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Pink Bollworm: Factors Affecting Survival of Diapause Larvae and Emergence of Overwintered Moths in the Spring in Central Arizona

ABSTRACT

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Survival of pink bollworm, Pectinophora gossypiella (Saunders), larvae during diapause and emergence of moths in the spring was reduced about 50 percent by winter and early spring irrigations. Fewer moths emerged from buried bolls than from bolls above or on the soil surface, and earlier burial of bolls caused higher mortality than later burial. Moths emerged earlier and faster from irrigated cages than from nonirrigated. Moths developing from larvae in bolls emerged more slowly than those from free larvae or from larvae that had cut out of bolls. Other factors, such as variety of cotton, date of collection, and chemical termination, had no consistent effect on survival or emergence patterns. A reevaluation of these results and analysis of the data also showed that accumulated heat units may provide a more consistent indication than calendar date of time of emergence.

KEYWORDS: cotton, Pectinophora gossypiella (Saunders), pest control (cultural), pink bollworm

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Pink Bollworm: Factors Affecting Survival of Diapause Larvae and Emergence of Overwintered Moths In the Spring in Central Arizona

By Louis A. Bariola[1]

INTRODUCTION

During the early 1970's, the mandatory plowdown date for cotton had been further delayed from January 31 to March 1 in central Arizona. In 1977, the plowdown regulations were completely removed to permit the growing of stub cotton (producing a 2d or 3d crop from the same stalks or root system without plowing the field). This has resulted in increased pink bollworm, Pectinophora gossypiella (Saunders), and Heliothis spp. populations and in an outbreak of the boll weevil, Anthonomus grandis grandis Boheman (Bergman et al. 1983). Both the survival rate and the emergence pattern of pink bollworm moths from diapause in the spring affect the population of pink bollworms during the coming season. The survival rate determines the number of moths that emerge; the emergence patterns reflect the percentage of those that do emerge that may find suitable host material on which to reproduce; thus their emergence, if too early, is considered suicidal (Bariola 1978)[2] and these would not contribute to the population. Any factors or cultural practices that reduce survival or increase suicidal emergence would be of benefit in reducing populations of pink bollworms during the coming season. Thus, there is a need for detailed data on survival of diapausing larvae and emergence of moths in the spring in central Arizona and the arid southwest.

The emergence of pink bollworm moths from diapausing larvae has been studied in the laboratory and under field conditions. Increasing photoperiod, temperature, and moisture during the diapause period are some of the factors that affect survival and time of emergence. Wellso and Adkisson (1964) reported that photoperiods of 14 to 16 h and higher moisture levels terminated diapause more rapidly than 12-h photoperiods or lower moisture levels; however contact moisture was not necessary.

Fife (1961) reported on the effects of temperature and rainfall on the patterns of spring moth emergence and winter survival in fields in central Texas. He reported major peaks of emergence following rainfall of one inch or more on one or more days. Drought during the spring months resulted in delayed emergence and poorer survival. Similar effects of

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[2] The year underscored, when it follows the author's name, refers to Literature Cited, p. 17.

rainfall or irrigation were shown by Chapman et al. (1960). They also showed that the effect of low temperature on pink bollworm survival is influenced by the amount of moisture present. Higher survival occurred in the cold arid climate of El Paso than in warmer localities with higher rainfall. Slosser and Watson (1972) showed that soil moisture of 11 to 14 percent was much more favorable for survival in Arizona than either higher or lower soil moisture.

Several researchers have reported that emergence in fields begins in early March, peaks in early May with a possible second peak in late May, and is nearly completed during June in Texas (Brazzel and Martin 1959, Fife 1961), in southern California (Rice and Reynolds 1971), and in Arizona (Watson et al. 1973, Wene et al. 1961). However, Fye (1979) reported substantially later emergence through August in insectary studies in Arizona.

The cultural practices of shredding cotton stalks and burial of all debris have been well documented as means of reducing survival (Noble 1969). Fife et al. (1963) reported that survival increased as the date of burial was delayed and survival decreased as the depth of burial was increased. Chapman et al. (1960) reported varying effects of burial in different areas with varying climatic conditions. Survival was highest when bolls were on the soil surface through the winter, except at Brownsville, Tex., where survival was greatest when bolls were suspended above ground, simulating standing stalks with infested bolls still attached. Also, when temperatures were -9.4°C (=15°F) or lower, the lowest survival occurred in bolls exposed above ground until burial in the spring. Watson and Larsen (1968) reported lowest survival with rototilling and thorough mixing of the top 15.2 cm (=6 inches) of soil, with plowing plus cultipacking having the next lowest survival. Winter irrigation has been shown to reduce survival in arid regions, for example, Presidio, Tex. (Chapman et al. 1960) and Safford, Ariz. (Wene et al. 1965).

A portion of the pink bollworm overwintering population emerges before cotton has begun to fruit, so no food and habitat are available for the newly hatched F_1 larvae; these moths do not produce any progeny that mature, so their emergence is commonly referred to as suicidal. The last date of suicidal emergence depends on temperature and the growth stage of the host plants (Bariola 1978). The percentage of the emerging population that emerges suicidally has been reported by various authors to range from 10 to more than 80 percent.

