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Insect Population Trends in Different Tillage Systems of Cotton in South Texas

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ABSTRACT

This study was conducted from 2000 to 2006 in experimental plots of the USDA-ARS-Subtropical Agricultural Research Center in Weslaco, Texas and privately owned cotton fields near Hargill and Santa Rosa, Texas. We evaluated the effects of conservation and conventional tillage systems on abiotic and biotic factors in dryland and irrigated cotton and how they affect major insect populations and damage to cotton throughout the growing season. Cotton producers are incorporating significant changes in management systems in an effort to decrease production costs and improve profits. For this reason conservation tillage practices have been adopted across most of the cotton acreage in the southern United States. This manuscript discusses changes in the pest spectrum and severity of pest problems associated with conservation versus conventional tillage systems in both irrigated and non-irrigated cotton. Our results demonstrated that different tillage practices had indirect potentially positive or negative effects on pest and beneficial populations in cotton and other crops. The effects of insect pest populations on the crop are influenced by both abiotic and biotic factors which can be created or manipulated by conventional and conservation tillage systems.

Additional Index Word: conservation and conventional tillage, microclimate, harmful and beneficial insects

Each year, insect pests cause significant losses in yield of cotton grown in various areas of the world. In the United States, arthropod pests reduced overall cotton yields by an average of $406.2 million each year during 2004-2006, which included $99.3 million in Texas and $5.6 million in the Lower Rio Grande Valley (LRGV) region (Williams, 2005, 2006, 2007). In the LRGV, principal insect pests include the boll weevil, *Anthonomus grandis grandis* Boheman; bollworm, *Heliothis zea* (Boddie); fleahopper, *Pseudatomoscelis seriatus* (Reuter); beet armyworm, *Spodoptera exigua* (Hübner); cotton aphids, *Aphis gossypii* Glover; "Biotype "B" whitefly, *Bemisia tabaci* (Gennadius); spider mites, *Tetranychus* spp.; and thrips, *Thrips* spp.

Chemical insecticides continue to be the main tool for insect control in cotton. At the beginning of 21st century, about 74.1 million kg of insecticides were used on agricultural crops in the United States. Over half of this amount was applied to cotton fields, corresponding to roughly 7.3 kg/ha of active ingredients (Statistical Highlights of U.S. Agriculture, 2006, 2007; National Cotton Council of America, 2008). In the LRGV of Texas, an average of five insecticide treatments were applied to each cotton field during 2005-2007, at a cost of approximately $169.30 per hectare (Williams, 2006, 2007, 2008).

Important alternatives to insecticides in cotton include various types of cultural control techniques (Reynolds et al. 1975, Summy and King 1992). The use of different tillage practices is an important cultural tool. Conservation tillage is being adopted by an increasing number of Texas farmers because it provides additional agronomic and environmental benefits. These benefits include (a) conservation of soil moisture, (b) decreased soil compaction and improved soil tillage, (c) increases in soil organic matter, (d) improved infiltration by water and reduction in runoff, (e) reduction in erosion caused by wind and water, and (f) substantially lower fuel and operational costs relative to conventionally tilled systems (Stevens et al. 1992, Smart and Bradford

2000, Johnson and Polk 2004, Wiedenfeld 2007).

Tillage operations modify soil habitats where some insect pests (Troxclair and Boethel 1984) and beneficial insects (McPherson et al. 1982, Funderburk et al. 1988) occur during at least part of their life cycles. Modifications to these habitats can alter survival and development of both soil- and foliage-inhabiting insects (Herzog and Funderburk 1986). During 2001-2002, 72.0 million ha were under no-tillage management in various areas of the world. This estimate includes 50% of the cropland in Brazil (17.4 million hectares) and Argentina (14.5 million hectares), 45% in Australia (9.0 million hectares) and 20.0% in the U.S. (22.0 million hectares). During 2002, no-till cotton production in the U. S. accounted for 27.6% of the total no-till acreage in cotton production throughout the world (Derpsch and Benites 2003). In the LRGV, 30% of cotton acreage is currently under conservation tillage.

Dryland cotton production in the LRGV is complicated by erratic precipitation, ranging from 40.6 to 55.9 cm annually, that occurs primarily during the late summer and early fall. The three key periods of cotton growth that require adequate moisture occur at stand establishment, pre-bloom, and shortly after boll set. Given average yearly weather conditions, cotton in the LRGV should be irrigated at least once during 7 out of 10 years. During the past ten years, irrigated cotton has represented about 35.8% of the total cotton acreage of the LRGV region. During 2006, yields for dryland cotton averaged 64.8 kg/ha while those for irrigated cotton were substantially higher (about 807 kg/ha). This is a typical trend and exemplifies the need for adequate soil moisture for cotton production and the potential value of production strategies which tend to conserve soil moisture.

Studies relating to the impact of different tillage practices on arthropods in cotton were conducted in the Southern Rolling Plains (SRP) of Texas (Sansone and Minzenmayer 2005) and in Louisiana (Leonard 1995). Different tillage practices in SRP have both potentially positive and potentially negative effects on pest and beneficial populations, although many of these potential effects in cotton production are poorly understood. In Louisiana, conservation tillage production practices have significantly influenced arthropod pest populations in terms of both diversity and densities. Louisiana State University scientists have documented changes in the pest spectrum and severity of pest problems associated with changes in agronomic practices (including effects of conservation tillage systems) in both cotton and corn. Results of these studies have indicated that population densities of certain insect pests may be influenced to a considerable extent by the type of tillage system used in crop production, while others are largely unaffected. IPM strategies in cotton and other crops are based on knowledge regarding the effects of production practices on the pest life system, although specific information regarding such affects in particular areas (e.g., the LRGV) are poorly understood.

The present study was conducted to increase our knowledge regarding the effects of conservation versus conventional tillage systems on populations of the principal pest species of cotton occurring in the subtropical LRGV region. Specific objectives were to evaluate the effects of the two tillage systems on soil surface temperature, soil moisture, plant canopy structure, light interception, and timing of fruit set in both dryland and irrigated cotton, and how these factors affect populations of boll weevil, cotton fleahoppers, whiteflies and other key and secondary pests and their natural enemy associates during the growing season. Such information is important in the development of effective IPM strategies based on the cultural control approach.

MATERIALS and METHODS

Studies were conducted during 2000-2006 in grower-managed conventional and conservation tillage fields located near Hargill (dryland cotton), Santa Rosa (irrigated and dryland cotton), and in experimental plots at the Subtropical Agricultural Research Center-ARS-USDA in Weslaco (dryland and irrigated cotton). The average size of each grower field was about 20 ha, and experimental plots were considerably smaller (about 1.5 ha). Each treatment (tillage method) was replicated 3-4 times. Soil type was fine sandy loam (Hargill, Santa Rosa) and sandy clay loam (Weslaco).

Conventional tillage consisted of chisel plowing, disking, bedding (75-cm centers), and cultivation, use of insecticidal and herbicidal applications, and shredding operations following harvest. Crop residue of the previous crop was destroyed or incorporated into the soil (fall 1999-2002). No-tillage (conservation tillage) consisted of leaving the soil undisturbed after the previous crop, utilizing a stalk puller to loosen stubble before planting, and shredding plants by mowing after harvest. Glyphosate was applied once in the fall and again in the spring prior to planting cotton. Cotton was planted using a no-till planter in stubble of the previous crop. All irrigated fields were furrow irrigated on three occasions (pre-plant, pre-bloom, and 3-5 days after boll set).

