INFLUENCE OF IRRIGATION ON OVERWINTER SURVIVAL OF THE PINK BOLLWORM, PECTINOPHORA GOSSYPIELLA (SAUNDERS) (LEPIDOPTERA: GELECHIIDAE)

by

Jeffrey E. Slosser

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SIGNED Jeffrey Slosser

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

T. F. Watson
T. F. Watson
Associate Professor of Entomology

January 15, 1968
Date

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ABSTRACT

Winter survival of pink bollworm larvae, *Pectinophora gossypiella* (Saunders), was studied in relation to seven irrigation treatments and two methods of larval burial. A split-plot design with three replications was employed.

Because winter survival was low in all experimental units, nonparametric statistical tests were used to analyze all treatment comparisons. Of the total number of larvae buried, only 1.3% survived. There were no significant differences among irrigation treatments; however, larval survival in buried bolls was significantly greater than survival of larvae buried in free cocoons.

Moth emergence appeared to be related to soil moisture and compaction. Approximately 75% of the moth emergence was suicidal, and more males survived than females.

INTRODUCTION

The history of the pink bollworm in Arizona has been summarized by Wene *et al.* (1965). Morrill (1918) reported that in 1914 a shipment of cotton seed from Egypt, received in the Salt River Valley of Arizona, was found to be highly infested with the pink bollworm, *Pectinophora gossypiella* (Saunders), and immediately destroyed. The pink bollworm was apparently not reported again in Arizona until November, 1926, when an infested field was discovered in Cochise County. Infestations have since occurred throughout central and southern Arizona.

Mature pink bollworm larvae enter diapause in the fall and survive the winter in this condition. They remain in cotton debris left in the field or in cocoons near the soil surface. It is during the period when the larvae enter diapause, and during the ensuing winter months, that cultural control measures are most effective.

Several fall cultural practices have been developed which prevent late-season population build-up. Defoliants hasten boll maturity, and a defoliated crop is less attractive to ovipositing pink bollworm moths.

Early harvest, followed by stalk shredding, eliminates the food supply, destroys many larvae remaining in unpicked bolls, and lengthens the host-free period (Adkisson _et al._ 1958; Adkisson and Gaines 1960).

Burial of cotton debris soon after stalk shredding effectively reduces survival of overwintering, or diapausing, populations under conditions found in western and southern Texas. When infested material is buried to a depth of six inches or more following shredding, 95% control can be obtained (Adkisson and Gaines 1960).

Chapman _et al._ (1960) found that early burial of infested bolls followed by two winter irrigations effectively reduced survival. Fenton (1928) reported that 99% mortality was obtained by irrigating immediately following winter burial.

The cotton producing counties in Arizona are regions of low winter rainfall, a situation different from many cotton areas in Texas where most cultural control research has been conducted. Obtaining the information reported herein is therefore essential to the development of more efficient cultural control measures in this state.

This study was undertaken with the objectives of determining (1) patterns of survival and spring emergence of overwintering larvae subjected to irrigation, and (2) the effects of irrigation on larvae buried within bolls and in free cocoons.

METHODS AND MATERIALS

Experimental Design

Overwintering larvae were subjected to seven treatments which included six differently-timed irrigations and one nonirrigated control. The effect of irrigation on winter survival of larvae buried within bolls and in free cocoons was tested within each of the seven treatments.

A split-plot design replicated three times was employed. The whole-plots were the irrigation treatments and the control, and were arranged in a randomized block design. The subunits within the whole-plots consisted of the two methods of larval burial. These subunits were randomly arranged by pairs within each whole-plot.

The whole-plots were irrigated in accordance with the dates and soil temperatures shown in Table 1. Approximately four inches of water were applied at each irrigation.

Three of the plots were irrigated during the winter, three during the spring, and one was nonirrigated.

Of the three winter-irrigated plots, Plot 3 received an early irrigation, Plot 5 a late irrigation;

Table 1

Various irrigation treatments applied to buried overwintering pink bollworm larvae, Tucson, Arizona, 1967.

