Impact of boll weevil eradication on cotton production and insect management in Virginia and North Carolina, USA

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ABSTRACT

A boll weevil (*Anthonomus grandis* [Boheman]) eradication program was begun in September 1978 as an approximately 6000 ha upland cotton (Gossypium *hirsutum* L.) trial in the north-east counties of North Carolina (NC) and the south-east corner of Virginia (VA), the northeastern-most cotton growing area of the US. It was subsequently expanded in 1983 to include the remainder of NC and all of South Carolina (SC) (48900 ha total). Primarily due to the elimination of the boll weevil, foliar insecticide use in NC has dropped from a mean of 10.2 applications/ha of primarily organophosphate insecticides employed at rates varying from 0.56 to 3.4 kg a.i./ha for the five year period preceding 1978, compared with the post-eradication (1979–1993) mean use of 2.6 applications of mostly pyrethroids at rates varying from 0.02 to 0.067 kg a.i./ha. Planted cotton acreage in NC has increased from an all-time low of 18 200 ha in 1978 to a high of 188 000 ha in 1991. Employing a linear yield model based upon 20 years of data from 19 NC counties, a yield increase of 77 kg/ha resulted from eradication, in addition to a 71% drop in total insect control costs (compared with a 39% drop outside the eradication area) and a greater return on investment to land which was converted from less profitable crops such as corn and soybean to cotton because of reduced costs achieved by the eradication. Despite the finding of occasional, passively transported boll weevils into the 'weevil-free' area (two weevils were found in 1993, one in 1992 and none in 1991 in approximately 200 000 total Grandlure@-baited traps) and an elevation in the pest status of the European corn borer (*Ostrinia nubilalis* [Hübner]) and the green stink bug (*Acrosternum hilare* [Say]) in the weevil-free area, the subsequent elimination of these transported localized weevils and the greater ease of managing the bollworm/tobacco budworm complex *Helicoverpa zea* (Boddie) and *Heliothis virescens* (F.), respectively, and other pests, such as the cotton aphid, Aphis gossypii Glover, has allowed the development and deployment of an inexpensive, biocontrol-oriented, threshold-based, pest-specific system of managing cotton insects unique to the south-west and the mid-south.

Introduction

The northeastern counties of North Carolina (NC) and adjacent counties of Virginia (VA) were selected for the initiation of a Boll Weevil Eradication trial program in 1978 because the area was characterized both by moderate boll weevil levels in most years (due to a high overwintering habitat to field size ratio) and geographic isolation due to a lack of adjacent cotton production (no cotton to the north, mountains to the west, the Atlantic Ocean to the east and a buffer zone of sparsely planted cotton to the south (Cross, 1981). The first year of the eradication program consisted of 10–13 aerially applied ultra low volume diapause treatments, primarily with malathion, field borders treated with azinphos-methyl from a truck-mounted mist blower and Grandlure@-baited pheromone traps used as a monitoring device in the fall to monitor and delineate areas of higher weevil populations for second year operations. Second year tactics involved saturation pheromone trapping (approx. four traps/ha), four releases of approximately 83 sterile male boll weevils/ha, pinhead square treatments on selected hectarage and a second fall diapause program on a small proportion of the hectarage. Third year tactics in 1980

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Table 1. Pheromone trap captures of boll weevils and presence or absence of reproduction in the Evaluation Zone of northeastern NC and VA (1979–1986) and in the whole 2-state area (1987–1993)

Year	No. weevils	Reproduction*	Year	No. weevils	Reproduction
1979	2	–	1987	112	+
1980	14	+	1988	12	+
1981	127	+	1989	37	+
1982	>1100	+	1990	1	–
1983	>400	+	1991	0	–
1984	73	+	1992	1	–
1985	66	+	1993	2	–
1986	1	–			

*–, no reproduction; +, reproduction confirmed or likely (that is, trap captures temporally spanned two or more weevil generations)