Two cotton varieties, DPL 451RR and DPL 5415RR, were planted during late-February through early-March. Seeds of each variety were planted at rates of 90,000-100,000 per hectare, which produced final densities of about 80,000-95,000 plants per ha. Two applications of fertilizer were applied: 25 kg/ha of nitrogen and 45 kg/ha of phosphorus at pre-planting, and 45 kg/ha of nitrogen when first squares appeared. Preventive insecticide applications of Vydate (oxamyl; 1.2 kg/ha) for early season boll weevil control were applied 1) when cotton had match head squares, 2) five days after the first treatment and 3) five days after the second treatment. Thereafter, cotton was treated when 10% or more of 100-square samples collected from the tops of cotton plants exhibited boll weevil egg punctures. During 2005 and thereafter, cotton was sprayed according to determinations by the boll weevil eradication program.

When 60% or more of cotton bolls opened, cotton fields were defoliated with Def (0.47 kgAI/ha), Dropp (0.23 kgAI/ha), or a combination of the two (50% Def + 50% Dropp). The herbicide 2,4-D-dimethylammonium (1.2 kg/ha) was applied immediately after cotton was shredded and 40 days later to destroy remaining cotton stalks (Makus, 2002; Lower Rio Grande Valley cotton, grain sorghum, and corn blue book, 2000-2005; Greenberg et al., 2004, 2007).

Measurements associated with cotton plant phenology (height, number of leaves, squares, and bolls) were collected weekly beginning 35-40 d after planting and throughout the growing season. On each sampling date, 25 plants were randomly selected from each field or experimental plot. Soil temperatures were measured weekly beginning 35-40 d after planting and continuing throughout the remainder of the growing season. Soil surface temperatures were recorded using HOBO® H8 4-channel loggers (Onset Computer Corporation, Pocasset, MA). Four TMC6-HA external sensors were used for each logger and were placed in the cotton rows under plants and between the rows. Data were recorded every 15 minutes and a HOBO shuttle data transporter was used to download data at the field sites. Soil moisture was measured at 60 and 100 days post-planting at depths of 0-10, 11-20, 21-30, and 31-40 cm using the gravimetric water content method of Gardner (1986). Light interception was recorded at 120 and 150 days post-planting. Measurements were collected between 12:00-1:00 p.m. at 10 randomly selected sites within crop rows, including shaded and unshaded areas, with a Line Quantum sensor (LI-COR, Lincoln, NE).

Cotton was checked for pests, beneficial insects, and damage by weekly scouting. Visual examination of samples were taken along diagonal transects across plots running from corner to corner. Leaves from the terminal, blooms, and squares were carefully observed from the bottom to the top of at least 25 individual randomly-selected plants. The data for all samples were averaged for each plot. The beat bucket method (Knutson and Wilson 1999) was modified by removing the bottom from a 19-L bucket (26 cm deep and 25.4 cm wide) and attaching a zip-lock bag. While holding the bucket at a 45-degree angle to the ground, we quickly inserted the stems of 5 standing plants into the bucket and beat them against the side of the bucket for 3-4 s. Insects dislodged from the plant in each sample were collected in the zip lock bag, and new bags were attached to the bucket. Bags with insect samples were held in a refrigerator until examination. Twenty-five plants were examined from 5 randomly selected sites in each plot on each sample date.

Survival of boll weevils in naturally infested fallen fruit was estimated by collecting samples of infested fallen squares from each of 10 randomly selected 5 m^2 quadrates located along the edges and middle areas of each conservation or conventional tillage field. In addition, the fruit under cotton plants and from the middle of the row were counted and collected separately. In the laboratory, all samples were dissected and examined for boll weevil infestation and survival. In another experiment to measure survival, boll weevils were reared in squares collected from cotton fields and infested in the laboratory. For convenience, these are termed "laboratory infested squares". When ≥ 75% of developing larvae in laboratory infested squares reached second or third instars, each fruit was tied to one end of a 10-cm string and the other end was tied to a 1-m long cord. Five of the 10-cm strings were tied at 20-cm intervals to the cord. Each cord was placed on the soil surface perpendicular to the rows. The squares were labeled from 1 to 5. Ten cords were placed randomly in each field weekly, beginning 90 days after cotton planting. After 7 d the squares were returned to the laboratory and dissected to determine the fate of the infesting weevils.

Boll weevil adult activity was evaluated by monitoring pheromone traps placed at 30 m intervals around the perimeter of each field. Percent boll weevil damage (feeding and egg punctures) was evaluated weekly by visual examination of 100 randomly selected top squares from each field.

To estimate damage of cotton fruit by bollworm, fall armyworm, and beet armyworm, fallen fruit were collected from the soil surface at 50 randomly selected 1- m^2 sites. Data were recorded for number of infested fruits and number of live larvae per fruit for conventional and conservation tillage plots. All plants within 10 randomly chosen 1 m-row sites in conventional and conservation tillage cotton were visually examined for typical cutworm damage (i.e. excised stems).

Statistical analyses were conducted using analysis of variance (ANOVA), and multiple means were separated by Tukey's studentized range test (Wilkinson et al. 1992).

RESULTS and DISCUSSION

Effects of tillage system on abiotic production factors. The amount of plant residue from the previous crop left on the soil surface of fields under conservation tillage was substantially greater than levels of residue in fields under conventional tillage (Table 1). Possible benefits of such residue include conservation of soil moisture; improved water infiltration and decrease in runoff of water, nutrients and herbicide; and reduced levels of wind erosion. Soil moisture content in dryland fields under conservation tillage was significantly higher than in fields under conventional tillage (*P*=0.001-0.043), while no significant differences in moisture content were detected among irrigated cotton fields under the two management systems (*P*=0.1-0.864) (Table 2). Because of apparent water stress, numbers of shed squares in bolls in dryland fields under conventional tillage were significantly greater than those in dryland fields under conservation tillage (Table 3).

Cotton under conventional tillage allocated more resources into vegetative growth while fields under conservation tillage responded by fruiting at a higher rate. During the growing season, the average cotton plant grown under conservation tillage was shorter in height than counterparts under conventional tillage (48.0 and 62.4 cm, respectively; *P*=0.01), had fewer leaves per plant (35.5 and 54.8, respectively; *P*=0.007), and had nearly twice as many fruit per plant (11.2 and 6.0, P=0.0001) (Greenberg et al. 2003). Growth indices of irrigated cotton grown under conservation and conventional tillage systems were not significantly different. During the growing season, plants under conservation and conventional tillage systems had heights (55.5 and 56.3 cm, respectively; *P*=0.762), similar numbers of leaves per plant (46.9 and 43.5, respectively, *P*=0.633), and similar numbers of fruit per plant (8.8 versus 9.0, respectively; *P*=0.782). A similar trend was observed in the Lower Mississippi River Valley (Pettigrew and Jones 2001).

Increased plant height and number of leaves in conventional tillage provided significantly more light interception and shading of the soil surface, which made soil temperatures lower than in conservation tillage fields. In conservation tillage dryland cotton at 120 days after planting, 52.3±2.3% of the incoming sunlight reached the soil surface compared to 39.4±4.2% in the conventional fields (*P*=0.02). Measurements at 145 days post-planting were 60.2±5.0% and 36.2±3.9% for conservation and conventional tillage fields, respectively (*P*=0.0001).

In dryland cotton under conservation tillage, average soil temperatures between the crop rows were 8-11ºC higher than in conventional fields. In conservation tillage fields, mean soil temperature during the cotton growing season under the plants was 30.4ºC and 41.2ºC between rows. Temperatures in conventional tillage were 29.2 and 31.4ºC, respectively. The highest temperatures occurred between 13:00h and 16:00h, averaging 39.3ºC under plants and 53.1ºC between rows in conservation tillage, while those in conventional tillage were 38.8 and 42.9ºC, respectively.

