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POSTHARVEST MORTALITY OF BOLL WEEVILS RELATIVE TO TILLAGE IN FALLEN COTTON SQUARES AND BOLLS

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Abstract

Studies were conducted to assess the effects of conventional and conservation tillage on boll weevil, *Anthonomus grandis grandis* Boheman, mortality in postharvest cotton fields. Samples taken just before harvest, indicated that the number of fallen fruiting structures per m^2, the number of infested fruits, and the number of fruits containing live boll weevils were significantly higher in conventionally tilled fields than in conservation tillage fields. By 7 days postharvest, boll weevil mortality in conservation tillage fields was 12.4-fold higher in infested squares, which remained on the soil surface, than in those buried in conventional tillage fields. The major factor responsible for boll weevil mortality immediately after harvest in conservation tillage plots was high soil-surface temperatures. Mortality of boll weevils in small or medium size bolls (10-15 mm in dia) on the soil surface was significantly lower than in squares, presumably because the bolls provided better insolation from the high temperatures. Mortality in the large laboratory-infested bolls (>20 mm in dia) was higher than in small or medium sizes bolls presumably because development in large bolls is more difficult.

Introduction

Among important alternatives to insecticides in cotton are cultural control techniques. Conservation tillage in Texas cotton, *Gossypium hirsutum* L., is increasingly finding acceptance among farmers in the U.S. because of its advantages over conventional systems in reducing soil erosion and in conserving soil moisture (Stevens et al 1992, Smart and Bradford 1996). Tillage operations modify soil habitats where many insect pests (Troxclair and Boethel 1984) and beneficial insects (McPherson et al. 1982, Funderburk et al. 1988) reside during at least part of their life cycles. These modifications can alter survival or development of both soil and foliage-inhabiting insects (Herzog and Funderburk 1986). Early area-wide cotton stalk destruction was among the initial recommendations for cultural control of boll weevil, *Anthonomus grandis grandis* Boheman (Howard 1896). A cotton stalk destruction campaign in the Rio Grande Valley of Texas demonstrated the feasibility of region-wide cultural management of boll weevil (Norman et al. 1984, Summy et al. 1985, Summy et al. 1986, Summy et al. 1993 a, b). However, published information about aspects of boll weevil mortality within the field in the period after cotton harvest is limited. The objectives of this study were to evaluate survival of boll weevils in fallen infested fruit soon after cotton harvest in conventional and conservation tillage systems.

Materials and Methods

Field studies were conducted in commercial conventional and conservation tillage fields (near Hargill, Hidalgo County, Lower Rio Grande Valley [LRGV] of Texas), and in experimental plots at the Kika de la Garza Subtropical Agricultural Research Center (North Farm, Weslaco Texas) during 2000-2001. For each tillage type, two 5-ac and one 2.5-ac fields were used. In the Dallas area, studies were conducted at the Texas A&M Stiles Foundation Research Center near Thrall during 2001 in four 1-ac plots, two under conventional and two under conservation tillage practices. In Lubbock there were six plots in a 4.1-ac field, three under conventional and three under conservation tillage.

Fallen Fruit Collections

The day before the cotton was defoliated in the LRGV, fallen bolls and squares were collected from the soil surface at 20 randomly selected sites (10 m^2 each) in each field or plot. All samples (from 869 to 1570 fruit / 20 sites) were returned to the laboratory to be dissected and examined for boll weevil infestation.

Post-Harvest Survival of Boll Weevils in Naturally Infested Fallen Squares and Bolls

One day after harvest in the LRGV, squares and bolls naturally infested with boll weevils were left on the soil surface in conservation tillage plots, while those in conventional tillage plots were buried 25 cm deep by a moldboard plow. After 7 days, the fruits 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 (10 m^2 in each site).