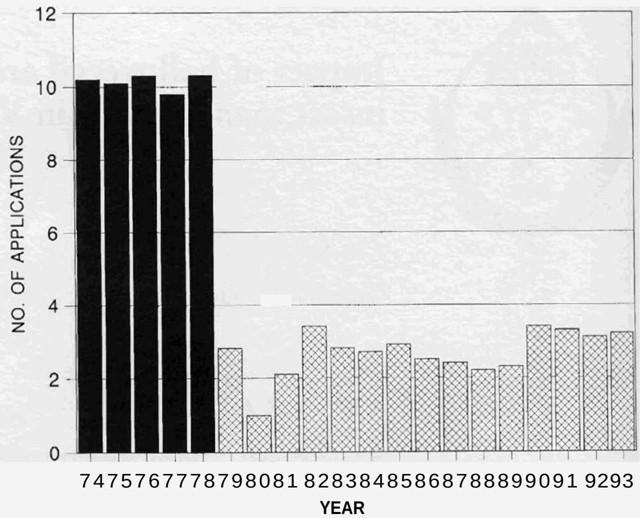

Fig. 1. Number of foliar insecticide applications on cotton prior to and following initiation of the Boll Weevil Eradication Trial Program in North Carolina and Virginia. 19741993. 19741977, pre-eradication; 1978–1985, post-eradication northeastern North Carolina-Virginia Evaluation Zone; 1986–1993, total North Carolina-Virginia area (Carlson. 1989; Carlson, pers. comm.; Toth. 1993).

consisted of lower density pheromone trapping (0.5–2 traps/ha) and fall diapause treatments on limited areas. Following a two year economic, biological and environmental evaluation of the trial program data, the program was expanded in 1983 into the remainder of NC (20 000 ha total) and all of South Carolina (28 000 ha). Although the record of adult captures in pheromone traps and probable reproduction in the original eradication zone (EZ) may suggest at first glance that eradication was not achieved (Table 1), in the past 10 years, all pheromone-detected populations have been eliminated, as confirmed by subsequent mass trapping in the respective fields and surrounding fields (W.A. Dickerson, NC Dept. Agr., pers. comm.; Planer , 1988). Additionally, no reproduction has been detected in NC during the past four years.

The eradication program has now expanded into all of Georgia, Florida and Alabama and, pending 1994 and 1995 referenda, may extend into east Tennessee, east Mississippi and Texas in the next two years. A Southwestern Boll Weevil Program was begun in parts of Arizona, New Mexico and California in 1983 (Brazzel, 1989).

The capture of widely scattered boll weevils in areas where cotton has not been produced in several years, the finding of trapped weevils in either areas into which cotton equipment was transported from outside of the EZ and the capture of occasional weevils along major highways strongly points toward passive transport as the principal, and perhaps only, source of boll weevil reintroduction into NC. From the perspective of the cotton producer, no economic infestations of boll weevils have existed in NC since the fall of 1983, and essentially all of this state's cotton hectarage has remained untreated with boll weevil-targeted insecticides since 1980. Thus, NC cotton growers have been managing cotton insects without boll weevils for 10 years.

Economics

The costs and benefits of the Virginia–North Carolina Boll Weevil Eradication Trial (BWET), as well as its expansion into the remainder of North Carolina and South Carolina, are well documented (Carlson and Suguiyama, 1985; Carlson et *al.*, 1989). In an evaluation of costs and returns of the BWET, Carlson and Suguiyama (1985) evaluated pesticide use changes, estimated yield changes, determined public versus private costs, estimated cotton acreage changes and computed rates of return due to eradication from 1978 through 1982. This information subsequently was updated from a later, more comprehensive information base (Carlson *et al.*, 1989).

