in burrower bug kernel feeding. The yield reductions measured from burrower bug injury were actually underestimates because severe spider mite injury occurred in the chlorpyrifos-treated plots, and this mite damage would have offset some of the positive response to chlorpyrifos treatment.

Grade. Neither tillage nor insecticide treatment had a measurable effect on peanut grade in 1998; but, in 1999, grades were significantly lower in the untreated strip tillage systems relative to untreated conventional tillage (Fig. 2D). Chlorpyrifos treatment resulted in improved grade in the strip tillage systems but not in conventional tillage in 1999; and, thus, there was a significant interaction effect for grade. The tillage effect on grade in 1999 was probably due to increased burrower bug damage in strip tillage systems. The positive response of grade to chlorpyrifos treatment was attributed to burrower bug suppression, and the significant interaction effect in 1999 indicates that grade response to burrower bug control is greater in reduced tillage systems. As with yield response, the data probably underestimate the effect of burrower bug on grade because severe spider mite injury in chlorpyrifos-treated plots would have offset some of the positive grade response to treatment. Our grade effects are based on the percentage total mature kernels, which takes into account relative kernel weight, size, and damage. Higher total mature kernel values are a measure of the fact that chlorpyrifos-treated strip tillage plots had a lower percentage of small and damaged kernels. For example, in the wheat strip tillage system, small kernel percentages by weight ("other kernels") were 10.8 vs. 4.7% ($t = 7.54$, $df = 4$, $P < 0.01$) for untreated and chlorpyrifos-treated plots, respectively; and damaged kernel values were 1.2 vs. 0.3% ($t = 3.75$, $df = 4$, $P = 0.02$) for untreated and chlorpyrifos-treated, respectively. Grade factors were not further reduced by classifying all feeding injury as damaged kernels because the majority of kernels on which burrower bug feeding was observed probably would not be detected in the normal grading process where the testa is not removed. When kernels are split in commercial grading to check for concealed damage, only burrower bug feeding injury which occurs on the plane of the joined kernel halves is detected. Most of the feeding sites counted in this experiment were hidden until the testa was removed. In addition, individual kernels were carefully examined in subsamples, and even kernels with minor discoloration from burrower bug were counted. By necessity, commercial grading is more superficial and, according to grading guidelines, damaged kernels must be "affected by flesh discoloration darker than light yellow, or more than slight yellow pitting of the flesh" (Anon., 1998). Lower grades have been associated previously with reduced tillage production, but these grade reductions have been related to delayed crop emergence (Grichar, 1998).

Crop Value. Tillage had no overall effect on crop value in either year, although in 1998 the crop value of the untreated corn residue strip tillage system was higher than that of untreated conventional tillage (Fig. 2F). This difference in crop value reflects a higher yield in the corn residue system which was previously attributed to lower levels of corn earworm damage. In 1999, chlorpyrifos treatment increased crop value in both strip tillage systems, and there was a significant interaction effect for crop value. The $249 and $388/ha increase in crop value in corn and wheat residue systems, respectively, was attributed primarily to suppression of burrower bug damage. These crop value data are based on yield and grade, but do not account for the additional risk of damaged kernel penalties when burrower bug damage is discovered in the grading process. If the entire grade sample had been processed through a kernel splitter, with concealed damage added to the damaged kernel category, additional economic loss probably would have been measured. For every percentage of kernel damage (by weight) above 1%, there is a crop value penalty. For example, 2% damaged kernels results in a $3.75/mt deduction; and 3% damaged kernels results in a $7.70/mt deduction. In addition, once kernel damage reaches 2.5%, peanuts are classified as "segregation 2" and crushed for oil (Anon., 1998). Although growers are compensated for loss of quota to segregation 2 peanuts, there is an additional $27.50/mt discount. Therefore, burrower bug injury exposes the grower to substantial economic risk which was not fully measured.

Management Implications. The results indicate both potential benefits and liabilities for insect management in reduced tillage peanut production. Strip tillage reduced the risk of corn earworm or velvetbean caterpillar reaching economic thresholds, as well as suppressing TSWV incidence. Strip tillage systems also had less pod damage from the lesser cornstalk borer/wireworm complex. Although tillage had no direct effect on spider mite injury, avoidance of foliar or soil insecticides in strip tillage systems could reduce the need to control secondary spider mite outbreaks and, thus, result in additional economic benefits. Conversely, strip tillage into a wheat cover crop increased threecornered alfalfa hopper damage, though the economic significance of this injury is unknown.

Finally, the substantial economic loss from burrower bug damage in strip tillage systems merits further investigation of the risk posed by this pest in conservation tillage peanut. Research conducted on reduced tillage peanut production may need to account for the potential confounding effect of burrower bug injury on yield and grade by evaluating kernel injury at harvest. Our data require cautious interpretation because the results could be an anomaly of drought conditions or the selective immigration of burrower bug into relatively small tillage plots. However, the ability to avoid or suppress burrower bug injury may be an important factor in the adoption of at least some reduced tillage peanut production systems. On-farm evaluations of burrower bug injury in reduced tillage systems are needed to assess the actual economic significance of this pest.

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