Post-Harvest Survival in Laboratory-Infested Squares and Bolls

Adult boll weevils were reared from infested squares collected from commercial cotton in the LRGV during the summers of 2000 and 2001. The infested fruit and adults were maintained in an environmental chamber at 28±1ºC and 65 % RH with a photoperiod of 14:10 (L:D) h, and the adults were maintained on squares 7-9 mm in diameter. On the day of eclosion adults were sexed using the method of Sappington and Spurgeon (2000), and males were marked with red paint on the right elytron. Mixed-sex groups of 20 weevils (10 males and 10 females) were held in 15-cm diameter Petri dishes for five days after eclosion under the conditions described above. Dishes were ventilated by a 4- cm diameter circular screened hole in the lid. Each dish contained a cotton wick saturated with water and was provided daily with uninfested, greenhouse-grown squares. By the end of the five-day period each female was placed in a Petri dish with five squares 7-9 mm in dia, five bolls 10-15 mm in dia, or five bolls 20-30 mm in dia as oviposition sites. After 24 h, all fruits with 1-2 apparent oviposition punctures were placed in screen cages (20x20x20 cm) within an environmental chamber to allow development under the conditions described above. When =75% of the larvae in subsamples reached 2nd or 3rd instars (evaluated by head capsule width; Parrott et al. 1970), the fruits were divided into cohorts of five infested squares (or bolls) and were each tied by a knot to a 10-cm string. The fruits were attached at equal distances by their 10-cm strings to a one meter string. Tags accompanied each fruit, and were numbered from 1 to 5. Ten cohorts were placed on the soil surface in fields or plots for 7 days for each of 3 weeks after cotton harvest in the LRGV under conservation tillage practice (cohorts from laboratory-infested squares, 7-8 mm in dia); Northern Blacklards (Dallas) (cohorts from laboratory-infested squares, 7-8 mm in dia), and the High Plains (Lubbock) (1st week, cohorts from laboratory-infested bolls, 10-15 mm in dia; 2nd and 3rd weeks, cohorts from laboratory-infested bolls, > 20 mm in dia) of Texas under conservation and conventional tillage practices. In addition, 20 cohorts (five cohorts per plot under conventional tillage in four 1-ac plots) were buried 25 cm deep in a 1.1 x 0.5 x 0.25 m (LxWxD) trench for one week in the LRGV.

We tested the differential effects of square and boll size on soil-surface survival of weevils. Ten cohorts each of laboratory-infested squares 7-8 mm in dia, laboratory-infested bolls 10-15 mm in dia, and laboratory-infested bolls 15.1-20 mm in dia were placed on the soil surface in a field for 7 days after cotton harvest in the LRGV under conservation tillage practice. Afterwards the fruits were dissected to determine the fate of the infesting weevils.

Boll Weevil Mortality Assessment

Boll weevil mortality was assessed using the method of Sturm and Sterling (1986). The exterior and contents of squares and bolls were examined under a dissecting microscope. Boll weevil larvae that died from heat were characterized by a failure to move when prodded, squeezed, or pressed, discoloration from a milky white to gray-brown, and loss of resiliency in the integument with slight shriveling. The criteria used to determine death by heat for pupae were the same, except they took longer to become discolored. Squares with a circular hole ca. 1 mm in diameter indicated that the weevil survived to the teneral adult stage and successfully emerged from the fruit. Holes made by ants can be the same size as weevil exit holes but were usually irregularly shaped. Boll weevil larvae that died from dessication were characterized by a failure to move, but retain the same color as in life.

Soil Temperature Measurement

During the experiments, soil temperatures were continuously monitored in all experimental plots in the LRGV, Dallas and Lubbock areas. Surface temperatures were recorded using HOBO® H8 4-channel loggers from Onset Computer Corporation (Pocasset, MA). Four TMC6-HA external sensors were used for each logger and were placed next to four of the squares or bolls on a string. Data were recorded every 15 minutes and a HOBO Shuttle data transporter was used to download data at the field sites. Temperatures on the depth of the soil were recorded using Reotemp thermometers, which monitored soil temperatures at depths of 5, 10, 20, and 30 cm every 2 h in 4 randomly selected sites in three conventional tillage plots in the LRGV.

Statistical Analyses

Paired comparisons *t* - tests were used to evaluate the effects of tillage regime on fallen squares, naturally infested squares, live weevils in infested squares, and live weevils after 7 d postharvest. Two-sample t-tests were used to evaluate the effects of tillage regime on weevil mortality in laboratory-infested fruits (Wilkinson et al. 1992).

Results

There were significantly more fallen fruiting structures per m^2 in the conventional tillage fields just before harvest than in conservation tillage fields ($t = 7.7$, df = 4, $P = 0.01$) (Table 1). Among the fallen fruit, a higher percentage were infested ($t =$

5.8, df = 4, *P* = 0.01), and a higher percentage harbored live weevils (*t* = 5.0, df = 4, *P* = 0.01) in conventional than in conservation plots (Table 1). The high number of infested squares with live weevils, in both conventional and conservation tillage fields, suggest high initial densities of potentially overwintering boll weevils in fallow dryland LRGV cotton fields.