Annual per hectare benefits from the BWET program:

- averaged approximately US$74 due to reduced pesticide use, (mostly due to elimination of the boll weevil but also to enhanced control of bollworms – approximately 10.2 *vs* 2.75 treatments prior to and following eradication, respectively [Fig. 1]);
- gained 77 kg of lint/ha (yield losses primarily attributable to the boll weevil);
- added US$34.50 due to increased land values as producers switched to cotton from less profitable crops such as corn and soybeans.

After the three year trial program was completed, a 71% drop in total insect control costs was realized in the original EZ, even when eradication program fees and scouting costs were added to the cost of pesticides and their application. This compared with a 39% drop in insect control costs in the non-radication area of southern North Carolina through 1982 (lighter bollworm pressure throughout the southeastern US and the introduction of synthetic pyrethroids positively impacted both insect control programs). The yield increase of 77 kg of lint/ha per year was determined by using

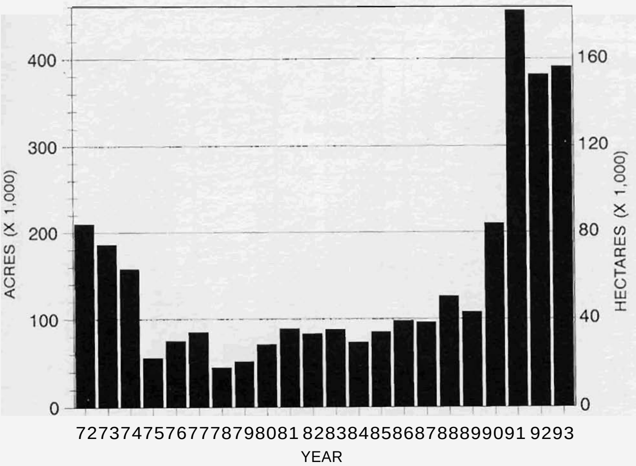

Fig. 2. North Carolina hectarage prior to and following initiation of the Boll Weevil Eradication Trial Program in North Carolina and Virginia, 1972–1993 (North Carolina Crop Reporting Service).

a linear yield model based upon 20 years of data from 19 North and South Carolina counties; the overall model fit (R^2 = 0.95) was high (Carlson and Suguiyama, 1985). Because eradication was successful, producers in the EZ expanded yield and pesticide savings to more land area by shifting from less profitable crops to cotton, which was an additional benefit to that obtained in the original cotton acreage and was analogous to an increase in land rent value. Additionally, a regression model (Carlson *et al*, 1994) showed a nine year, 92% increase in the NC acreage (Fig. 2) due to the reduced costs achieved by the eradication program.

The following assessment of North Carolina's changing pest situation following eradication represents an evaluation of the eradication effect in one unique situation. Indeed, the change in pest status following eradication has varied somewhat within NC's borders. However, with the aforementioned 10 years of subeconomic levels of boll weevils, we have been able to observe and quantify the status of emerging and declining pests under a wide range of weather and cropping pattern changes following eradication of the boll weevil.

Elevation in pest status of stink bugs and the European corn borer

The successful boll weevil eradication program has enhanced the pest status of the green stink bug, *Acrosternum hilare* (Say), and to a lesser degree the brown stink bug, *Euschistus servus* (Say), and the European corn borer, *Ostrinia nubilalis* (Hiibner). Multiple applications of organophosphate insecticides directed against boll weevils and bollworms up through the late 1970s coincidentally tended to keep both green stink bugs and European borers at virtually non-detectable levels. Of these two 'new' post-eradication pests, the green stink bug relationship with eradication is the more easily understood.