In irrigated cotton, light interception was not significantly different (*P*=0.924) in conservation and conventional tillage fields, with 46.0±1.9% and 45.8 ± 1.7% of incoming sunlight reaching the soil surface at 120 days after planting, respectively. In the conservation tillage fields, mean soil temperature for the growing season was 31.5ºC under the plants and 37.2ºC between rows; temperatures in conventional tillage were 32.2ºC and 36.9ºC, respectively.

Effects of tillage practices on insect pests. Population trends of the major insect pests of LRGV cotton and their natural enemy associates in conservation and conventional tillage systems is summarized in the following discussion.

Boll weevils. Mortality of boll weevils was not significantly different in fallen, naturally-infested fruit collected from conservation and conventional tillage fields in dryland cotton under plants at the field edges (27.0±2.4%, conservation tillage; 31.3±3.3% conventional tillage; *P*=0.3) or under plants in the interior of the field (24.1±1.3% conservation; 29.8±2.6% conventional tillage, *P*=0.1). Mortality was significantly higher in fallen infested fruit between rows in conservation tillage fields (*P*=0.001) (Fig. 1). The same trend of boll weevil mortality was observed in cohorts of laboratory-infested fruit (Fig. 2). Infested fruit exposed to direct solar radiation resulted in some mortality, and shaded fruit provided survival niches enhancing population maintenance during periods of excessively high temperatures. In irrigated cotton, we did not observe significant differences in mortality in naturally infested fruit between conservation (32.6±3.1%) and conventional (33.2±5.4%) tillage fields.

In dryland cotton, the average number of boll weevils per plant in conventional tillage fields were 2.3-fold higher than conservation fields in 2000 (0.633 conventional; 0.279 conservation; *P*=0.011) and 3.5-fold higher in 2001 (0.284 conventional; 0.082 conservation; *P*=0.019). Percent of top fruit punctured by boll weevils (egg and feeding) during the squaring

Table 1. Cotton crop residue on soil surface after harvest, Hargill, TX, 2001

Treatments	Residue on Soil Surface, kg/ha [1] (Mean ± SE)
Conservation till irrigated	5,910.0 ± 1,102a
Conservation till dryland	3,586.7 ± 661.8a
Conventional till irrigated	0b
Conventional till dryland	0b

[1] Means followed by same letter not significantly different at 5% probability level (Student's-t).

Table 2. Soil moisture at different soil depths in cotton fields under conservation (CS) and conventional (CV) tillage.

	Soil Moisture, %[1]			
	Dryland		Irrigated	
Soil depth, cm	CV	CS	CV	CS
	60 days after cotton planted			
0 - 10	7.5±0.7a	4.8±0.5b	8.5±0.7a	8.2±0.7a
11 - 20	10.4±1.2a	6.0±0.9b	10.5±0.7a	9.9±1.0a
21 - 30	18.6±1.5a	9.7±0.5b	14.7±0.9a	12.5±0.7a
31 - 40	22.0±1.9a	13.0±1.0b	23.2±1.2a	22.8±1.9a
	100 days after cotton planted			
0 - 10	9.2±0.7a	5.0±1.6b	11.3±0.8 a	10.5±0.9a
11 - 20	11.2±1.2a	7.6±0.5b	10.8±1.0a	11.4±0.9a
21 - 30	20.0±2.5a	10.4±0.5	19.8±0.9a	18.4±1.3a
31 - 40	24.0±1.4a	14.0±1.4b	24.2±0.9a	24.8±0.6a

[1] Pairs of means (±SE) within a row (dryland vs irrigated separately) followed by same letter are not significantly different at 5% probability level (Student's-t,).

Table 3. Numbers of abscised cotton fruit under different tillage and watering regimes, Weslaco, TX 2000

	Mean (+/- SE) abscised cotton fruit/ha[1]	
Treatment	Dryland	Irrigated
Conventional	26,676.4 ± 2,498.2a	7,571.4 ± 1,950.1a
Conservation	9,790.2 ± 841.4b	8,142.8 ± 1,183.8a

[1] Means within columns followed by same letter not significantly different at 5% probability level (Student's-t).

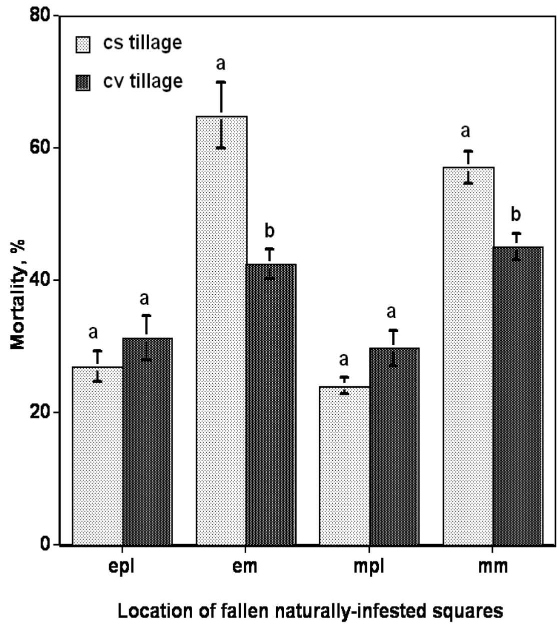


Fig. 1. Mean ± SE mortality of boll weevil larvae in naturally infested fallen cotton fruits in different tillage system of dryland cotton: epl = under plants at field edges; em = middle of crop row at field edges; mpl = under plants in middle of the field; mm = middle of crop row in middle of the field. Pairs of means within locations with different letters are significantly different at 5% probability level (*P*<0.05).

period in dryland cotton averaged 2.1-fold higher in conventional tillage than in conservation tillage (Table 4). The number of boll weevils captured in pheromone traps were 2.2-fold (*P*=0.01, 2000) and 2.3 -fold (*P*=0.01, 2001) higher in conventional than conservation tillage fields. No significant differences were detected in irrigated cotton fields (Table 4, Fig. 3).

After harvest, naturally infested fruit were left on the soil surface in conservation tillage plots, while those in conventional tillage were buried 25 cm deep in the soil. After 7 d, the fruit were collected from the soil surface at 10 sites (10 m^2 in each site), and from the upper 25 cm of soil at 5 sites (10m^2 in each site) to examine post harvest survival of boll weevils. The number of live weevils in infested fruit was 13.5-fold higher in conventional tillage than in conservation tillage fields. Mortality of boll weevils in cohorts of laboratory infested fruit ranged from 84.4 to 100% in conservation tillage fields, and 17.3-28.0% in conventional tillage fields (Greenberg et al. 2004).

Mortality was lower in small bolls, (15 mm dia.), 73.3±5.0%, and medium, (20 mm dia.), 64.0 ±4.4% than in squares (7-8 mm dia.), 92.0 ±3.3%, presumably because the bolls provide better insulations from high surface temperatures.

Thrips. There were no observed effects of tillage systems on number of thrips in dryland cotton (Fig. 4a). The average number of thrips per 100 plants during the cotton growing season and from all 4 examined plots were 9.9 in conventional tillage and 7.6 in conservation tillage (*t*=0.718; *P*=0.5). Thrips are normally an early season pest of seedling cotton and migrate to this crop from a multitude of wild hosts, onion, and other vegetables. Thrips may be a problem under cool, wet conditions when plant growth is slowed. Plants may be sensitive to even low populations of thrips and may not be able to outgrow a thrips infestation. During late spring and summer, when it becomes hot and dry, thrips migrate from other host plants to succulent crops like cotton (Fig.

