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USE OF SHORT-SEASON COTTON MANAGEMENT FOR PINK BOLLWORM CONTROL IN TRANSGENIC COTTON SYSTEMS IN THE IMPERIAL VALLEY, CALIFORNIA

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Abstract

We developed the short-season cotton management system that was adopted by the Imperial Valley, California for pink bollworm control in 1989. Trap catches of male pink bollworm (PBW) moths were reduced from 10.81 to 0.17 male moth/trap/day from 1989 to 1994. During the same period, lint yield increased from 6.2 to 6.9 bales/ha and grade 31 or above lint increased from 54 to 99. The short-season cotton management system may be useful as a component of resistance management programs to delay or reduce development of PBW resistance to transgenic (Bt) cotton.

Introduction

Pink bollworm (PBW) *Pectinophora gossypiella* (Saunders) has been a key economic pest of cotton in Arizona and southern California since 1966 (Noble 1969). The 15% yield loss and $487/ha for the insecticides used to control PBW in the Imperial Valley and the Mexicali Valley of Mexico from 1978 to 1990 (Burrows et al.1982, Gonzales 1990) were major factors resulting in reduced cotton production in the Imperial County from 57,871 ha in 1977 to 5,248 ha in 1989 (Imperial County Agricultural Crops and Livestock Report 1968-2003). A community-wide PBW cultural control strategy using a short-season cotton management system (SSC) for cotton was initiated and mandated by the California Department of Food and Agriculture in 1989. The success of the SSC was documented elsewhere (Chu et al. 1996). The Imperial Valley Cotton Pest Management Abatement District Board in 1999 (CPAD 1999) voted to discontinue the SSC beginning in 2000 season. The reason for the return to full-season cotton production was based on the outstanding performance of transgenic (Bt) cotton for PBW control in 1998 and 1999. Objective of this report was to advance the concept of using SSC as a tool for managing PBW resistance in the refugia of Bt cotton (Bollgard®, Monsanto Co., St. Louis, Mo).

It was designed to reduce the PBW overwintering diapause larval populations and the magnitude of PBW infestation the following spring. Numbers of diapause larvae were reduced by limiting the numbers of late season bolls by water management and/or plant growth regulators (Chu et al. 1996). Season long average numbers of male PBW moths caught in traps declined from 8.6 per gossyplure-baited trap per night in 1990 to 0.17 male moth per trap per night in 1994. When compared with 1984-1988 averages, lint yield increased from 6.2 to 6.9 bales per ha and percentages of top grade lint increased from 54 to 99% because of uniformity of matured lint with fewer trashes. The cotton planting dates were rescheduled to 15 February or later and plowdown 1 January. contains the gene from *Bacillus thuringiensis* Kurstaki (Berliner) that mediates production of insect toxic protein in the cotton plant (Greenplate et al. 1998, Greenplate 1999).

The success of SSCs encouraged evaluation of sterile PBW moth releases and gossyplure (pheromone) behavioral control that are most efficient at low population insect densities (Knipling 1955, Staten 1995). Shin-Etsu (Shin-Etsu Chemical Co. Ltd., Niigata, Japan) gossyplure dispensers were applied at the pin-head-square stage of plant development in Imperial Valley to suppress PBW populations from 1994 through 1999 and sterile PBW moth releases (a minimum ratio of 60 sterile male moths to 1 native male moth caught in traps) were included in the program from 1994 through 1998 (Pierce et al. 1995, Staten et al. 1986, Staten et al. 1999). The impact of these additional control strategies on the PBW population dynamics in the Imperial Valley from 1994 to 1999 is not known since the results cannot be separated from the effects of the SSC and Bt cotton.

We tested two null hypotheses using analyses of PBW male moths trap catches in gossyplure-baited traps during the 15 years from 1989 to 2003. The hypotheses were that SSC production and Bt cotton had no significant impact on (1) yearly and monthly PBW trap catch variations during the years from 1989 to 2003, and (2) PBW moth trap catches at five geographic trap locations were not affected by the amount of cotton grown in the north of Mexicali Valley bordering on the Imperial Valley.