By seven days after harvest, the number of live weevils in infested fruits was 13.5-fold higher (2.3±0.2) in conventional-tillage fields where they had been buried 25 cm deep, than in conservation-tillage fields (0.17±0.05) where they remained on the surface (*t* = 13.8, df=2, *P* = 0.01). During the study, the average temperature of the soil surface in the conservation tillage fields ranged from 41.0ºC to 47.0ºC during the hours of 10:00 - 19:00, and from 27.5ºC to 30.0ºC during the hours of 19:00 - 10:00. The highest temperatures occurred between 12:00-15:00, ranging from 52.5ºC to 66.0ºC. Mean daytime soil temperatures at a depth of 25 cm in the conventional tillage fields ranged from 27 - 29ºC, with the highest temperatures (12:00-15:00) ranging from 31 - 34ºC

Mortality of boll weevils in cohorts of laboratory-infested squares which were exposed on the soil surface for one week in the LRGV (conservation tillage fields) ranged from 84.4 to 100 % (Table 2). Most of the mortality (80-100%) was from heat. The same apparent dependence of mortality on temperature was observed in the Dallas fields where cohorts of laboratory-infested squares were disposed on the soil surface in both conservation and conventional tillage plots (Table 2). In the Dallas plots, mortality was much higher in August than in September (*t* = 11.6, df = 42, *P* = 0.001), presumably because the mean soil surface temperature in August was 10.1ºC higher than in September. Most of the weevil mortality in August was from heat (84.8-98.0%), while that in September was from desiccation (100%). Mortality did not differ significantly between plots in August (*t* = 1.5, df = 18, *P* = 0.151), or September (*t* = 0.6, df = 22, *P* = 0.532). Likewise, in the Lubbock plots all cohorts of infested bolls remained on the soil surface. In Lubbock, mortality was generally low during the test periods in October and November, presumably because the mean soil surface temperature was lower (14.4-20.9ºC, October; 11.9-18.4ºC, November) than those in August in the LRGV and Dallas (Table 2). Mortality was significantly higher in the November cohorts than in the October cohorts (*t* =-9,1, df = 82, *P* = 0.001), but the reason is probably the different sizes of bolls rather than soil surface temperatures. In the November experiments, we used large laboratory-infested bolls (>20 mm in dia) in which the development of weevils is more difficult than in small bolls (10-15 mm in dia) (unpublished data), which were used in October.

When laboratory-infested squares were buried 25 cm deep in conventional tillage plots in the LRGV, mortality ranged only from 17.3 to 28.0% and was significantly less than that in conservation plots (*t* =13.5, df= 148, *P* =0.001 for 2000; and *t* = 14.6, df = 78, *P* = 0.001 for 2001) (Table 2). All of the mortality in the buried squares appeared to have been caused by factors other than heat, including ants.

Size of fruit affected soil surface mortality of infesting weevils (*F* = 13.5; df = 2, 42; *P* = 0.001). Mortality was lower in small, 10-15 mm in dia (73.3±5.0%), and medium, 15-20 mm in dia (64.0±4.4%), size bolls than in squares, 7-8 mm in dia (92.0±3.3%) (Tukey's HSD, ?=0.05).

Discussion

Our results indicate that the major factor responsible for the mortality of boll weevils in fallen fruit in postharvest conservation tillage fields was high soil surface temperatures. When the infested fruit were buried in conventional tillage fields, boll weevil mortality was significantly reduced by the covering soil which buffered the larvae from extreme temperatures. When temperatures were high in August in the Dallas fields, where none of the infested squares were buried, mortality was much higher than in September when soil surface temperatures average 10ºC cooler. Low temperatures in the late fall in Lubbock resulted in low weevil mortality in the experimental bolls. Hunter and Hinds (1905) placed 500 infested squares on the soil surface at a temperature of 47.2-48.9ºC and observed only 6% mortality. However, time of exposure, the size of the squares, and boll weevil stage were not reported. In contrast, Pierce (1911), Smith (1936), Fye and Bonham (1970), Bacheler et al. (1975), DeMichele et al. (1976), Curry et al. (1982), Sterling and Dean (1989), and Sturm and Sterling (1990) concluded that extreme temperatures on the soil surface of cotton fields is a major mortality factor of the boll weevil.

There are two possible mechanisms of boll weevil mortality related to prolonged exposure to high mean temperatures inside squares or bolls (Sterling et al. 1990). First, drying of the fruit tissues may render them unfit for larval consumption, resulting in larval death from starvation. In this case, the dead larvae would retain the same color as in life. DeMichele et al. (1976) and Curry et al. (1982) concluded that infested fruits exposed to high soil temperatures resulted in weevil death via desiccation. However, Reardon and Spurgeon (2000) demonstrated that removal of food from third instars did not lead to death in most cases. Instead, the larvae usually completed development, producing adults that were smaller than normal. They concluded that starvation after food desiccation is unlikely to be an important mechanism of boll weevil mortality. Second, death can be caused by direct thermal lethality. This appeared to be the case in our experiments, in that the dead larvae changed color to gray-brown.