Irrigation Treatment	Plot Number	Date of Irrigation	Soil Temperature
Control	6	-	-
Early Winter	3	Jan. 5, 1967	-
Late Winter	5	Feb. 10, 1967	-
Two Winter	7	Jan. 5, 1967 Feb. 6, 1967	- -
Early Spring	2	Mar. 7, 1967	57° F.
Mid Spring	1	Mar. 28, 1967	67° F.
Late Spring	4	May 10, 1967	77° F.

and Plot 7 received two irrigations applied one month apart. The interval between the early and late irrigations was approximately one month also.

The three spring irrigations were not applied until the average diurnal soil temperature at the six-inch depth was 57°, 67°, and 77° F. for three consecutive days for Plots 2, 1, and 4, respectively. Because only one thermograph was available, the spring irrigation dates were determined by the soil temperature in the nonirrigated control, Plot 6.

Reference to the irrigation treatments will be made by plot numbers throughout the remainder of this discussion.

There were 42 experimental units, or burial sites, with 100 overwintering larvae used per unit. On a subunit basis, 2100 larvae were buried within bolls and 2100 in free cocoons.

Source of Overwintering Larvae

Several thousand short-staple cotton bolls, known to be infested with pink bollworms, were collected near Gilbert, Arizona, on November 18, 1966. The bolls were held in the laboratory for 35 days, and the larvae that had not pupated during this interval were assumed to be in diapause. Ankersmit and Adkisson (1967) considered larvae to be in diapause if they had not pupated in a 25-day interval.

The 2100 larvae buried in free cocoons were hand-picked from the bolls during the 35-day interval and held in petri dishes for three to 20 days before burial. Ten larvae were placed in each petri dish and allowed to spin cocoons between folds of tissue paper.

Examination of 60 bolls randomly selected from those remaining showed an infestation of 3.5 ± 2.3 larvae per boll. By taking the standard deviation into account, 30 bolls containing 105 larvae were required to obtain the minimum of 100 larvae for each of the 21 experimental units in which larvae within bolls were to be buried. A total of 630 bolls were therefore used to supply a minimum of 2100 larvae buried in bolls.

Field Arrangement

These experiments were conducted in Field Number Three at The University of Arizona Ewing Farm, Tucson, Arizona. The soil in this field was a sandy loam which consisted of 72.2% sand, 25.8% silt, and 2.0% clay.

The field was disced and seven main plots, 60 feet long by 8.5 feet wide, were constructed. Adjacent plots were separated by irrigation borders. An irrigation ditch was constructed along one end of the plots.

Six burial sites, 12" x 12" x 8" deep, were dug 8.5 feet apart along the center line of each whole plot. The distance between burial pits of adjacent plots was approximately 8.5 feet.

Each pit was lined with a single piece of 18-mesh nylon screen, 30" x 30", to confine the larvae within the burial site. Two inches of loose soil were placed in the bottom of each lined pit. One hundred larvae, which had spun cocoons in tissue paper, or 30 infested bolls were placed in each pit and covered with six inches of soil. This work was completed by December 23, 1966.

Field Methods and Materials

A thermograph was placed in the control plot on February 10, 1967, and was attached to a soil thermocouple buried six inches deep. A daily record of the soil temperature was kept for the remainder of the experiment, and the spring irrigations were based on this record.

A pyramidal emergence cage, of the type described by Shiller (1946), was placed over each burial site, or experimental unit, on March 8, 1967. The cages measured 29" x 29" at the base and 26 inches high at the center. Emerged moths were collected in an inverted pint jar, equipped with a screen cone, placed at the apex of each cage. These collecting jars are also described by Shiller (1946). Daily records of moth emergence were kept for each cage.

Beginning January 7, 1967, soil samples were taken at weekly intervals. A sample consisted of three soil cores taken adjacent to each pair of subunits, and three samples were taken in each whole-plot. The cores were obtained with a soil auger, and the percent moisture content at the six-inch depth was calculated from Formula 1, Appendix. Sampling was discontinued on June 1, 1967, because the soil became too hard to penetrate with the auger. To reduce water loss by plant transpiration, the plots were kept free of weeds.