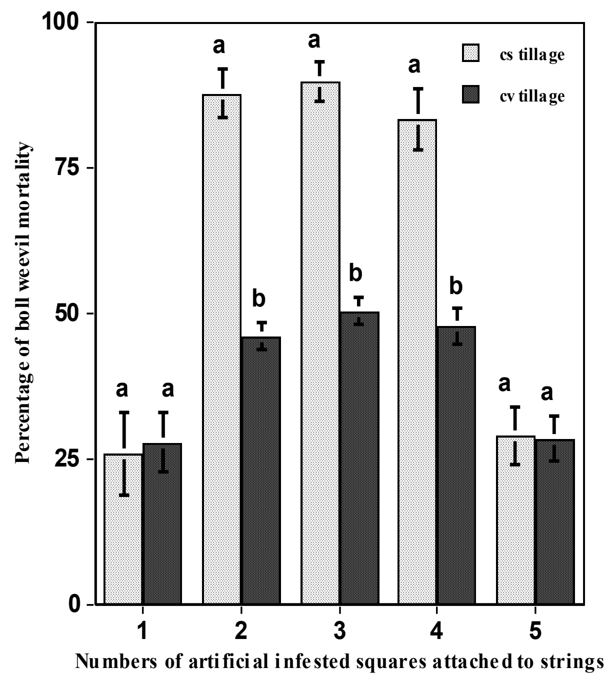
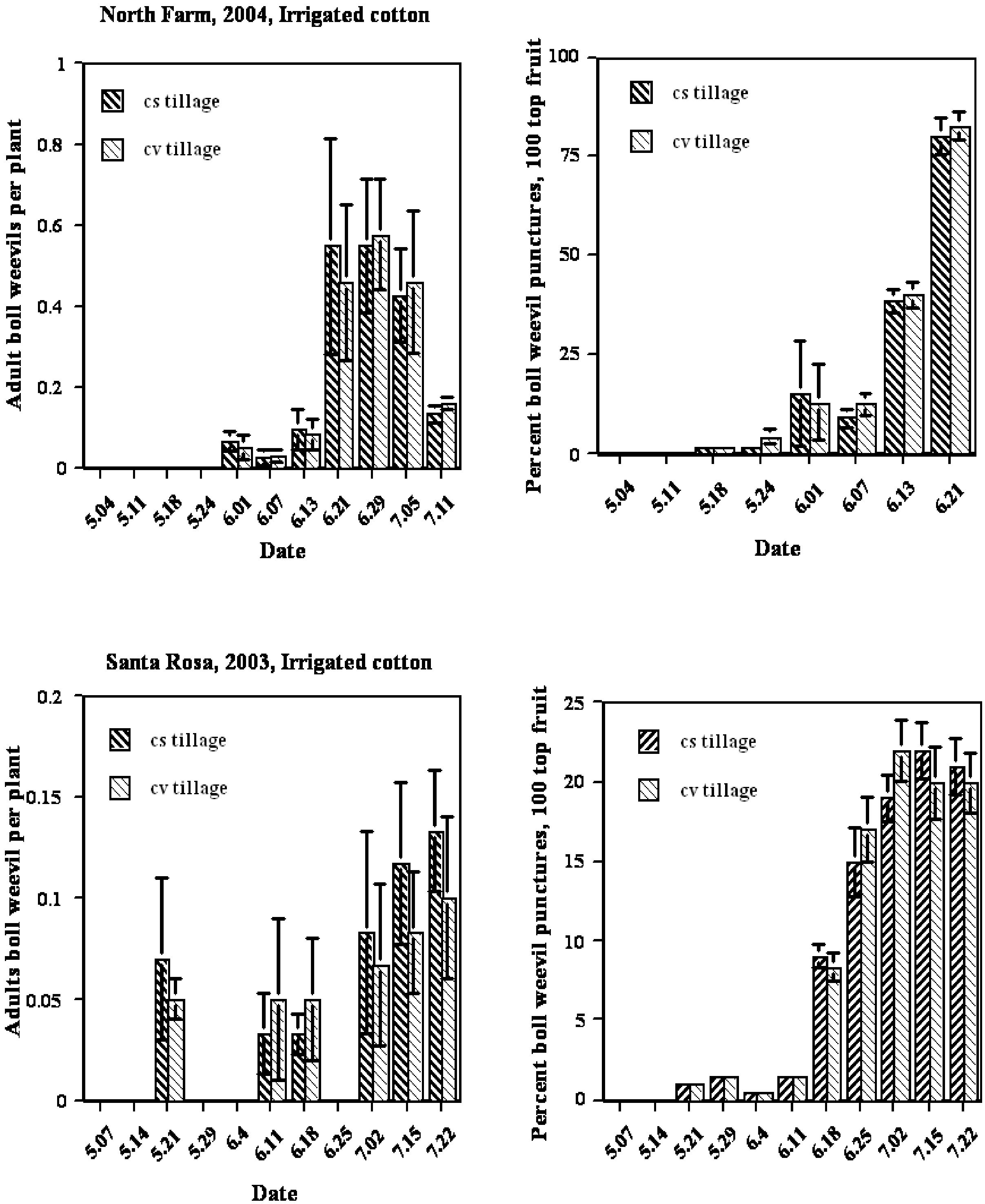


Fig. 2. Mean ± SE mortality of boll weevil larvae in artificial infested cotton fruits under different tillage system in dryland cotton: in fields 1 and 5, squares were disposed under plants; in fields 2, 3 and 4, squares were disposed in middle of crop rows. Pairs of means with different letters are significantly different at 5% probability level (P<0.05).



4b;

Fig. 3. Mean ± SE number of adult boll weevils per plant and percentage of punctured top cotton fruits under different tillage systems in irrigated cotton. Pair of means with overlapping error bars are not significantly different (P>0.05)

4b, Field #2, 2004 and Field #3, 2005). Population shifts during the season also depend on frequency of encounter among species and their preference for different cotton stages. IPM control of thrips infestations on seedling cotton may be enhanced using a combination of no-tillage, cultivar selection and seeds treated with systemic insecticides. Khalilian et al. (1991), All et al. (1992), and Leonard (1995) observed lower population densities of thrips in conservation than in conventional tillage cotton fields. Cotton plants in the conventional tillage plots develop more rapidly and may be more attractive to migrating adult thrips (Leonard 1995). DeSpain et al. (1992) reported that there was no effect of tillage system on thrips numbers in seedling cotton, while Sansone and Minzenmayer (2005) noted that thrips population density in the early season was dependant on planting dates, and suggested that more thrips are expected in early planted cotton.

Aphids. Cotton aphid population dynamics can be influenced by both tillage and pest management practices. Aphid populations were low during 2004-2005 in all cotton fields. During this period the average density of aphids was 23.4% higher in conservation than in conventional tillage fields, but the difference was not significant (P=0.767) (Fig. 5a). Aphids migrated to cotton fields after plant stands became established, which are significantly improved under conservation tillage. The number of aphids on seedling cotton did not differ significantly in these tillage systems. In the late spring and early summer aphids mostly migrated to conservation tillage cotton where soil moisture and relative humidity were higher and the plants were more succulent and attractive to aphids than cotton under conventional tillage (Fig. 5b). The current insecticides used in the LRGV increased tend to increase cotton aphid populations because they are resistant to most organophosphate (OP) compounds. Furthermore, predators and parasitoids of cotton aphids are eliminated by the pesticides in OP-treated fields. Leonard (1995) reported that cotton aphid densities were higher in conservation tillage plots compared with conventional plots, while Leser (1995) observed fewer aphids in reduced tillage systems.