Summy et al. (1986) showed that mortality of the boll weevil was strongly influenced by seasonal weather patterns. He found that during late August, boll weevil mortality was 90.8% under conditions of 52.9ºC average maximum temperature and 9.6 hours/day with temperatures >38.0ºC. Surface temperatures were substantially lower during mid-October (39.1ºC average maximum, 2.2 hours/day with temperatures >38ºC), and was accompanied by a significant reduction in weevil mortality to 15.7%. In our study, when the cohorts of laboratory-infested squares were buried (conventional tillage), weevil mortality after one week was only 17.3-28.0%. It seems clear that burial of weevils in infested fruit can increase short-term survival during periods of excessively high surface temperatures. Summy et al. (1993a) documented significant emergence of adult boll weevils during March and April from cotton residue buried by conventional tillage the previous fall.

The mortality of boll weevils in infested small or medium size bolls distributed on the soil surface was significantly lower than in squares, presumably because the bolls provide better insolation from high surface temperatures. But in the large bolls (>20 cm in dia) we observed high mortality of weevils even if temperatures for their development were adequate, presumably because the nutritional value of large bolls is not conducive to larval development.

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Table 1. Boll weevil infestation of fallen fruits the day before defoliation (Mean±SE).

			Fallen Fruit / m^2		
Year	**Field**	**Tillage Regime***	**Total**	**Infested**	**Infested with live weevil**
2000	Hargill 1	CV	7.6±0.3	5.8±0.3	4.2±0.2
		CS	5.3±0.2	4.1±0.2	2.9±0.1
	Hargill 2	CV	6.5±0.2	5.2±0.2	3.3±0.1
		CS	4.9±0.2	3.8±0.2	2.4±0.1
	North Farm	CV	7.8±0.1	6.0±0.1	4.9±0.1
		CS	5.5±0.2	4.2±0.1	3.4±0.1
2001	Hargill 1	CV	5.9±0.1	3.6±0.05	2.2±0.04
		CS	4.3±0.2	2.6±0.1	1.6±0.1
	Hargill 2	CV	7.2±0.3	4.2±0.2	2.8±0.1
		CS	6.1±0.2	3.6±0.1	2.3±0.1

*CV - conventional tillage.
CS - conservation tillage.

Table 2. Mortality of boll weevil in cotton of laboratory-infested squares (bolls).

Location	Year, Month	Tillage regime	Infested fruit	Treatment	N	Dead per string	Mortality due to, % Heat	Dessication	Ants	Surface or buried temperatures
LRGV	2000, 08	Cs	squares	surface	105	4.2±0.1*	100	0	0	34.0
LRGV	2000, 08	Cv	squares	buried	45	1.0±0.1	0	100	0	25.2
LRGV	2001, 08	Cs	squares	surface	61	4.7±0.1*	93.1	2.0	4.9	34.6
LRGV	2001, 08	Cv	squares	buried	19	1.4±0.2	0	100	0	26.3
Dallas	2001, 08	Cs	squares	surface	50	4.8±0.1	98.0	0	2.0	32.1
Dallas	2001, 08	Cv	squares	surface	50	5.0	84.8	5.1	10.1	32.1
Dallas	2001, 09	Cs	squares	surface	60	1.6±0.3	0	100	0	22.2
Dallas	2001, 09	Cv	squares	surface	60	1.3±0.4	0	100	0	22.2
Lubbock	2001, 10	Cs	bolls[2]	surface	70	0.3±0.1	0	100	0	20.2
Lubbock	2001, 10	Cv	bolls[2]	surface	70	0.2±0.1	0	100	0	20.2
Lubbock	2001, 11	Cs	bolls[3]	surface	70	2.1±0.3	0	100	0	17.2
Lubbock	2001, 11	Cv	bolls[3]	surface	70	2.4±0.4	0	100	0	17.2
Lubbock	2001, 11	Cs	bolls[3]	surface	70	1.9±0.2	0	100	0	13.7
Lubbock	2001, 11	Cv	bolls[3]	surface	70	1.8±0.2	0	100	0	13.7

[2] bolls 10-15 mm in dia.

[3] bolls 20-25 mm in dia.

*Significant different by tillage regimes within year by two sample t-test, *P*<0.0001.