Soil compaction in each experimental unit was determined on August 8, 1967, with the aid of a hydraulic soil penetrometer. A strain gauge measured the force in pounds per square inch (p.s.i.) on the probe tip, and a monitoring unit measured the depth to which the probe tip penetrated.

RESULTS AND DISCUSSION

Evaluation of Results

The number of moths that emerged from each of the experimental units is shown in Table 2. Of the 4200 overwintering larvae buried, only 55 emerged as moths. The symbol B represents those larvae buried within bolls, and the symbol C, those buried in cocoons. The subscripts represent the three replications.

The binomial probability distribution describes the sampling characteristics of larval survival; i.e., a buried larva either survived with the end result that a moth emerged, or it did not survive and no moth emerged. In the following discussion, only the proportion of buried larvae that survived is considered. The binomial probability distribution approaches the normal distribution when certain requirements are met. These limitations are discussed by Li (1965). An examination of Table 2 revealed that these data could not be assumed to be normally distributed. Therefore, the analysis of variance for a split-plot experiment was not justified.

Nonparametric techniques offered an alternative. These statistical tests do not require the assumption of normality and were used for all treatment comparisons.

Table 2

Total pink bollworm moth emergence from larvae buried in bolls and free cocoons, by plot and replication, Tucson, Arizona, 1967.

Plot	B_{I}[a]	B_{II}[c]	B_{III}	C_{I}[b]	C_{II}	C_{III}	Total	Mean
1	4	1	1	0	0	1	7	1.2
2	1	5	2	1	2	3	14	2.3
3	2	1	0	0	0	0	3	0.5
4	1	2	3	1	0	0	7	1.2
5	1	2	1	3	0	2	9	1.5
6	3	0	1	0	0	2	6	1.0
7	1	2	1	1	3	1	9	1.5
Total	13	13	9	6	5	9	55	1.3

a. B - Larvae buried in bolls.

b. C - Larvae buried in free cocoons.

c. Subscripts I, II, III - Replication identity.

The Kruskal-Wallis one-way analysis of variance by ranks (Siegel 1956) was used to test the hypothesis of no difference among the seven irrigation treatments. The analysis is shown in Table 3. Moth emergence data from each paired method of larval burial, B and C in the same plot and replication, were added to form one observation. Thus, there are three totals for each plot and 21 altogether. The 21 observations were ranked in a single series. The smallest totals of moth emergence received the lowest rank values, and the highest total received the rank of 21. Tied observations, those of equal value, received the average rank value. The rank values are shown in parentheses beside each total for moth emergence. The sum of the ranks in each plot was then determined.

The statistic used in the Kruskal-Wallis test is H, defined by Formula 2 in the Appendix. A value of $H = 6.73$ with six degrees of freedom is not significant at the 5% level. Therefore, it can be concluded that no differences among the irrigation treatments were demonstrated in this study.

Chapman *et al.* (1960) stated that winter irrigation decreases pink bollworm survival and that two

Table 3

Krusdal-Wallis one-way analysis of variance by ranks for total pink bollworm moth emergence in seven irrigation plots, Tucson, Arizona, 1967.

	Plot						
Replication	1	2	3	4	5	6	7
I	4[a] (17.5)[b]	2(8.5)	2(8.5)	2(8.5)	4(17.5)	3(14.5)	2(8.5)
II	1 (3.5)	7(21.0)	1(3.5)	2(8.5)	2(8.5)	0(1.5)	5(19.5)
III	2 (8.5)	5(19.5)	0(1.5)	3(14.5)	3(14.5)	3(14.5)	2(8.5)
Rank Sum	29.5	49.0	13.5	31.5	40.5	30.5	36.5
$H^c = 6.73$; not significant at 5%							

a. Plot totals for each replication obtained by adding corresponding B and C subscripts (replications) of Table 2.

b. Assigned rank value.

c. The statistic used in the Kruskal-Wallis test, defined by Formula 2, Appendix.

winter irrigations were more effective than one. These workers found that survival decreased with depth of burial and was least at the six-inch depth.