But these field studies did not investigate the effects of factors that occurred during the diapause induction period on the survival and emergence pattern of the moths. Also, more information is needed on the effects of winter irrigations, as applied to winter grain crops, in combination with early burial on survival and emergence of the moths. Therefore, tests were conducted at Phoenix, Ariz., from 1976 through 1981 to determine the effects of several factors on the survival of the overwintering pink bollworm larvae and the emergence pattern of the moths in the spring. Some of the conditions or factors occurred during the diapause induction period (fall), the overwintering period (winter), and the emergence period (spring and early summer); these included variety of cotton, chemical termination, free larvae or larvae in bolls, burial, date of burial, and irrigations. This paper is a report of the results of these tests.

Bolls were collected from cottonfields or variously treated plots in the Phoenix area during the late summer and fall of each year (1975-81). Larvae or bolls from each collection date were kept separate from those from other collection dates. The bolls were held in ventilated plastic boxes (Fye 1976) or a 2 by 2 m^2 frame with a 15 by 15 mm screen bottom in an insectary or other shaded outdoor area for 2 weeks to allow larval development and diapause induction at ambient temperature and photoperiod. Larvae and bolls were held for an additional 2-week period to allow for pupation of those that did not go into diapause. Larvae that had exited the bolls were collected and placed in plastic petri dishes (150 by 25 mm) with paper toweling in which to spin a hibernaculum; these larvae were called cutout larvae. After the cutout period was over, some bolls were dissected, and the larvae remaining in the bolls were removed and also placed in petri dishes; these were called larvae from bolls. Collectively, these two groups of larvae were called free larvae if they were combined into one group. In some years, bolls containing larvae were used in tests; these were called larvae in bolls. All larvae or bolls containing larvae were kept in the insectary until the initiation of the tests (=placement under emergence cages). All larvae in petri dishes were counted just before start of a test; the number of larvae in bolls was estimated by dissecting a sample of bolls just prior to use, and sufficient numbers of bolls were used to give the desired number of diapause larvae per cage.

All tests were conducted in a plowed field on the University of Arizona Cotton Research Center in Phoenix. This field had not been planted to cotton for 2 years before 1976 so that there were no resident pink bollworm larvae in the soil. Larvae or bolls containing larvae were placed under 1 m^2-screen pyramid emergence cages (Shiller 1946) fitted with jars and screen cones for collection and removal of emerged moths. In 1977, 1978, and 1979, diapausing larvae were kept in petri dishes in the insectary to monitor moth emergence at ambient temperature and photoperiod only; that is, without the effects of direct sunlight, soil, and rainfall.

Monitoring of emergence began immediately after the cages were set in place and continued until emergence had apparently ceased, which was usually about mid-July, except in 1979 when monitoring was continued through September. Certain treatments applied during the overwintering period included burial under 6 to 8 cm of loose soil or no burial, burial on different dates, or irrigation with water equivalent to 4 to 6 cm of rainfall at monthly intervals, in addition to natural rainfall that occurred or no irrigation.

Bolls were sometimes collected from plots that were treated with certain chemicals to terminate cotton fruiting (Bariola et al. 1976). Chemicals used in one or more of these tests were 2,4-D,[3] chlorflurenol,[4] chlormequat,[5] MCPA,[6] and Pennwalt TD-1123.[7]

Heat units (HU's) were calculated using 12.8°C (55°F) as a threshold of development (Allen 1976). HU's were accumulated for each year beginning on January 1 and compared with the emergence of pink bollworm moths. Amounts of rainfall after the insects were placed under the emergence cages were accumulated. Temperature and rainfall records were obtained from the University of Arizona Cotton Research Center.

3/ (2,4-Dichlorophenoxy)acetic acid.
4/ Methyl 2-chloro-9-hydroxyfluorene-9-carboxylate.
5/ (2 Chloroethyl)trimethylammonium chloride.
6/ [(4-Chloro-*o*-tolyl)oxy]acetic acid.
7/ 3,4-Dichloroisothiazole 5-carboxylic acid.

1976

Bolls were collected from untreated or from plots treated with MCPA plus chlorflurenol on September 2 to terminate cotton fruiting on the Cotton Research Center at 2-week intervals during the fall of 1975. The cutout larvae and larvae from bolls from each collection date were combined into one sample. All larvae were buried under emergence cages on January 14, 1976.

Emergence began in early February and continued through June, though it was monitored through July. Chemical termination caused no consistent differences in percentage of survival or the emergence pattern of the moths; however, emergence during late May tended to be slightly delayed by chemical termination (table 1). Date of boll collection caused no consistent differences in the percentage of survival of larvae, but moths from the earlier collections, in September, emerged earlier than did those from later collections. The emergence from larvae in bolls collected in early November appeared to be delayed more than from those collected on earlier dates. However, by June 4, the differences in the accrued percent emergence were negligible.

Table 1.--Percentage of survival and emergence pattern of pink bollworm moths from free larvae collected at different times and buried in emergence cages on Jan. 14, 1976[1/]

Treatment and collection date	No. of--		Survival (%)[2/]	Accrued emergence (%)[3/] on--					
	Larvae buried	Moths emerged		May 7	May 14	May 21	May 28	June 4	June 11
Treatment:									
Chemical termination...	648	78	10.6	8	29	49	74	94	97
Control................	1,766	251	14.2	3	32	54	86	94	96
Collection date:									
Sept. 6-18	154	24	15.6	8	50	71	88	92	100
Oct. 2-14	1,061	128	12.1	4	34	61	83	95	98
Oct. 24-29	619	117	18.9	3	29	43	81	97	99
Nov. 6,7	431	49	11.4	4	14	31	47	88	88

[1/]Each figure is a mean of 8 cages for chemical termination and 4 cages for each collection date.
[2/]Based on number of larvae buried on Jan. 14, 1976.
[3/]Based on total number of moths emerged through July.