Green stink bugs damage cotton by injecting their stylets through the carpal wall of medium-sized bolls, feeding upon the developing seeds (Glover, 1955), often injecting hardlock-inducing pathogens, primarily *Nematospora coryli* Pegl., which are expressed at boll opening (Barbour, pers. comm.). This species is usually present in most North Carolina cotton fields in low numbers in June to mid-July (Barbour, 1988). In late July or early August, immigration into cotton fields from senescing wild hosts such as wild cherry, *Prunus serotina* Ehrhart, augments the typically low resident population. The subsequent appearance of nymphs, indicating successful reproduction, marks the beginning of a potentially damaging population. In situations where *H. zea* does not reach treatable levels or where biological insecticides are employed, stink bugs have accounted for over 30% boll losses in some fields (personal observation). In these low bollworm situations, stink bugs must now be managed in their own right. Fortunately, due to the usual parallel appearance of bollworm moths along with stink bugs, employment of the bollworm egg threshold (Bacheler and Bradley, 1989) for *Helicoverpa* control (2–5 applications) usually suppresses stink bugs to low, tolerable levels.

The European corn borer's (ECB) rise as an economic pest of cotton in North Carolina (King *et al.*, 1986; Gourd and Gouger, 1983; Savinelli *et al.*, 1986) following boll weevil eradication appears to be multicausal. Although reported to have over 100 hosts in the southeastern United States, in North Carolina field corn, *Zea mays* L., is the predominant host of the ECB for its first two generations (Anderson, 1984). Like the bollworm, the major damaging third generation of ECB adults is released from corn in late July to early August and flies to cotton and cultivated hosts such as late corn, and wild hosts such as cocklebur (*Xanthium strumarium* L.). Unlike bollworm adults, ECB female moths deposit egg masses deep within the plant canopy on the undersides of leaves (Savinelli *et al*, 1988). Neonate larvae feed briefly (only 2–3 days) upon leaves and stem petioles before seeking out medium- to large-sized bolls (Savinelli, 1984; Savinelli *et al.*, 1986). With their propensity to feed within large, lower bolls as second through last instars, these larger larvae are virtually impossible to control. ECB is now regarded as second to the bollworm as the most significant insect pest of cotton (Table 2).

One factor in this species' elevation, as was the case with the green stink bug, is the absence of insecticides formerly directed against the boll weevil. Although the insecticides usually selected for boll weevil control, such as methyl parathion and azinphosmethyl, are only marginally effective against ECB, their multiple-usage patterns undoubtedly suppressed ECB larvae. This species is also becoming a more widely recognized pest of field corn, due both to the recent quantifying of the mechanical damage to corn caused by second generation larvae and to a greater mean level of abundance of this species in corn (Van Duyn, pers. comm.). This ECB rise in field corn translates into a spillover into

Table 2. North Carolina damaged boll survey summary, fall 1985–1993

	Number surveyed		% Boll damage (100 bolls per field)					
Year	Counties	Fields	Boll-worm	Eur. corn borer	Fall† army-worm	Stink‡ bug	Total	% at aphid thresh.§
1985	11	118	6.61	6.22	0	–	12.83	–
1986	12	143	4.30	0.80	0	–	5.10	–
1987	14	168	1.05	1.55	0	2.44	5.04	–
1988	14	168	5.24	1.27	0	2.34	8.85	–
1989	14	168	3.94	1.90	0	1.17	7.01	–
1990	17	204	2.82	1.24	2.77	0.47	7.30	2.47
1991	19	228	6.02	1.14	0.08	0.82	8.06	0.88
1992	21	252	2.89	0.37	1.15	0.77	5.18	1.19
1993	24	288	2.35	0.40	141	0.21	4.10	0.35
Mean			3.91	1.65	0.57	1.32	7.45	1.22

†Fall armyworm damage to bolls extremely low from 1985 through 1989.
‡ Stink bug damage to bolls recorded beginning 1987.
§ The percent of fields at the spray threshold (0-5 scale: 3 = most plants with aphids; occasional plants with heavy infestations; honey dew present) for aphids was recorded beginning in 1990.

other crops such as cotton, also explaining some changing status of the ECB on this crop.