Suicidal moth emergence, or those emerging before squares were available, is shown in Table 4. All emergence prior to June 1, 1967, was considered suicidal. Again, B and C represent the two methods of larval burial, and the subscripts represent the replications.

The Kruskal-Wallis test was used to analyze these data, but the analysis is not shown since the calculated H was 8.24 and was not significant at the 5% level. Under the conditions of the experiment, this shows that suicidal emergence was the same in all treatments.

The Mann-Whitney U test (Siegel 1956) was used to test the hypothesis that larval survival in bolls, B, was the same as in free cocoons, C. The results of this analysis are shown in Table 5.

There were 21 observations for both B and C. The 42 observations were ranked in a single series without regard to irrigation treatment, and tied observations received the average of the tied rank values.

The statistic used in this test is U, and the sampling distribution of U approaches the normal

Table 4

Suicidal pink bollworm moth emergence from larvae buried in bolls and free cocoons, by plot and replication, Tucson, Arizona, 1967.

Plot	B_{I}^{a}	B_{II}^{c}	B_{III}	C_{I}^{b}	C_{II}	C_{III}	Total
1	2	1	1	0	0	1	5
2	1	5	2	1	2	2	13
3	2	0	0	0	0	0	2
4	1	2	2	1	0	0	6
5	1	2	0	0	0	0	3
6	2	0	1	0	0	2	5
7	1	2	1	1	2	0	7
Total	10	12	7	3	4	5	41

a. B - Larvae buried in bolls.

b. C - Larvae buried in cocoons.

c. Subscripts I, II, III - Replication identity.

Table 5

Mann-Whitney U test for comparison of moth emergence from larvae buried in bolls and in free cocoons, Tucson, Arizona, 1967.

Plot	Replication	B[a]	Rank	C[b]	Rank
	I	4	41.0	0	6.5
1	II	1	20.0	0	6.5
	III	1	20.0	1	20.0
	I	1	20.0	1	20.0
2	II	5	42.0	2	31.5
	III	2	31.5	3	38.0
	I	2	31.5	0	6.5
3	II	1	20.0	0	6.5
	III	0	6.5	0	6.5
	I	1	20.0	1	20.0
4	II	2	31.5	0	6.5
	III	3	38.0	0	6.5
	I	1	20.0	3	38.0
5	II	2	31.5	0	6.5
	III	1	20.0	2	31.5
	I	3	38.0	0	6.5
6	II	0	6.5	0	6.5
	III	1	20.0	2	31.5
	I	1	20.0	1	20.0
7	II	2	31.5	3	38.0
	III	1	20.0	1	20.0
Total		35	529.5	20	373.5

$z^c = -1.96$; significant at 5%

a. B - Larvae buried in bolls.

b. C - Larvae buried in free cocoons.

c. The statistic used for the normal approximation in the Mann-Whitney U test, defined by Formula 3b, Appendix.

distribution when the sample size of one of the two samples under consideration is greater than 20. Since both B and C consisted of 21 observations, the normal z approximation could be used. The calculation of U and z are defined in the Appendix by Formulas 3a and 3b, respectively.

The value of z is -1.96 and is significant at the 5% level. Therefore, moth emergence from larvae buried in bolls was considered greater than emergence from free cocoons.

Noble (1955) and Chapman et al. (1960) found that survival in bolls was several times greater than survival in cocoons. However, their experiments were conducted in Texas under environmental conditions different from those in Arizona. The data in Table 5 show that survival in bolls was 1.75 times greater than in free cocoons; the ratio was 35 : 20.

Moth emergence in relation to soil compaction is shown in Table 6. The 42 penetrometer readings were grouped into six class intervals. The size of each class interval is 49.9 p.s.i., and the readings ranged from 5.4 to 294.5 p.s.i. The frequency f of moth emergence in each class interval was based on the

Table 6

Kolmogorov-Smirnov one-sample test comparing total moth emergence in six class intervals of soil compaction, Tucson, Arizona, 1967.