1977

Bolls were collected at 7- to 12-day intervals from September 22 to November 22, 1976, from plots on the Arizona State University Experiment Farm, Tempe. One-half of the bolls were from plots that had been chemically terminated with Pennwalt TD-1123 plus chlorflurenol on September 17. Each sample was held separately, as were the cutout larvae and the larvae removed from bolls. There were no bolls available in the chemically terminated plots after October 28, whereas bolls were collected until November 22 in control plots. The larvae were buried on February 8, 1977. The first emergence occurred in late March, and the last moth emerged in mid-July.

The survival of larvae from bolls collected in chemically terminated plots was significantly less than of those collected in the control plots (table 2). This was true for total emergence and for reproductive emergence (=total minus suicidal emergence). Neither collection date nor larval category caused consistent or significant differences in percentage of

Table 2.--Percentage of survival of pink bollworm moths from larvae collected on different dates from control and chemically terminated plots and buried Feb. 8, 1977

Treatment (fall 1976)	No. buried and percentages of emergence by collection date--					Average[1]
	Sept. 22	Sept. 30	Oct. 7	Oct. 19	Oct. 28	
	No. of larvae buried					
Control................	341	265	399	515	351	....
Chemical termination..........	308	222	284	301	162	....
	Total emergence (%)[2]					
Control................	26.5	35.2	16.8	21.0	24.7	24.8a
Chemical termination..........	20.2	22.2	15.9	6.9	21.9	17.4b
	Reproductive emergence (%; after May 25)[2]					
Control................	8.5	20.7	9.0	7.3	11.5	11.4a
Chemical termination..........	8.1	9.1	3.2	2.6	9.1	6.4b

[1]Means within an emergence group followed by different letters are significantly different(P=0.05); survival percentages converted to ARCSIN transformations, analysed by 2-way ANOVA, 5 dates, with 2 observations per date (cutout larvae and larvae from bolls).
[2]Based on number of larvae buried.

survival. There were slight differences in the emergence pattern of the moths (table 3). Those from later collections (late October and November) appeared to emerge faster than those from the earlier collections. Also, the larvae from bolls emerged faster than the cutout larvae.

Also, during the fall of 1976, infested bolls were collected from upland cultivars, Gossypium hirsutum (L.), and from the extra-long staple cultivar Pima, G. barbardense (L.), from September 12 to November 2. All larvae were kept in petri dishes; those in diapause were counted on January 31, 1977, and kept in the insectary; and pupation or emergence were monitored until July 13.

Neither collection date nor cotton cultivar produced differences in percentage of survival (data not shown). The emergence patterns of the moths differed slightly among the different collection dates and between the two cultivars (table 4). Moths from larvae collected in September emerged at a slightly slower rate than from those collected later and those from larvae collected from upland cotton emerged slightly more slowly than those from larvae from Pima. The emergence of all moths that were kept in petri dishes in the insectary was delayed beyond that of larvae buried under emergence cages. There was only 37 percent accrued emergence of these moths on June 4 (table 4), compared to 68 to 91 percent accrued emer-

Table 3.--Emergence pattern of pink bollworm moths from larvae collected during fall of 1976 and buried Feb. 8, 1977

Collection date, larval category, and treatment	No. of--		Survival (%)[1]	Accrued emergence (%)[2] on--					
	Larvae buried	Moths emerged		May 9	May 16	May 24	June 1	June 10	June 17
Collection date, 1976:									
Sept. 22,30	1,136	302	26.6	26	40	55	68	82	98.0
Oct. 7,19	1,599	273	17.1	42	53	67	77	91	99.6
Oct. 28; Nov. 5,22	1,068	199	18.5	59	64	72	91	99	99.5
Larval category:									
Cutout larvae	1,509	316	20.9	29	39	53	71	88	98.7
Larva from bolls	2,294	458	20.0	48	59	70	81	94	99.0
Treatment:									
Chemical termination	1,277	231	21.5	39	52	66	76	86	97.0
Control	2,526	543	18.1	41	50	62	78	92	99.6

1/Based on number of larvae buried.
2/Based on number of moths emerged through July 1977.

Table 4.--Emergence pattern of pink bollworm moths from larvae collected during the fall of 1976 and from upland and Pima cotton and held in petri dishes in an insectary, 1977

Collection date and cotton type	No. of larvae in diapause on Jan. 31, 1977	Accrued emergence (%)[1] on-- May 15	June 4	June 22	July 13	Larvae (%) on July 13
Collection date:[2]						
Sept. 12-26	232	16	25	65	77	23
Oct. 6-12	307	22	39	72	84	16
Oct. 25-Nov. 2........	411	25	42	73	86	14
Cotton type:[3]						
Upland................	522	18	30	66	79	21
Pima..................	428	27	45	76	88	12
Total...............	950	22	37	71	83	17

1/Based on total number of insects--emerged moths plus live larvae on July 13, 1977.
2/Each collection date includes larvae from upland and Pima cottons.
3/Each cotton type includes larvae from each collection date.

gence of those that were buried in soil under the emergence cages on June 1 (table 3). This delayed emergence resulted in 14 to 23 percent of the insects being found as larvae on July 13, whereas, in field cages, emergence was usually complete before or on that date.