Whiteflies. On average, we observed a slight but no significant increase (~7.5%) in whitefly densities in conservation tillage plots (*P*=0.164) (Fig. 6a). Densities peaked in early and late summer (Fig. 6b). Information about effects of tillage systems on whitefly survival is lacking. The mechanisms affecting survival and population densities of *Bemisia tabaci* can be divided into behavioral and physiological adaptations. Possible chemical differences between host plants may cause differences in host plant selection. We suggest that the nutritional value of the food plant may be most important factor in successful control of whiteflies with chemical and biological (e.g., parasitoid) agents.

Fleahoppers. Fleahopper densities were 37.2% higher in conventional tillage, than in no-tillage fields (P<0.05). The average number of fleahoppers in 3 experimental cotton plots over the cotton growing season were 17.3 in conventional tillage and 7.9 in conservation tillage (Fig. 7a). The numbers of fleahoppers peaked in conventional tillage in the middle of May and June and gradually declined thereafter. In late summer, the number of fleahoppers slightly increased in conservation tillage fields (Fig. 7b). Leser (1995) concluded that cotton fleahopper numbers were unaffected by tillage practices and crop residue, but Sansone & Minzenmayer (2005) observed that numbers were generally higher in conventional than in conservation tillage fields.

Lepidopterous pests. The percentage of fallen fruit infested with larvae of bollworms, budworms and beet armyworms did not differ significantly (*P*=0.527) between conventional and conservation dryland cotton (Fig. 8a). However, numbers of live larvae in infested fruit were 5.9-fold higher in conventional than in conservation tillage plots (61.6% vs. 10.5%, *P*=0.033) (Fig. 8b). Lepidopteran larvae in infested fallen fruit in conservation tillage exposed to the direct solar radiation resulted in higher mortality than in conventional tillage where fallen fruit were buried 25 cm deep in the soil by plowing or shaded fruit which provided survival niches. We did not record the differences in irrigated cotton. Heliothine damage to cotton in conservation tillage did not differ significantly from that in conventional tillage (Gaylor et al. 1984, DeSpain et al. 1992).

A higher rate of plant damage caused by cutworms was observed in seedling cotton fields under conservation tillage (18.3%) than under conventional tillage, (2.7 %, *P*=0.003) (Fig. 8c). Conservation tillage promotes the development of weeds that serve as oviposition sites for adult cutworms and alternative plant hosts for larval development. It has been reported that conventional tillage increases mortality of cutworms (Gaylor and Foster 1987, Leonard et al.1993). Plant stand losses were significantly lower in herbicide treated (no-till) plots one and two weeks before planting compared to conventional tillage plots.

Beneficial insects (above-ground predators). We did not observe differences in tillage systems on beneficial insect numbers (*P*=0.870) (Fig. 9). Sansone & Minzenmayer (2005) observed that reduced tillage systems show higher numbers of ground predators and spiders early in the season than in conventional tillage. These predators may play a role in reducing the first generation of harmful insect populations. An important predator of cotton aphids, the red imported fire

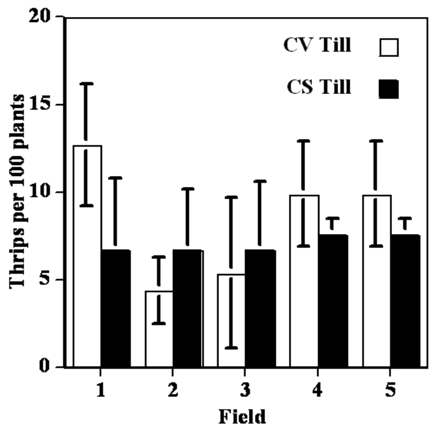


Fig. 4a. Mean number (+/- SE) of thrips per 100 plants during the cotton growing season: 1) fields 1-2 North Farm, Weslaco, 2004; 2) fields 3-4 North Farm, Weslaco, 2005; and 3) mean number of thrips for fields 1-4, 2004-2005.

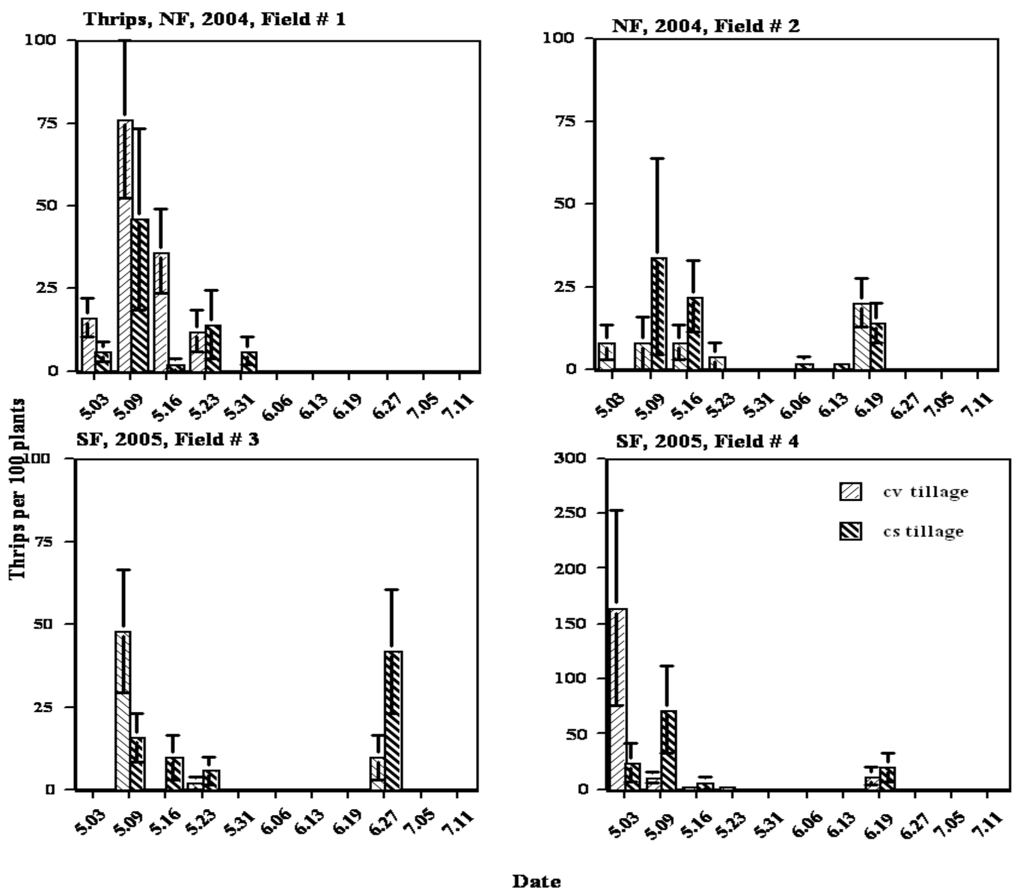


Fig. 4b. Mean number (+/- SE) of thrips per 100 plants in different tillage systems of cotton. Pairs of error bars which overlap are not significantly different at 5% probability level.