	Force in Pounds per Square Inch					
	0.6 - 50.5	50.6 - 100.5	100.6 - 150.5	150.6 - 200.5	200.6 - 250.5	250.6 - 300.5
f^{a}	13	8	11	19	2	2
$F_o(X)^{b}$	9.17/55	18.34/55	27.51/55	36.68/55	45.85/55	55/55
$S_{55}(X)^{c}$	13/55	21/55	32/55	51/55	53/55	55/55
$\lvert F_o(X) - S_{55}(X)\rvert^{d}$	3.83/55	2.66/55	4.49/55	14.32/55	7.15/55	0/55
D^{e} = 0.26; significant at 5%						

a. Observed frequency of moth emergence in each class.
b. Theoretical cumulative frequency.
c. Observed cumulative frequency.
c. Absolute difference.
e. The statistic used in the Kolmogorov-Smirnov test, defined by Formula 4, Appendix.

highest force encountered by the probe tip from the soil surface to a depth of six inches.

The Kolmogorov-Smirnov one-sample test (Siegel 1956) was used to test the hypothesis that the observed distribution of moth emergence was drawn from the specified theoretical distribution of moth emergence. The equation for the calculation of D, the statistic used in this test, is shown in Formula 5, Appendix.

D is equal to 0.26 and is significant at the 5% level. This indicates that moth emergence was related to soil compaction.

Richmond and Clark (1961, 1965) found that soils which become compacted when irrigated are unfavorable for survival of buried larvae. They investigated a sandy loam soil from Buckeye, Arizona and found that it became extremely hard after irrigation. They concluded that the soil virtually imprisoned the pink bollworm larvae at the burial site. Swailes (1960) suggested that soil compaction may contribute to the mortality rate of buried beet webworms.

The sex ratios for the total moth emergence are shown in Table 7. Significance for each plot was determined by using a table of exact probabilities for a binomial distribution. Significance for the total

Table 7

Sex ratios of emerged pink bollworm moths in seven irrigation plots, Tucson, Arizona, 1967.

Plot	Total Emergence	Sex Ratio Male:Female	Significant at 5%
1	7	6:1	No
2	14	11:3	Yes
3	3	2:1	No
4	7	5:2	No
5	9[a]	7:1	Yes
6	6	5:1	No
7	9[a]	5:3	No
Total	55 53[b]	41:12	Yes

a. Sex of one moth not determined, and corresponding ratio reduced by one.

b. Sex of two moths not determined (see footnote a), and corresponding total ratio reduced by two.

male to female ratio was determined by using the normal approximation, the variable of which is denoted by z. The method for the calculation of z is shown in Formula 5, Appendix, and is discussed by Siegel (1956).

The sex of two moths was not determined because one escaped and one was partially destroyed, apparently by a spider found in the collecting jar. Therefore, only 53 moths could be used in the total comparison, and the ratios in Plots 5 and 7 were decreased by one each. The results of these tests show that at the 5% level female emergence was significantly smaller than male emergence in Plots 2 and 5. Total female emergence was also significantly smaller than total male emergence.

The sex ratios for suicidal emergence were determined, but the results are not shown in table form. The two moths that were not sexed emerged during this period. The male to female ratio in Plot 2 was 10:3, and for total suicidal emergence, 30:9. In both cases, female emergence was significantly smaller at the 5% level. There were no significant differences in the other six plots.

Richmond and Clark (1965) found that there were no significant differences between male and female survival. However, their tests were conducted in the laboratory under conditions quite different from those that occurred in this field experiment. These workers noted that 2% of the males spun webs but that none were spun by the females. This may account for the greater male survival that occurred in the field experiment reported herein.

Non-suicidal and suicidal emergence are compared in Table 8. This table is a summary of the data in Tables 2 and 4. As stated previously, moth emergence prior to June 1 was considered suicidal. The range of suicidal emergence in the winter-irrigated plots (3, 5, and 7) was 33.3 - 77.7%; while in the spring-irrigated plots (1, 2, and 4), the range was 71.4 - 92.8%. In the nonirrigated control (Plot 6), 83.3% of the emergence was suicidal. Total suicidal emergence in each winter-irrigated plot was less than in the control; however, the mean percentage of total suicidal emergence for the three spring-irrigated plots was 83.3% and equalled total suicidal emergence in the control.