1978

Bolls were collected from August 23 to October 27, 1977, from various plots and fields, some of which had been chemically terminated with 2,4-D or TD-1123 plus chlorflurenol or chlormequat. After the larvae cut out or were taken from bolls, they were placed in large petri dishes on filter paper and kept in the insectary until March 15. Then the larvae were counted and buried in the emergence cages with one petri dish containing 50 diapause larvae from each collection date and chemical termination and control treatment returned to the insectary. Emergence began during the first week of April and continued to early July.

Chemical termination treatments caused no differences in percentage of emergence of moths in the emergence cages (table 5). There was a slightly higher percentage of emergence of those collected August 23 through September 16 than of those collected later. There was a slightly higher survival rate in the petri dishes kept in the insectary than in those buried

Table 5.--Survival and emergence patterns of pink bollworm moths from diapause larvae collected on different dates or from chemically terminated plots and buried under cages on Mar. 15 or held in petri dishes in an insectary, 1978

Collection date and treatment	No. of-- Larvae	Moths emerged	Survival (%)[1]	Accrued emergence (%)[2] on-- Apr. 21	May 5	May 19	May 26	June 2	June 9
Collection date:[3]									
Aug. 23-Sept.16..	138	36	26	36	58	81	86	100	....
Sept. 18-29......	601	125	21	24	33	52	66	86	94
Oct. 4-12........	934	203	22	13	31	60	76	91	95
Oct. 19-27.......	774	159	20	19	30	47	75	88	96
Treatment:[4]									
Chemically terminated......	1,174	256	22	20	31	54	72	89	95
Control.........	1,273	267	21	18	35	57	76	89	96
In petri dishes[5].	1,037	351	34	7	17	42	62	71	93

[1] Based on number of live larvae on Mar. 15.
[2] Based on total number of moths emerged through July 7.
[3] Includes larvae from both chemically terminated and control plots.
[4] Includes larvae from each collection date.
[5] Includes larvae form each collection date and from chemically terminated and control plots.

under emergence cages. The emergence rate of moths in petri dishes was slower than that of those that had been buried. Those moths from bolls collected August 23 to September 16 emerged slightly faster than those collected later.

1979

Bolls containing diapause larvae were collected on September 18 and on October 2, 16, and 30, 1978, from plots chemically terminated with Pennwalt TD-1123 plus chlorflurenol and from untreated control plots. Cutout larvae and larvae removed from bolls were kept separately in petri dishes in the insectary until March 15, 1979, when survivors were counted and buried under emergence cages. At least one petri dish containing 35 to 70 larvae from each collection date and category was returned to the insectary. Bolls were also collected from untreated plots on September 19 and 29, October 11, and November 9, 1978, and kept in the insectary. The number of larvae remaining in the bolls was estimated, and bolls containing a total of about 320 larvae were placed under each emergence cage on April 9. Sufficient numbers of bolls were available from the September 19 collection date to place under five emergence cages; in two cages, one of which was irrigated, the bolls were buried 6 to 8 cm deep; in two other cages, one of which was irrigated, the bolls were left on the soil surface; in the remaining cage, the bolls were suspended above ground, without irrigation. For each of the other collection dates, the bolls were all buried under two cages, one of which was irrigated. Emergence began within 2 weeks after cages were set up and monitoring was continued until late September. Among larvae buried under the emergence cages or held in the petri dishes, neither chemical termination, date of collection, nor larval category produced differences in percentage of survival or in emergence patterns. Among larvae in bolls, the percentage of survival was slightly reduced by burial (76 percent) compared to those left on the soil surface (95 percent) and irrigation also reduced survival (53 percent vs 78 percent for nonirrigated), with no apparent differences in emergence patterns.

There were differences in the percentage of survival and the emergence patterns among the three groups (table 6). Survival was lowest among those buried as free larvae. The percentage of survival for those in bolls (71 percent) may be in error due to an apparent underestimation of the number of larvae in bolls, since some cages had more moths emerged than the estimated number of larvae in the bolls at the time of placement under the cages. The higher survival rate (compared with those of previous years) may be attributed to the late burial date of April 9, 1979. The emergence patterns (table 6) showed a faster rate of emergence for those buried as free

Table 6.--Survival and emergence patterns of pink bollworm moths from diapause larvae in petri dishes and free larvae and larvae in bolls buried under cages on Mar. 15 and Apr. 9, 1979

Category	No. of--		Survival	Accrued emergence (%)[1] on--					
	Larvae	Moths emerged	(%)	May 12	May 19	May 26	June 2	June 9	June 30
Larvae in petri dishes.......	850	534	[2]63	5	11	22	34	57	89
Free larvae buried...........	1,970	597	[2]30	22	37	53	70	96	99
Larvae in bolls buried.......	3,187	2,258	[3]71	9	20	32	46	78	98

[1] Based on total number of moths emerged through September.
[2] Based on number of live larvae in diapause counted on Mar. 15.
[3] Based on estimated number of live larvae in bolls on Apr. 9.

larvae, with those in bolls slightly faster than those in petri dishes. There was little (less than 1 percent) or no emergence of moths during July and the first week of August in both groups in the emergence cages; moths in the petri dishes continued to emerge through mid-September, when all emergence ceased. During July, August, and September, emergence in the field cages was 1 to 2 percent of total emergence, compared with 11 percent of total emergence in petri dishes in the insectary.