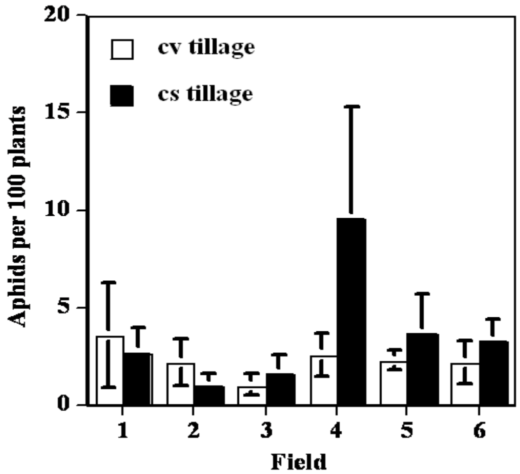


Fig. 5a. Mean (+/- SE) number of aphids per 100 plants during the cotton growing season: Fields 1-2 North Farm, Weslaco, dryland, 2004; Fields 3-4 North Farm, Weslaco, dryland, 2005; Field 5 Average number of thrips in all four fields; Field 6 North Farm, Weslaco, irrigated, 2005. Pairs of error bars which overlap showed that the means are not significantly different (*P*>0.05).

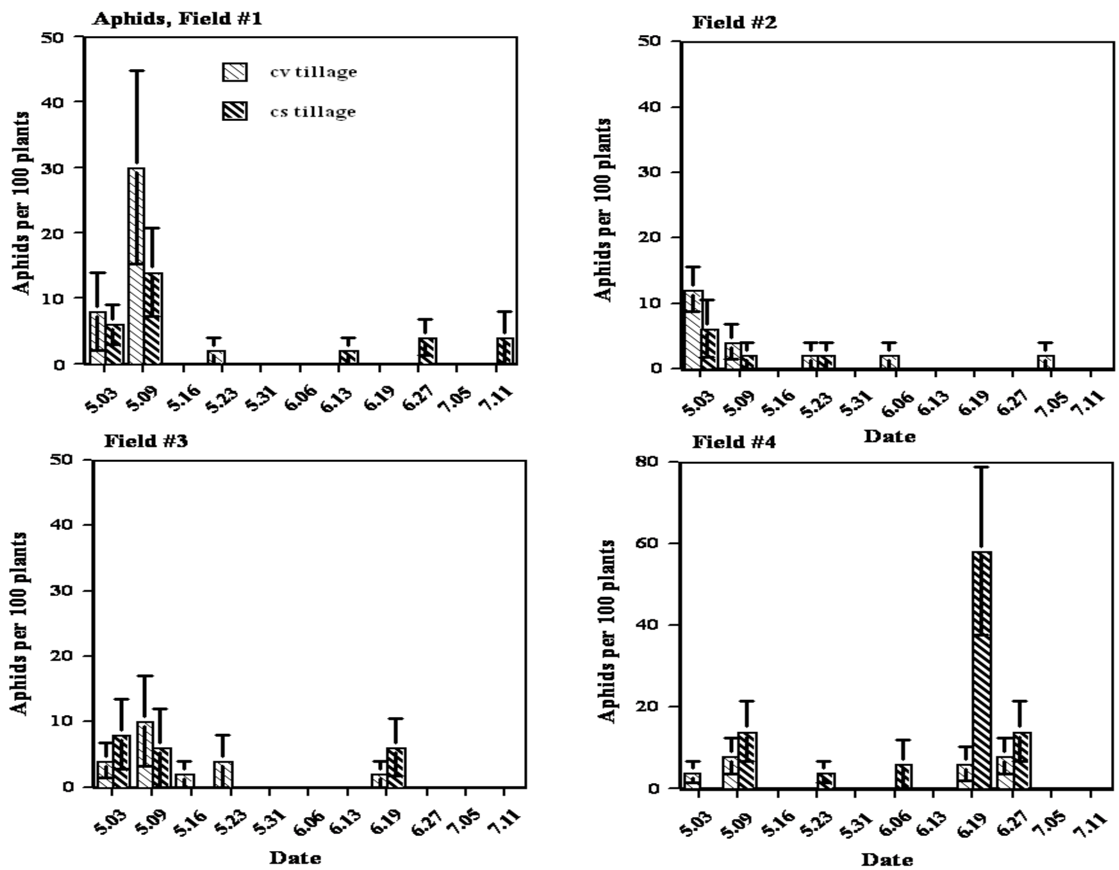


Fig. 5b. Mean ± SE number of aphids per 100 plants in different tillage systems of cotton. Pairs of means with overlapping error bars are not significantly different (P<0.05)

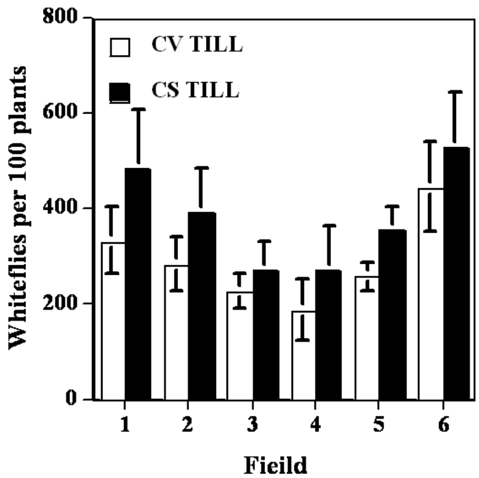


Fig 6a. Mean (±SE) number of whiteflies per 100 plants during the growing cotton season: Fields # 1, 2 – North Farm, Weslaco, dryland, 2004; Fields # 3, 4 - North Farm, Weslaco, dryland, 2005; Field # 5 average number of whiteflies of all 4 fields; Field # 6 – North Farm, Weslaco, irrigated, 2005. Pairs of error bars which overlap showed that means are not significantly different (*P*>0.05).