Because the ECB and bollworm adults often annually immigrate into cotton fields from field corn at approximately the same time (peak ECB moth flights are typically a few days to approximately three weeks later than the peak bollworm moth flights) (Ellsworth and Bradley, 1992), insecticides applied against the bollworm egg stage often result in a residue of one or two applications on the cotton plants at the time of ECB egg hatch. This phenomenon appears to help explain the relatively high control of ECBs in screening tests where treatments have been applied at egg threshold for bollworms. Earlier tests (1984) against the ECB larval stage yielded controls varying from 2 to 48% after four applications (J.R. Bradley, pers. comm.). Although the effect of boll weevil eradication on increasing ECB damage to cotton is difficult to quantify accurately and will vary greatly from one region to the next as the eradication program expands, higher boll damage by the ECB in the southeastern United States is a likely prospect following boll weevil eradication wherever significant corn and cotton hectarage are present in close proximity and overall insecticide use declines.

Rise and fall of the cotton aphid

Although the cotton aphid only began infesting cotton in NC at economic levels within the past five years, this pest is now almost completely suppressed by predators (*Geocoris* sp., *Nabis* sp., *Hyppodamia convergens* Guerin, *Coleomagila maculata* [DeGeer], *Chrysopa* sp., and others) and braconid wasp parasites, partially a result of lack of disruptive boll weevil sprays. Late in the year, levels of an entomophtherian fungus, *Neozygites fresenii* (Nawakowski) Batko, are typically at such high levels that cotton fields are seldom at treatment threshold levels (Table 2). Because of the magnitude of this natural control, primarily in July and August, and because of high resistance levels to organophosphate insecticides in some populations (Lee, 1992), NC producers are advised not to treat for aphids until just prior to cotton opening. Because of the potential for grade reductions due to either honey dew-vectored sooty mold (discoloration) or 'sticky cotton', NC producers are advised to treat for aphids in opening cotton in situations where established, active aphid populations (a descriptive threshold) have created the potential for significant honey dew related problems.

Damaged boll survey

A high percentage of NC's yield-reducing insect damage is expressed as late-season damage to bolls. Therefore, a comprehensive, statewide fall damaged boll survey was begun in 1985 to assess and quantify the status of our primary late season boll-damaging insects following boll weevil eradication. The initial survey evaluated this area's two major yield-reducing pests – the bollworm and the European corn borer – and covered 10–12 cotton fields in each of 11 counties (n = 118 fields). Subsequent annual surveys were expanded to include 17 counties in 1990 (n = 204 fields) and, additionally, evaluated stink bugs (mostly the green stink bug), the fall armyworm, *Spodoptera frugiperda* J.E. Smith (rarely a damaging pest in this area but significant in 1990) and the cotton aphid, *Aphis gossypii* Glover. In 1993, the survey included 24 counties (n = 288 fields).

With the exception of 1985, prior to the general adoption of an egg threshold approach to managing late-season bollworms and European corn borers (Bacheler and Bradley, 1989), damage trends for European corn borers and bollworms are difficult to extract (Table 2), although a decline in ECB damage may be in evidence. Fall armyworm

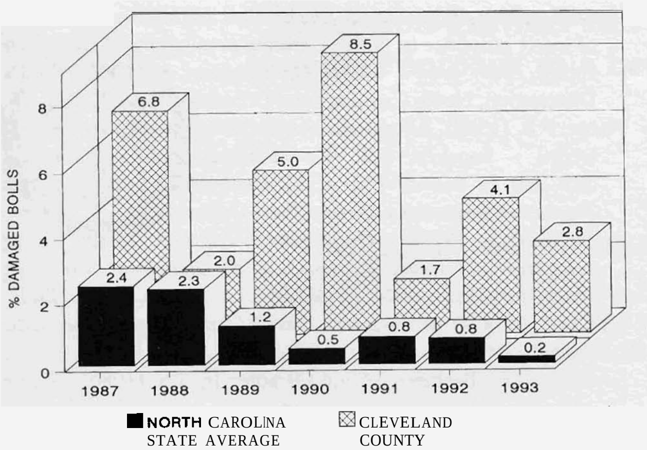

Fig. 3. Stink bug damage to cotton bolls in an area (Cleveland County) characterized by low insecticide use (0.5 treatments per year) compared with the statewide mean (2.8 treatments per year) in North Carolina, 1987–1993 (Bollrot and/or hardlock caused by stink bug feeding constituted damage).