Materials and Methods

The Imperial Valley is located in Imperial County, California, south of Riverside County and bordering the north of the Mexicali Valley of Baja California, Mexico (Fig. 1). It is bordered on the northwest by the Salton Sea, on the north by the Chocolate Mountains, on the east by the Algodones Sand Dunes, and on the west by the Yuha Desert.

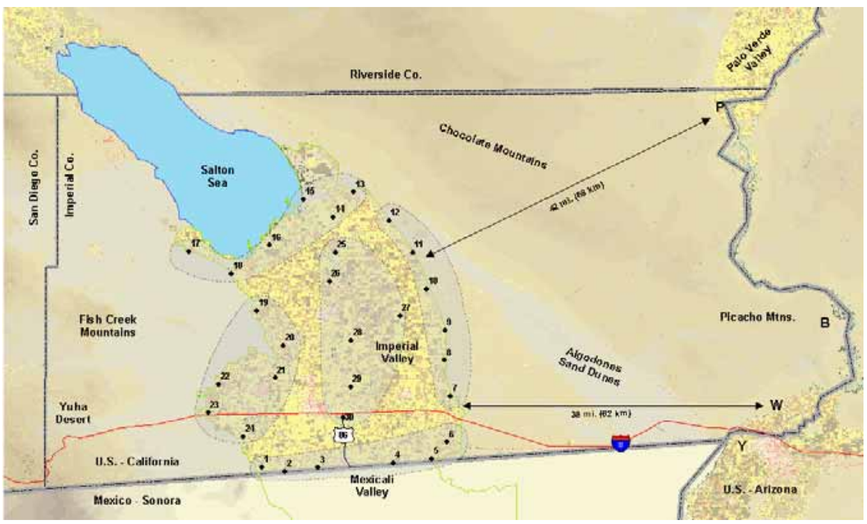

Fig. 1. Geographical locations of Imperial Valley, California and locations of gossyplure-baited pink bollworm live moth capture traps around the perimeter of the Imperial Valley from 1989 to 1994. Trap numbers 1-6, 7-12, 13-18, 19-24, and 25-30 were assigned as south, east, north, west and center of the valley, respectively.

PBW Moth Monitoring Traps in Imperial Valley. Thirty Multi-sphere III non-over-loading (Lingren et al. 1980) PBW traps (1.25 liter by volume, Great Lakes, Vicksburg, MI) were used for monitoring PBW population changes beginning from September 1989 to 1994 when the SSC was evaluated. Based on the geographical locations, six traps each were grouped into south (#1-6), east (#7-12), north (#13-18), west (#19-24), and central (#25-30) areas to examine the effect on PBW of cotton grown in the Mexicali Valley of Mexico (Fig. 1). Traps #1-24 were installed near the irrigation gates around the perimeter of the valley at ca. 9.7-km intervals. Traps #25-30 were installed in the center of the valley and oriented in a north to south direction. Traps were near roads that bordered cultivated fields at ca. 16.1-km intervals. The traps were operational from 1989 to 2003 during the 15-year period. Traps were each equipped with one 4 mg gossyplure-loaded rubber septum. Trap catches were counted from two to four times a month from 12 September 1989 to 17 February 1994 to evaluate the effect of SSC production on PBW populations. Trap catches were counted once a month from March 1994 to December 2003 to monitoring yearly PBW moth population changes in relation to PBW control activities and a cotton production. All gossyplure-baited traps were replaced at least once a month throughout the 15 years of operation.

Cotton hectares in Imperial County, Imperial Valley and Mexicali Valley. The numbers of cotton hectares in the Imperial County were obtained from the Imperial County Agricultural Crops, and Livestock Report 1968-2003. The total cotton hectares and Bt cotton hectares each year in the Imperial Valley from

1996 to 2003 were obtained from the California Department of Food and Agriculture, Sacramento, California. The numbers of cotton hectares and Bt cotton hectares each year in the Mexicali Valley were obtained from the Annual Cotton Crop Report for Baja California, 1989-2003.

Cotton hectares in Mexicali Valley and relationship to PBW trap catches in Imperial Valley. The geographical continuity of the Imperial Valley and Mexicali Valley and cotton production patterns in the two areas stimulated the study to determine the impact of the number of the cotton hectares in Mexicali Valley on the PBW trap catches in Imperial Valley. The relationships were studied during three time periods: from 1990 to 1996 when the SSC was initially implemented, from 1997 to 2000 when the SSC and Bt cotton were both used, and from 2001 to 2003 when Bt cotton alone was relied on for PBW control.