1980 and 1981

The tests in 1980 and 1981 were replicated tests with different dates of boll collection, free larvae or larvae in bolls, different dates of burial or no burial, and irrigations or no irrigation. These results have recently been reported (Bariola 1983) but are relevant to the 1976 to 1979 tests and are briefly summarized and discussed here.

In 1980, larvae in bolls were buried on February 1 and March 1, or not buried, and one-half of the cages were irrigated at monthly intervals after burial. Free larvae from bolls collected August 30 to September 23, October 11, October 25, and November 7 were placed in emergence cages on February 4, and one-half of the cages were irrigated.

Results show that irrigation reduced survival and emergence about 50 percent (table 7), and emergence from cages buried on February 1 was significantly lower than from March 1 burial and no burial. Moths emerged slightly faster from irrigated

Table 7.--Average number of moths per cage that emerged from larvae in bolls that were buried on different dates and irrigated or not irrigated, 1980

	Average No. emerged from cages[1]		
Burial treatment	Not irrigated[2]	Irrigated[2]	Combined[3]
Buried Feb. 1......	73	16	44
Buried Mar. 1......	73	51	62
Not buried.........	148	78	113
Average.........	98	48	73

[1]2-way ANOVA shows highly significant differences (P=>0.01) between irrigated and nonirrigated cages and among burial treatments.
[2]Average number of moths that emerged from 2 cages, 120 larvae per cage.
[3]Average number of moths that emerged from 4 cages, 120 larvae per cage.

cages than from nonirrigated cages (table 8). The moths from the earlier collections emerged slightly faster than those from the later collections; however, there was no difference in survival among the different collection dates.

For the 1981 test, a large number of infested bolls was collected from one field in early November 1980, and cutout larvae were collected for 2 weeks. Then, on December 1, 150 cutout larvae were placed in each of 24 cages, and bolls containing about 150 larvae were placed under each of 40 cages. Treatments (eight cages of each) were: cutout larvae buried on December 1, buried on March 9, and not buried, and larvae in bolls buried on December 1, buried on January 15, and buried on March 9; not buried; and suspended 15 cm above ground (simulating bolls remaining on stalks). One-half of the cages (four in each case) of all treatments were irrigated at monthly intervals after burial; cages not buried were irrigated in March and at monthly intervals thereafter.

The results show that irrigation significantly reduced survival and emergence, there was less survival and emergence from cutout larvae than from larvae in bolls, and burial on December 2 reduced survival more than burial on January 15 or later (table 9). There were no differences in survival for March 9 burial, no burial, and suspension of bolls above ground. The

Table 8.--Percentage of survival and emergence pattern of free larvae from bolls collected on different dates, buried Feb. 4, and irrigated or not irrigated, 1980

Collection date and treatment	No. of-- Larvae	No. of-- Moths emerged	Survival (%)[1/]	Accrued emergence (%)[2/] on-- May 2	May 16	May 23	May 30
Collection date:							
Aug. 30-Sept. 23[3/]....	64	9	14	78	100	....	....
Oct. 11[4/]..............	450	49	11	35	80	98	100
Oct. 25[4/]..............	450	47	10	28	72	89	94
Nov. 7[4/]...............	450	55	12	15	45	69	84
Treatment:[5/]							
Irrigated............	675	45	7	36	73	86	98
Nonirrigated.........	739	115	16	25	64	84	90

1/ Based on total number of larvae buried.
2/ Based on total number of moths emerged.
3/ Nonirrigated cage only.
4/ Average of irrigated and nonirrigated cages.
5/ Average of cages from each collection date.

Table 9.--Pink bollworm moth emergence from diapause larvae buried on different dates or not buried and irrigated or not irrigated, 1981

Larvae source and burial treatment	Average No. of moths emerged from cages[1/]		
	Irrigated	Nonirrigated	Combined
Cutout:			
Dec. 2............	7d	29b	19c
Mar. 9............	27abc	40b	33bc
Not Buried........	43a	43b	43ab
In bolls:			
Dec. 2............	11cd	54ab	32bc
Jan. 15...........	32ab	82a	57a
Mar. 9............	34ab	64ab	49ab
Not buried........	38ab	88a	63a
Above ground......	22bcd	64ab	43ab
Average.........	26.7	57.9	37.6

[1/] Each figure is an average of 4 cages (8 cages for combined), about 150 larvae per cage. A 2-way ANOVA (8 burial treatments by 2 irrigation treatments with 4 replicates of each) showed a highly significant difference (*P*=0.01) between irrigated and nonirrigated cages and significant differences (*P*=0.05) among the burial treatments. Figures within a column followed by the same letter are not significantly different according to Duncan's multiple-range test (*P*=0.05).

moths emerged at a slightly faster rate from the irrigated cages than from the nonirrigated cages (table 10). Also, the moths from cutout larvae emerged faster than those from larvae in bolls.