damage to cotton in NC has begun to show up in recent years, particularly in the southern half of the state. Additionally, a trend toward lower levels of stink bugs seems to be evidenced. In Cleveland County, NC, an area characterized by little corn acreage, very low populations of bollworms and ECBs and little insecticide use (approximately 0.5 sprays per year), stink bug damage was considerably higher than the mean for the remainder of the state (Fig. 3).

Patterns of insecticide use

Foliar insecticide-use patterns were quantified for four years prior to eradication up until the present (Carlson, pers. comm.; Toth, 1993). Foliar insecticide use decreased dramatically from a pre-eradication mean of 10.2 treatments to post-eradication mean of 2.75 treatments (Fig. 1). The somewhat higher overall insecticide use from 1990–1993 is likely due to the recent expansion of cotton production into the south-east coastal plain of NC, an area characterized by high insect pressure. Usage rates of organophosphates on cotton prior to eradication typically varied from 0.56 to 3.4 kg a.i./ha; presently foliar rates of recommended pyrethroids range from approximately 0.02 to 0.067 kg a.i./ha. Although 1979, the first year of greatly diminished insecticide use in NC, marked the introduction of widespread use of pyrethroids, total insecticide use in other states where pyrethroids were similarly adopted remained the same or decreased only slightly (Bacheler, 1985). Additionally, because most other weevil-infested states still had to rely on the more mammalian-toxic organophosphates for boll weevils, cotton aphids and, in some areas, plant bugs, North Carolina's selective use of pyrethroids represented a usage pattern of significantly fewer human exposure problems (lower rates of less toxic materials).

Summary

Fifteen years of post-eradication research, survey information and grower experience in NC suggest that the benefits of eliminating the boll weevil from the cotton ecosystem and the present ease of tobacco budworm and cotton bollworm control far outweigh the negative impact of species, such as the European corn borer and the green stink bug, which have been elevated in status following eradication. Without the disruptive treatments once required to control boll weevils, NC's cotton producers can now manage cotton insects relying largely upon:

- a minimal 2.75 foliar applications per year for all insects (except the at-planting treatment)
- naturally occurring predators and parasites for early season aphid and tobacco budworm control
- avoidance of late 'cutout' to shorten the late season protection window by avoidance of organophosphate insecticides
- pathogenic fungi to reduce or eliminate aphids in opening cotton.

If the Boll Weevil Eradication Program continues to expand, the relative contributions of boll weevil eradication in other cotton production regions will likely vary and await quantification. However, the dynamics of insect-related changes in the various regional cotton agroecosystems induced by the elimination of the boll weevil and its requirement of organophosphate insecticides for control in many situations likely will be positive and place a greater premium on beneficial arthropods and less reliance upon insecticides.

References

Anderson, T.E. (1984). Distribution of the European corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Pyralidae) as related to oviposition preference of the spring-colonizing generation in eastern North Carolina. *Environ. Entomol.* 13, 248–251.

Bacheler, J.S. (1985). Pyrethroid use patterns in the U.S., as influenced by *Heliothis* complex species composition and population dynamics. pp. 120-122 *In* Brown, J.M. (Ed.) *Proceedings Beltwide Cotton Production Research Conferences.* National Cotton Council of America, Memphis, TN.

Bacheler, J.S. and Bradley Jr., J.R. (1989). Evaluation of bollworm action thresholds in the absence of the boll weevil. pp. 308–311 *In* Brown, J.M. (Ed.) *Proceedings Beltwide Cotton Production Research Conferences.* National Cotton Council of America, Memphis, TN.