Because emergence records were not sufficient, plot totals were used in Table 8. It has already been pointed out that there were no significant differences in suicidal emergence among the seven plots. Comparisons with the control in the previous paragraph were made with

Table 8

A comparison of suicidal, non-suicidal, and total pink bollworm moth emergence in seven irrigation plots, Tucson, Arizona, 1967.

Plot	Suicidal Emergence	Non-suicidal Emergence	Total Emergence	% Suicidal Emergence
1	5	2	7	71.4
2	13	1	14	92.8
3	2	1	3	66.6
4	6	1	7	85.7
5	3	6	9	33.3
6	5	1	6	83.3
7	7	2	9	77.7
Total	41	14	55	74.5

caution since no information on a range of suicidal emergence in the control was available when plot totals were used. Also, the plot totals were very small.

If winter irrigation does reduce suicidal emergence as the data in Table 8 suggest, a statistical test, such as the Wald-Wolfowitz runs test (Siegel 1956), might show that winter irrigations reduce suicidal emergence when compared to spring irrigations. However, a test such as the one suggested would have to be based on larger sample sizes so that observations of each experimental unit could be used.

In these tests, moth emergence appeared to be related to the soil moisture. This is illustrated in Table 9. The percent soil moisture indicated is the moisture of the soil approximately two weeks prior to moth emergence. The table includes only suicidal emergence because moisture samples were discontinued after June 1.

Brazzel and Martin (1959) reported that moth emergence increased 10 to 14 days following a rainfall of one-half inch or more. Richmond and Clark (1965) found that moist soils (50% field capacity) favor pupation while dry (no moisture) or extremely wet (field capacity) soils hinder pupation.

Table 9

Suicidal pink bollworm moth emergence in relation to soil moisture, Tucson, Arizona, 1967.

% Soil Moisture[a]	No. Moths Emerged	% Moths Emerged
≤ 10	10	24
11-14	25	61
≥ 15	6	15

a. Percent soil moisture two weeks prior to emergence.

It therefore seems reasonable that the soil moisture at the time of pupation is more important than the soil moisture at the time of moth emergence. Although emergence records were meager, the data obviously fell into the three class intervals indicated. This suggests that pupation and emergence are stimulated by a critical moisture range.

Evaluation of Techniques and Experimental Design

The major difficulty encountered in all the analyses was that created by the limited sample size. In each experimental unit, 100 larvae were used. Reference to Table 2 will reveal that the number of moths emerging in each experimental unit resulted in the following sets of ties among the observations: 12 zeros, 15 ones, 8 twos, 5 threes, but only 1 four and 1 five. Thus, 40 of the 42 observations, or 95.2%, were tied.

If any true differences did exist among the seven treatments, a sample size larger than 100 larvae should have been used for the following reasons: (1) The number of ties among the observations would have been decreased; (2) according to Li (1965), rejection of a false hypothesis would have been more likely; and (3) the parametric statistical tests could have been used provided that the sample means were normally distributed.

The field capacity of the soil in the experimental area was 32.8%. Irrigation increased the moisture content of each irrigated plot by an average of 19.1% which was 58.2% of its field capacity.

It was noticed that an irrigation in one plot would slightly increase the moisture content in adjacent plots. This shows that the plots were not spaced far enough apart. This problem can be solved simply by increasing the distance between plots. This complicates the field work involved, but it is essential in order to meet the requirement of independence among the treatment samples.

It should be pointed out that soil compaction readings were taken three months after the last irrigation, and caution should be used in the interpretation of the results. Readings at the time of emergence would undoubtedly give a better indication of the effects of compaction on survival.

Chapman *et al.* (1960) and Richmond and Clark (1965) have shown that soil type influences winter survival. With this in mind, a split-plot design offers a major advantage over the comparable randomized complete block design. The area required for a field experiment can be decreased by using a split-plot design, and variations introduced by soil differences within the field would probably be reduced. The merits of a split-plot design are discussed by Cochran and Cox (1957).