Data analyses. Male PBW moth trap catch data from each trap were totaled monthly, yearly, and for the five geographic trap locations. Traps stolen, blown down, or for other reasons were non-functional during monitoring periods were considered missing data. Missing trap data were estimated from the male moths catch before and after the day in the same month using the estimates from a linear regression model. Data were analyzed using ANOVA (Anonymous 1994). Means were separated using Tukey's test or orthogonal contrasts. Liner and non-linear regression analyses (Sokal and Rohlf 1995) determined relationships between numbers of cotton hectares in the Mexicali Valley and PBW trap catches in Imperial Valley in the three time periods described earlier.

Results

PBW Moth Monitoring Traps in Imperial Valley. The total numbers of PBW male moths caught per trap per year varied significantly. Catches decreased from 2,858 male moths in 1990 to 81 per trap per year in 1994 during SSC production. The numbers of PBW male moths caught per year increased from 81 per trap per year in 1994 to unexplained numbers of 1,793, 3,928, and 5,262 per trap per year in 1995, 1996 and 1997, respectively, when the PBW control strategies of SSC production and Bt cotton (1997 through 2003) were implemented. The small amount of Bt cotton grown (61 ha) in the Imperial Valley in 1996 compared with 1,941 ha of non-Bt cotton probably had little effect on the PBW moth catches in the traps. The numbers of male PBW moths caught per trap per year decreased from the peak of 5,263 per trap per year in 1997 to 796 male moths per trap per year in 1998, but increased to 2,440 per trap per year in 1999. The numbers of male PBW moths caught per trap per year decreased from 2,440 per trap per year in 1999 to 557, 475, 198, and 392 per trap per year for 2000, 2001, 2002, and 2003, respectively.

The numbers of PBW male moths caught per trap per month from 1990 to 2003 varied significantly. The numbers of male PBW moths caught were ≤ 1.0 per trap per month from January to March and increased to 3.2 and 8.2 per trap per month from April to July. The numbers of male PBW moths caught per trap increased to 85.8 per trap in August, peaked at 695.3 in September and decreased to 546.6 in October, 70.6 and 5.2 in November and December, respectively. The total numbers of male PBW moth caught from August to November contributed 97.84% of the total male moths numbers caught from January to December ($F = 4,840$, df = 1, 318, and $P < 0.001$, orthogonal treatment comparison). The numbers of PBW male moths caught per trap from August to November were significantly higher each year of the study ranging from 81.1% of the total yearly catches in 1992 to 99.5% in 1997 when compared with total catches from December to July catches during the 15-year studied (not tabulated).

Traps located closest to the Mexicali Valley and at the south end of the Imperial valley (numbered 1-6, Fig. 1) consistently caught higher numbers of male moths per month per trap from 1989 to 2003 compared with the numbers of male PBW moths caught in traps located on the east, west and north perimeters of the Imperial Valley.

Cotton hectares in Imperial County, Imperial Valley, and Mexicali Valley. Cotton grown in the Imperial County ranged from 2,515 (2003) to 6,689 ha (2001) compared with 9,976 (1994) to 44,151 ha (1996) in the Mexicali Valley during 1989 to 2003 . Mexicali Valley had from 2.97 X to 13.96 X and from 3.59 X to 22.75 X more cotton grown compared with Imperial County and Imperial Valley during the 1996 to 2003. However, in 1993, the Mexicali Valley had 714 ha compared with 3,609 ha in Imperial County. No data were available from Imperial Valley alone from 1989 to 1995. Bt cotton acreages as percentages of total acreages ranged from 80% in 1998 to 94% in 2001 and 2003 for Imperial Valley and from 0.3% in 1998 to 14% in 2001 for Mexicali Valley during 1998 to 2003 period.