Heat Units, Rainfall, and Emergence

A comparison of emergence patterns over the different years shows a wide variation in responses. The dates when 50 percent of total emergence in emergence cages had occurred ranged from April 25 in 1981 for irrigated cages to June 4 in 1979 for larvae in bolls (table 11). Comparison of emergence with accumulated heat units showed that 50 percent emergence occurred between 1,146 and 1,423 heat units for the field cages in different years. This compares favorably with the work of Huber (1982) in which he reports 1,180 heat units required for 50 percent emergence in field cages. More heat units were required for larvae held in petri dishes to reach 50 percent emergence (and also 90 percent emergence) than larvae in field cages. Since the larvae in petri dishes experienced temperatures similar to those recorded by the weather station (both

Table 10.--Emergence patterns of pink bollworm moths in emergence cages from free larvae and larvae in bolls or in cages that were irrigated or not irrigated, 1981

Catagory	No. of cages	Avg. No. moths emerged per cage	Accrued emergence (%)[1] on--					
			Apr. 24	May 1	May 8	May 15	May 22	May 29
Cutouts.........	24	31.5	[2]50	[2]63	[2]80	[2]88	[2]94	96
In bolls........	40	48.8	33	50	66	76	85	97
Nonirrigated....	32	57.9	34	52	69	76	85	90
Irrigated.......	32	26.7	[3]47	[3]59	72	[3]87	[3]94	98

[1] Based on total number of moths emerged through July 27, about 150 larvae per cage.
[2] 2-way ANOVA showed significantly more emergence from cutouts than from larvae in bolls on these dates (*P*=0.05).
[3] 2-way ANOVA showed significantly more emergence from irrigated cages than from nonirrigated cages on these dates (*P*=0.01).

in a shaded ventilated area), the larvae in field cages probably experienced higher temperatures in the direct sun than those recorded. Thus, their emergence rate would be faster than that of larvae in petri dishes in a shaded insectary.

The emergence patterns of all larvae in field cages for each year by calendar date and by accumulated heat units are shown graphically in figures 1 and 2. In figure 1A, the 1979 data show the 50-percent emergence to be about 10 to 12 days later than in 1977 and 1978, but the differences in HU's to 50 percent emergence are less than 100 (which, during May, may be only 1 to 2 days).

Rainfall may have affected the emergence patterns. Years with low rainfall, such as 1977 and 1979 (table 11) had generally later emergence. Also the time that the rainfall occurred may have affected the emergence. In 1979, no rainfall occurred until May, and emergence was delayed. This supports the conclusions of Fife (1961) that rainfall stimulates emergence peaks and of Fullerton et al. (1975) and Slosser and Watson (1972) that spring irrigation hastens emergence. The results of emergence during 1977 were quite different from those of the other years; there were significant differences between chemically terminated plots and control plots and faster emergence from bolls collected in November than from September-

Table 11.--Dates and accumulated heat units [1/] when 50% and 90% of total emergence occurred 1976-81

Category	Rainfall (cm)[2/]	50% emergence		90% emergence	
		Date	HU	Date	HU
		1976			
Cages...........	9.75	May 21	1,409	June 4	1,723
		1977			
Cages...........	1.30	May 16	1,282	June 10	1,838
Petri dishes.............		June 11	1,861	....[3/]	....
		1978			
Cages...........	4.06	May 16	1,210	June 3	1,603
Petri dishes.............		May 22	1,346	June 8	1,728
		1979			
Cages:					
Free larvae...	2.31	May 25	1,193	June 7	1,498
In bolls................		June 4	1,423	June 23	1,905
Petri dishes.............		June 7	1,498	June 30	2,105
		1980			
Cages:					
Free larvae...	10.16	May 11	1,176	May 28	1,492
In bolls................		May 9	1,146	June 4	1,629
		1981			
Cages:					
Nonirrigated..	8.31	Apr. 30	1,297	May 29	1,944
Irrigated...............		Apr. 25	1,174	May 18	1,692

1/ Heat units, based on daily maximum and minimum temperatures, with 12.8°C (=55°F) as the threshold of development, according to Allen (1976).
2/ Accumulated rainfall from date larvae and/or bolls were placed in emergence cages to June 30 of each year.
3/ 83% accrued emergence on July 13 (2,743 HU's accumulated), when test was terminated.