SUMMARY

Mature larvae of the pink bollworm, _Pectinophora gossypiella_ (Saunders), overwinter in cotton debris or in cocoons near the soil surface. Burial of the larvae followed by winter irrigation has been found to be an effective method for reducing the survival of the overwintering populations. However, most of the research on the pink bollworm in the United States has been conducted in Texas. This field study was therefore undertaken to determine the effects of various irrigations on winter survival and spring emergence at Tucson, Arizona.

Seven irrigation treatments and two methods of larval burial were arranged in a split-plot design with three replications. One hundred larvae were buried to a depth of six inches in each experimental unit.

Of the 4200 larvae buried, only 55 survived and emerged as moths. Nonparametric statistical tests were used to analyze all treatment comparisons because the data were not normally distributed. There were no significant differences among the seven irrigation treatments. This may have been a result of the large

number of tied observations that occurred among the treatment samples. Larval survival in bolls was significantly greater than in free cocoons. Male survival was significantly greater than female survival in two of the treatments, and total male survival was significantly greater than total female survival. Survival also appeared to be related to soil compaction.

Although a small proportion of the larvae survived, the data showed that 61% of the suicidal emergence occurred within a soil moisture range of 11-14%. Of the total emergence, 74.5% was suicidal; and suicidal emergence was greater than 65% in all but one treatment.

Parametric statistical tests could not be used because the proportion of winter-surviving larvae was very small, indicating the necessity for a larger sample size in future investigations of this type.

The objectives of this study were partially fulfilled. The results indicate that winter mortality is very high, even though an effective irrigation practice was not defined. The high percentage of suicidal emergence, the low winter survival of female larvae, and the effects of soil moisture and compaction indicate areas for future research. It may be possible to design cultural treatments which could take advantage of several of these factors and thereby even further reduce non-suicidal emergence.

APPENDIX

LIST OF FORMULAS

1. % Soil Moisture =

$$\frac{\text{wet weight of soil} - \text{dry weight of soil}}{\text{dry weight of soil}} \times 100$$

2. $$H = \frac{\dfrac{12}{n(n+1)} \displaystyle\sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(n+1)}{1 - \dfrac{\sum T}{n^3 - n}}$$

where H is the statistic used in the Kruskal-Wallis test and is distributed approximately as chi-square with k - 1 degrees of freedom (Siegel 1956).

and k = number of treatments

n_i = number of observations in the i^{th} treatment

$n = \Sigma n_i$, the number of observations in all k treatments

R_i = the sum of the ranks in the i^{th} treatment

$\sum_{i=1}^{k}$ is a summation over all k treatments

$T = t^3 - t$

t = number of tied observations in a tied group of scores

3a. $$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

where U is the statistic used in the Mann-Whitney test and is determined by the number of times a n_2 observation is greater than a n_1 observation (Siegel 1956).

and n_1 = number of B observations = 21

n_2 = number of C observations = 21

R_1 = sum of the ranks for the B observations

3b. $$z = \frac{U - \mu_U}{\sigma_U}$$

when n_2 is greater than 20, the sampling distribution of U approaches the normal distribution and z is approximately normally distributed with a mean of zero and unit variance (Siegel 1956).

and μ_U = mean of U = $\frac{n_1 n_2}{2}$

σ_U = standard deviation of

$$U = \sqrt{\frac{(n_1)(n_2)(n_1+n_2+1)}{12}}$$

U is defined by formula 3a

4. $$D = \text{maximum} \left| F_o(X) - S_n(X) \right|$$

where D is the statistic used in the Kolmogorov-Smirnov test and is the maximum absolute deviation between the theoretical cumulative distribution and the observed cumulative distribution (Siegel 1956).

and $F_o(X)$ = the theoretical cumulative distribution

$S_n(X)$ = the observed cumulative distribution of the n observations

n = 55, the total number of emerged moths

5. $$z = \frac{(X + 0.5) - np}{\sqrt{npq}}$$

with n greater than 25 and p = 0.5, z is approximately normally distributed with zero mean and unit variance (Siegel 1956).

and X = number of females

n = total number of moths = 53

p = q = 0.5

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