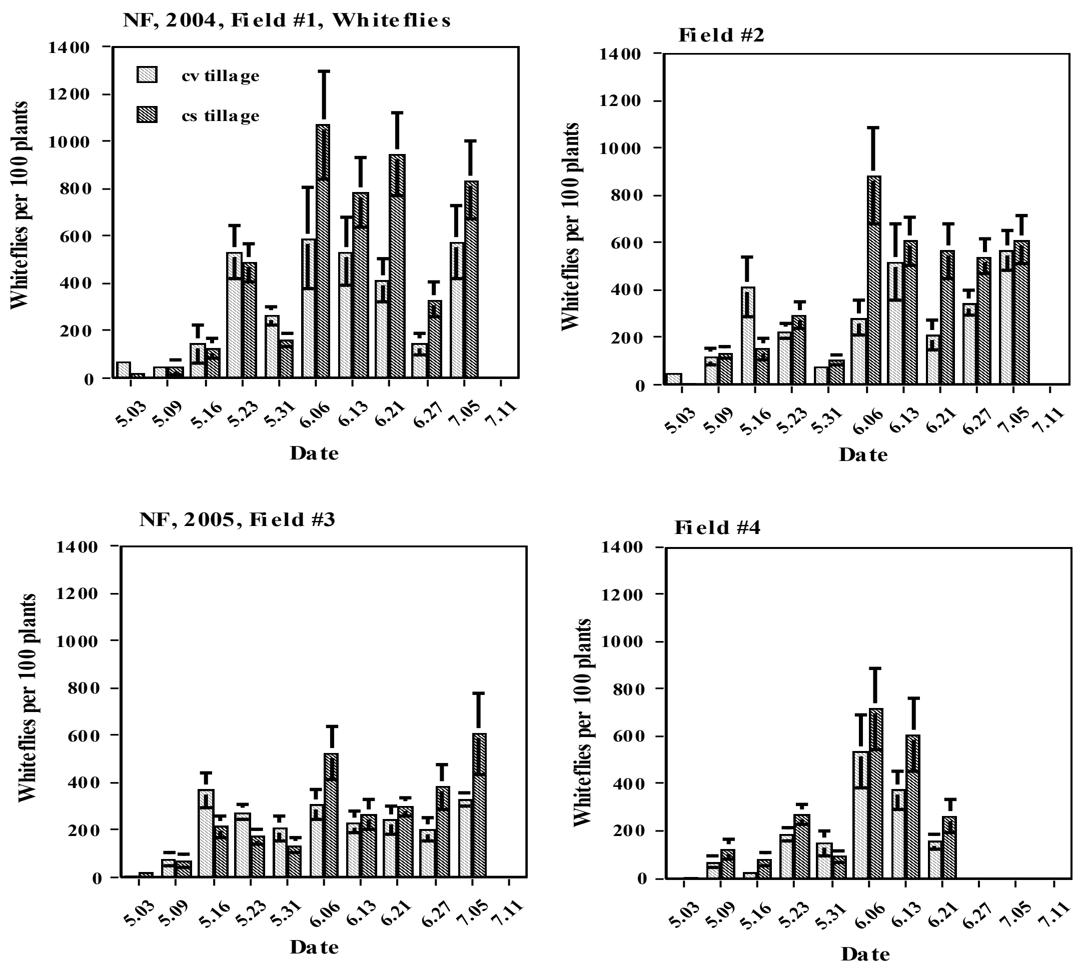


Fig. 6b. Mean ± SE number of whiteflies per 100 plants in different tillage systems of cotton. Pairs means with overlapping error bars are not significantly different (P<0.05)

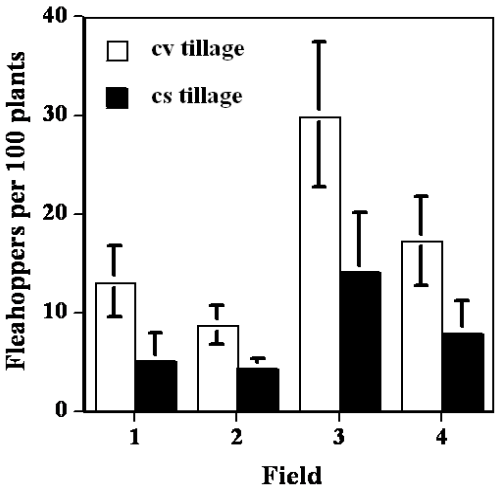
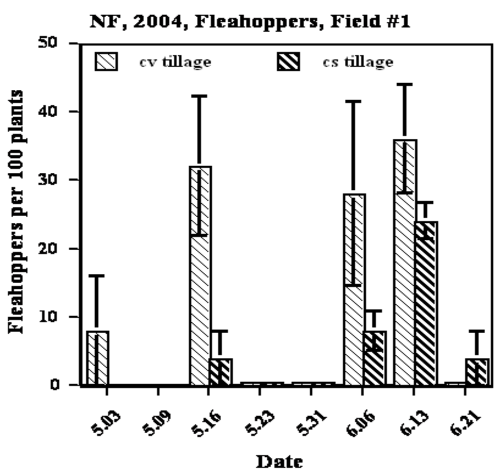
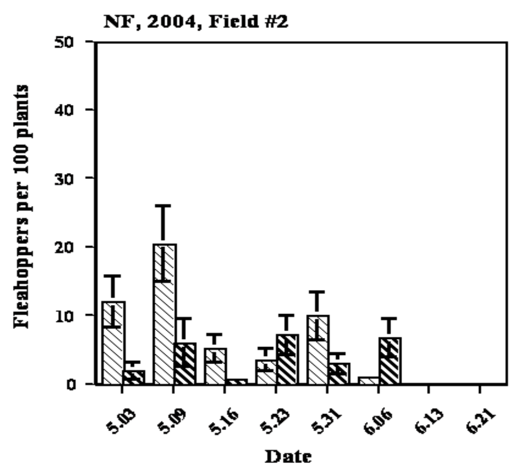


Fig. 7a. Mean (+/- SE) number of fleahoppers per 100 plants during the cotton growing season: Field #1,2—North Farm, Weslaco, dryland, 2004; Field #3—North Farm, Weslaco, dryland, 2005; Field #4, average number of fleahoppers in all three fields. Pairs of error bars that do not overlap are not significantly different at 5% probability level (P>0.05).





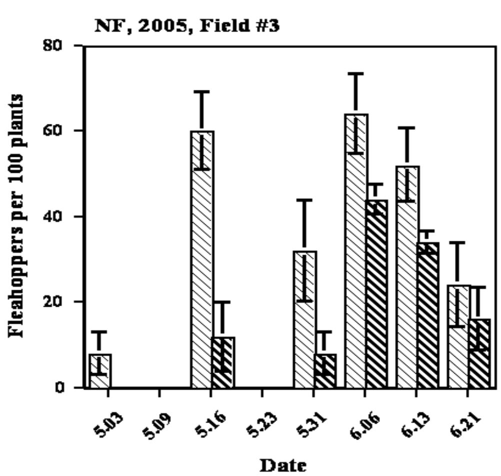
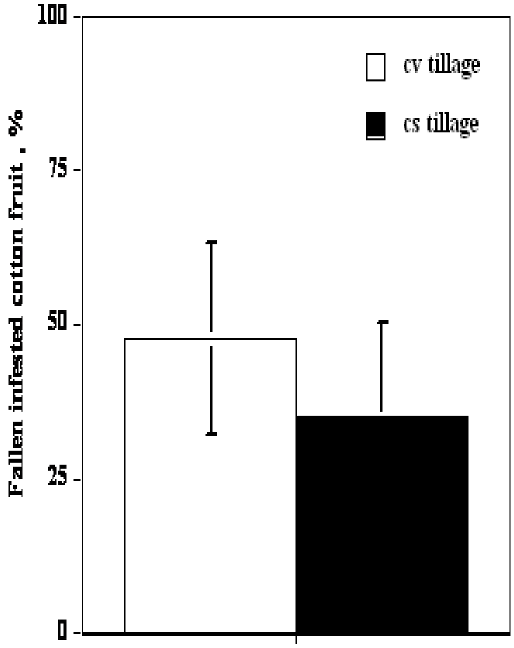
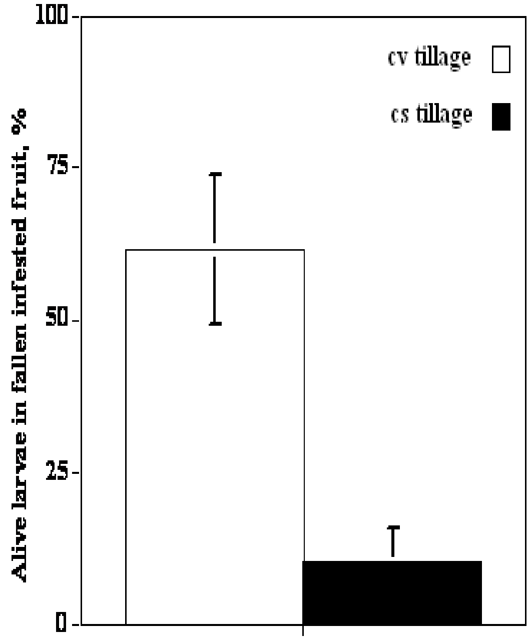


Fig. 7b. Number of fleahopper per 100 plants in different tillage systems of cotton: Field #1—North Farm, Weslaco, 2004 (upper left); Field #2—North Farm, Weslaco, 2004 (upper right); Field #3—North Farm, Weslaco, 2005 (lower left). Pairs of error bars that do not overlap are not significantly different at 5% probability level (*P*>0.05).