Cotton hectares in Mexicali Valley and relationship to PBW trap catches in Imperial Valley. Best fit regression analysis of the amount of cotton grown in Mexicali Valley (X) and yearly PBW trap catches in Imperial Valley (X) was a squared power relationship ($Y = a + bX^2$), where, $Y = -84.99 + 1.8*10^{-6}X$ ($R^2 = 0.8447$ and probability = 0.0034) during 1990 to 1996 (SSC impact); the quadratic relationship ($Y = a + bX + cX^2$), where, $Y = -11397 + 1.058X - 17.8*10^{-6}X^2$) ($R^2 = 0.7516$ and probability = 0.1331) for 1997 to 2000 (SSC plus Bt cotton impact); and a quadratic relationship ($Y = a + bX + cX^2$), where, $Y = -8389 + 1.0166X - 27.0*10^{-6}$ ($R^2 = 0.9998$ and probability = 0.0087) for 2000 to 2003 (Bt cotton impact alone).

Discussion

PBW population suppression activities in Imperial Valley, California, prior to 1989 heavily reliant on insecticide applications. Implementation of the areawide SSC was initiated in 1989 (Chu et al. 1996). The reduced PBW male moth trap catches in Imperial Valley from 1990 to 1994 were a measure of the impact of SSC on numbers of overwintering PBW each year and PBW populations developing in each subsequent year. The reasons for the large increases of PBW male moth trap catches in 1995, 1996 and 1997 in the Imperial Valley could be a result of high cotton prodution (about 27, 44, and 34 thousand hectares) in Mexicali Valley in 1995, 1996, and 1997, respectively, assuming the PBW moth migration occurred. However, about 44, 35, 15, 24, and 13 thousand hectares were grown during 1998 to 2002 and moth trap catches remained low except for 1999. Bt cotton production in the Imperial Valley dramatically suppressed PBW population development beginning in 1998. Yearly Bt cotton sampling from

1997 to 2003 in Arizona has consistently shown less than 0.1% boll infestation (Dennehy et al. 2003, Henneberry 2003) and equivalent Bt efficacy is expected in Imperial Valley. The results do not explain why PBW male moth catches did not increase in Imperial Valley corresponding to the high cotton production in Mexicali Valley as they did in 1995, 1996, and 1997. Possibly weather conditions preventing moth migration and/or levels of chemical control pressure in Mexicali Valley were increased that kept PBW populations low. The small proportion of Bt cotton hectares to conventional cotton hectares in Mexicali Valley does not appear to be adequate to account for the overall PBW moth population reduction over the entire Mexicali Valley. Traxlera et al. (2001) estimated that less than 10% of the total Bt cotton hectares grown in Mexicali Valley from 1998 to 2003 and probably has not significantly affected total PBW populations impact in the area. In Coahuila, Mexico, 96% of the cotton production in 2000 was Bt cotton. The total number of pesticide applications for PBW control in 2000 was 2% of the number applied in 1988 indicating the extremely low PBW moth populations in Coahuila and presumably as a result of PBW suppression by Bt cotton.

The areawide approach to manage PBW is most likely to succeed in Imperial Valley since Mexicali Valley is an extension of the Imperial Valley. PBW moths in the Imperial Valley and Mexicali Valley likely disperse to and from each area (Chu et. al. 1992, Staten et al. 1999). Both Imperial Valley and Mexicali Valley must adopt areawide technologies.

The dispersal of PBW moths into Imperial Valley from other cotton growing areas is also possible (Stern and Sevecharian 1978). The Palo Verde Valley and Yuma Valley are 66 km and 51 km distant, respectively and are separated by the Chocolate Mountains and Algodones Sand Dunes, from Imperial Valley, respectively, but moth activity in the desert between the valleys has been documented (Stern 1979). PBW male moths caught in San Luis, Rio Colorado Valley, Sonora, Mexico (east of Mexicali Valley and south of Yuma Valley, AZ) were from 851 ± 86 to 2072 ± 70 per month from May to August in 2003 (Source: Raul León López, 2004) and may contribute to the higher trap catches for the east trap group in the Imperial Valley that was higher than the north and west groups of traps.

The SSC is a proven effective strategy that is compatible with Bt cotton in PBW management programs in the Imperial Valley. It should be evaluated for its contribution to Bt resistance management and reintroduced into the valley to reduce PBW moths emerged from overwintering diapause larvae in the Bt cotton's 5% refugia area.

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