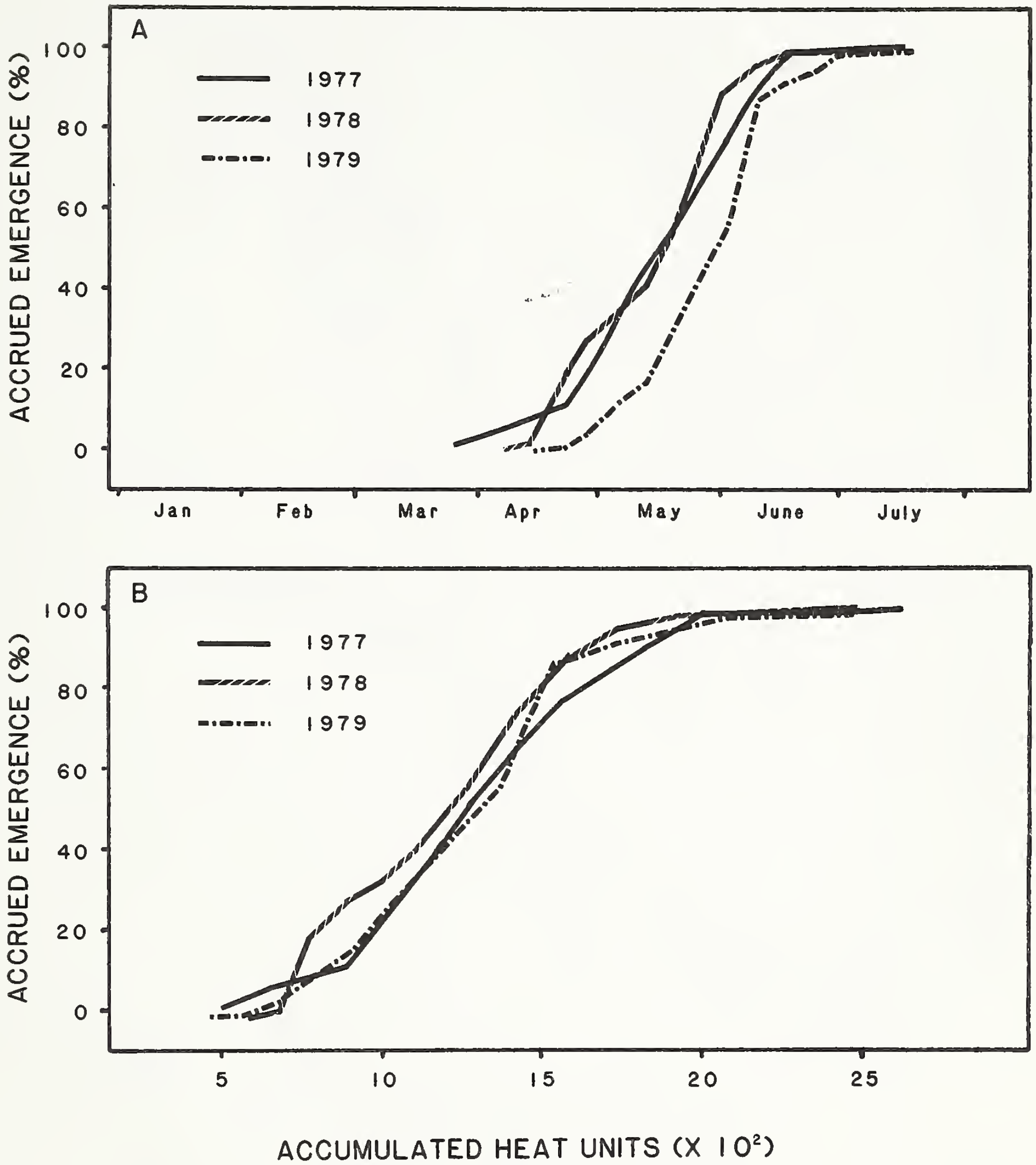

Figure 1.--Accumulated percentage of emergence of pink bollworm moths from free larvae or larvae in bolls buried in spring of 1977, 1978, and 1979: A, emergence by calendar date; B, emergence by accumulated heat units.