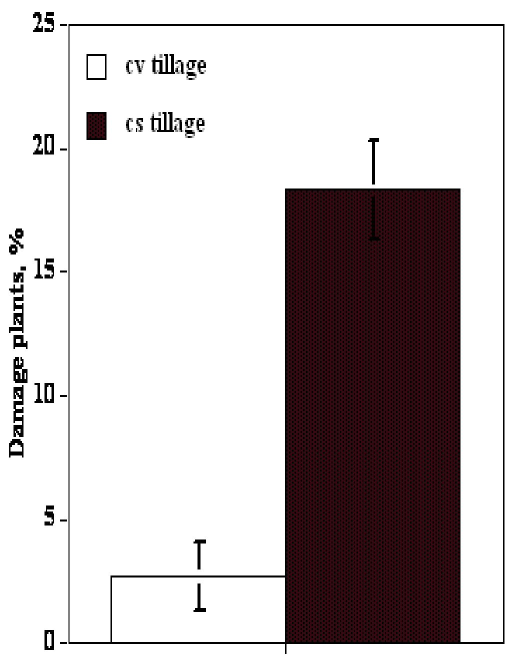


Fig. 8a (upper left). Mean (+/- SE) percent fallen cotton squares infested with larvae of various noctuid species in different tillage systems. Pairs of error bars that overlap are not significantly different at 5% probability level (P>0.05).

Fig. 8b (upper right). Mean (+/- SE) percent live noctuid larvae per 100 fallen infested squares in different tillage systems. Pairs of error bars that overlap are not significantly different at 5% probability level (P>0.05).

Fig. 8c (lower left). Mean (+/- SE) percent damage to seedling cotton caused by cutworms in different tillage systems. Pairs of error bars that overlap are not significantly different at 5% probability level (P>0.05).

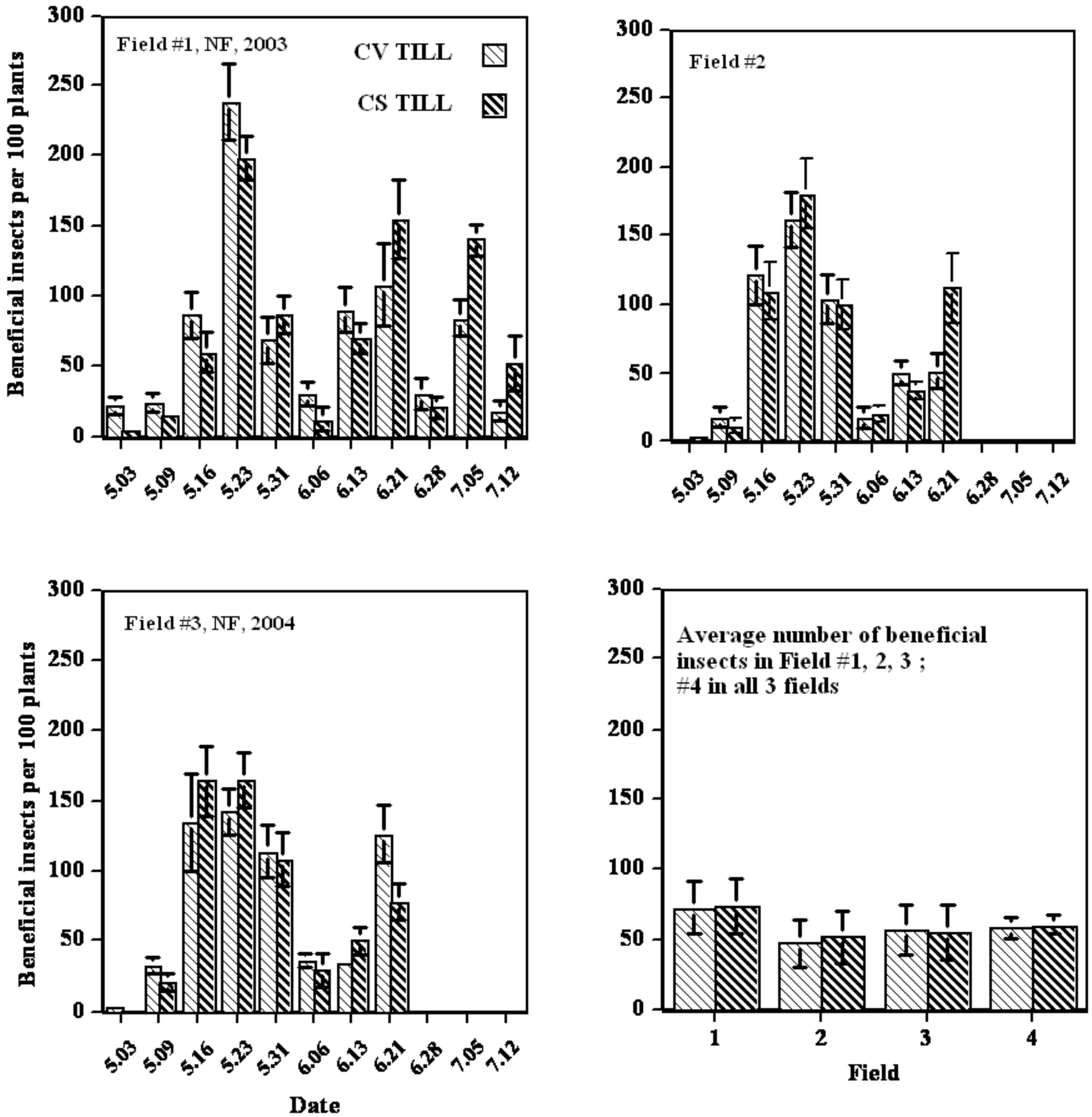


Fig. 9. Mean ± SE number of beneficial insects per 100 cotton plants in different tillage systems (Weslaco, TX). Pairs of error bars that overlap are not significantly different at 5% probability level (*P*>0.05).

Table 4. Effects of different tillage systems on square punctures by boll weevil, Weslaco, TX, 2001

	% Punctured squares +/- SE	
Date	No-till (conservation)	Conventional tillage
	Dryland	
5.31	4.0±1.6a	7.0±2.6a
6.06	0b	13.0±1.9a
6.13	7.0±4.7a	11.3±3.0a
6.20	4.2±1.6b	14.0±2.6a
6.27	18.3±4.8b	38.0±2.6a
7.03	20.0±1.6b	47.2±3.0a
7.10	33.1±3.4b	75.1±1.9a
	Irrigated cotton	
5.22	2.3±0.5a	2.4±0.5a
5.29	6.8±0.7a	6.6±0.8a
6.05	11.3±0.8a	10.5±0.7a
6.12	8.6±0.8a	9.1±0.9a
6.18	11.0±1.2a	11.8±1.4a
6.26	11.2±1.1a	10.7±0.9a

Pairs of means ±SE within a row followed by different letters are significantly different (*t*-test, $P<0.05$)

ant, *Solenopsis invicta* Buren, had higher survival and higher densities in conservation than conventional tillage plots (Leonard, presentation at Louisiana State University AgCenter, 2006).

In conclusion, different tillage practices had potentially positive or negative effects on pest and beneficial insect populations in cotton depending on species and on whether the fields were irrigated or dryland. The direct effects of insect pest populations on cotton are influenced by abiotic and biotic factors which can be created or corrected by conventional or conservation tillage systems. Variable results reported by different researchers on effects of tillage systems are difficult to interpret without statistical determination of significant differences. IPM of harmful insects on cotton may be enhanced using a combination of no-tillage, cultivar selection, and minimizing insecticide application strategies.

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