Barbour, K.S. (1988). *Acrosternum hilare (Say) in cotton: a study of direct and indirect feeding damage.* M.S. thesis. North Carolina State University, Dept. Entomol. Raleigh, NC., 68 pp.

Brazzel, J.R. (1989). Boll Weevil eradication – an update. pp. 218–220 *In* Brown, J.M. (Ed.) *Proceedings Beltwide Cotton Production Research Conferences.* National Cotton Council of America, Memphis, TN.

Carlson, G.A. and Suguiyama, L. (1985). Economic evaluation of area-wide cotton insect management: boll weevils in southeastern United States. *N.C. Agr. Res. Sew. Bull.* No. 473. Raleigh, NC.

Carlson, G.A., Sappie, G. and Hamming, M. (1989). *Economic returns to boll weevil eradication.* Resources and Technology Division, Econ. Res. Serv., U. S. Dept. Agr. Agric. Econ. Rept. No. 621. Washington, DC.

Carlson, G.A., Wetzstein, M. and Sappie, G. (1994). Evaluation of insect eradication: the case of boll weevils in the Southeast. Chapter 26. *In* King, E.G., Brown, J.M. and Phillips, J.R. (Eds) *Cotton insects and mites: characterization and management.* Miles Company.

Cross, W.H. (1981). Biological evaluation report (Appendix A) of the Beltwide Boll Weevil/Cotton Insect Management Programs. U.S. Dept. Agr., Science and Education Admin.

Ellsworth, P.C. and Bradley Jr., J.R. (1992). Comparative damage potential and feeding dynamics of the European corn borer (Lepidoptera: Pyralidae) and cotton bollworm (Lepidoptera: Noctuidae) on cotton bolls. *J. Econ. Entomol. 85*, 402-410.

Glover, T. (1855). Agric. Report. p. 93. Cited in Morrill, A.W. (1910). Plant bugs injurious to cotton bolls. *U.S. Bur. Entomol.* 86, 78.

Gourd, T.R. and Gouger, R.J. (1983). Observations in the biology of the European corn borer in North Carolina. pp. 186–187 *In* Brown, J.M. (Ed.) *Proceedings Beltwide Cotton Production Research Conferences.* National Cotton Council of America, Memphis, TN.

King, E.G., Phillips, J.R. and Head, R.B. (1986). Annual Conference Report. p. 127 *In* Brown, J.M. (Ed.) *Proceedings Beltwide Cotton Production Research Conferences.* National Cotton Council of America, Memphis, TN.

Lee, S.Y. (1992). Physiological, biochemical and behavioural aspects of insect resistance in North Carolina populations of the cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae) Ph.D. Dissertation, North Carolina State University. Raleigh, NC., 88.

Planer, F.R. (1988). Advantages in oulation suppression of the boll weevil – Southest Boll Weevil Eradication Progam. pp. 239–240 *In* Brown, J.M. (Ed.) *Proceedings, Beltwide Cotton Production Research Conference.* New Orleans, *LA.*

Savinelli, C.E. (1984). *Ovipositional responses, larval feeding behauiour and injury assessment of the European corn borer, Ostrinia nubilalis (Hubner), and cotton in North Carolina.* Ph.D. Dissertation. Dept. Entomol., North Carolina State University. Raleigh, NC.

Savinelli, C.E., Bacheler, J.S. and Bradley Jr., J.S. (1986). Nature and distribution of European corn borer (Lepidoptera: Pyralidae) larval feeding change to cotton in North Carolina. *Environ. Entomol.* 15, 399–402.

Savinelli, C.E., Bacheler, J.S. and Bradley Jr., J.R. (1988). Ovipositional preferences of the European corn borer (Lepidoptera: Pyralidae) for field corn and cotton under field cage conditions in North Carolina. *Environ. Entomol.* 17, 688–690.

Toth Jr, S.J. (1993). A *survey of pesticide use by North Carolina cotton growers in 1992.* Project 92-EPIX-1-0071. North Carolina State University. Raleigh, NC (National Agriculrural