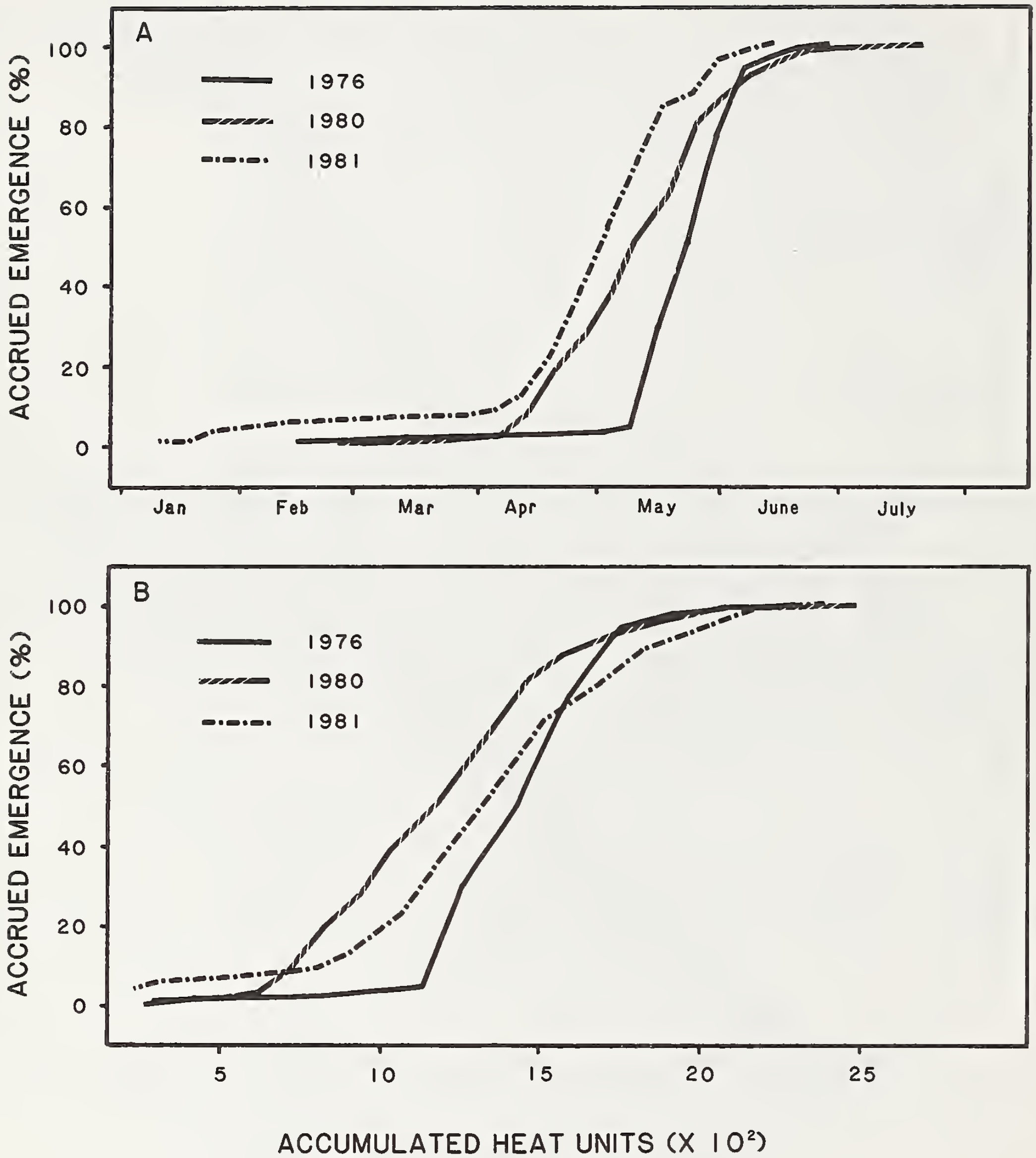

Figure 2.--Accumulated percentage of emergence of pink bollworm moths from free larvae or larvae in bolls buried in January 1976, January 1980, or December 1980 (1981 emergence): A, emergence by calendar date; B, emergence by accumulated heat units.

collected bolls. These differences may be the result of low rainfall during this emergence period. There was only 1.30 cm rainfall recorded from February through June; the maximum in any month was 0.66 cm during March. However, the 1976 emergence was also delayed until early May (fig. 2A) with higher amounts of rainfall; there were 1.02 to 3.94 cm of rainfall for each month from February through May, with none during June. Little or no emergence (less than 2 percent) occurred during the February to April period when the greater amounts of rainfall occurred, even though nearly 1,000 HU's had accumulated. After May 1, when rainfall ceased, emergence increased rapidly.

DISCUSSION

Diapause larvae kept in petri dishes emerged slower and over a longer period than larvae put in cages (tables 4 and 6). In all these tests, emergence from larvae in field cages was more than 98 percent completed by July 1, whereas emergence from larvae in petri dishes continued until late September, with 11 to 23 percent emergence occurring or live larvae remaining after July 1 (tables 4 and 6). The extended period of emergence in the insectary into July and August is similar to that reported by Fye (1979) when diapause larvae were held in shaded moist vermiculite in an insectary. Thus, predictions for emergence in fields should be based on observations of field-cage tests rather than laboratory tests.

The cultural practice having the greatest effect on survival in these tests was irrigation. In all tests, irrigation reduced survival by about 50 percent or more below that of nonirrigated treatments. The reductions due to winter irrigations reported by Fullerton et al. (1975) and Slosser and Watson (1972) were considerably smaller; however, their irrigation treatment consisted of one or two irrigations during the winter. The irrigation treatments performed here were applied at about monthly intervals, which is similar to the schedule of irrigations to winter grain crops that may be planted in late fall or early winter following cotton. Fye (1979) reported decreased survival when additional moisture was applied at monthly intervals. Thus, these results are consistent with previously reported results.

Burial of diapause larvae reduced the survival rate below that of larvae not buried, with earlier burial causing greater reductions in survival than later burials. There was less survival from free larvae that were buried than from larvae in bolls, with no differences among free larvae that had cut out or had been removed from bolls. On the other hand, Crowder et al. (1975) reported no difference in survival of larvae that overwintered in bolls vs. those that exited the boll and overwintered outside the bolls.

In one year (1977), the survival of larvae from chemically terminated plots was significantly lower than that of larvae from untreated plots. However, there were no differences between these treatments in 1976 and 1978. Also, different collection dates caused no consistent differences in survival of larvae.

The emergence patterns of the moths in the spring varied considerably over the years and among the treatments. Moths emerged from irrigated cages faster or earlier than from nonirrigated cages. Free larvae emerged earlier and at a faster rate than larvae in bolls (similar to the rate reported by Fye

(1979)), with no differences between cutout larvae and larvae from bolls, except in 1977 when larvae from bolls emerged faster than cutout larvae. Crowder et al. (1975) reported no differences in the emergence patterns of free larvae and larvae in bolls. Chemical termination treatments in these tests had no effect on the emergence pattern.

The date of collection had a varying effect on the emergence patterns; that is, in some years the moths from bolls collected early (September) emerged at a faster rate than those collected later (late October and November) as in tables 1, 5, and 8, and in some years the reverse occurred (tables 3 and 4). Gutierrez et al. (1981) reported that diapause larvae collected in September 1975 emerged earlier in 1976 than those collected in November, which supports the hypothesis of "earliest in, earliest out." However, this hypothesis is not consistent in all years of the tests reported here. So there are factors affecting time of emergence other than time of entering diapause.

Thus the emergence of pink bollworm moths in the spring and early summer is the result of a complex interaction involving temperature, time of year (photoperiod), moisture levels, overwintering site (deep burial, in a boll, above ground, etc.), satisfaction of physiological requirements, and possibly other factors. Any prediction based on only one of these factors could result in erroneous information.

These tests confirm previous recommendations that early stalk destruction and plowdown of all infested bolls and debris are effective in reducing pink bollworm populations. The addition of winter irrigations to the system decreases the survival and emergence of moths in the spring.

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